Sudip Datta Banik *Editor*

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ISBN 978-3-031-27847-1 ISBN 978-3-031-27848-8 (eBook)
https://doi.org/10.1007/978-3-031-27848-8

This Springer imprint is published by the registered company Springer Nature Switzerland AG
The registered company address is: Gewerbestrasse 11, 6330 Cham, Switzerland

Foreword

Latin America, a simple pair of words, refers to the linguistic origins in Spain and Portugal of Romance languages. This simplicity belies the profound complexity of any collective and general consideration as a whole for our Region, which is designated as Latin America and the Caribbean (LAC) in the parlance of the United Nations. An overriding reality is the diversity and variety in almost every domain one scans from the Rio Bravo and the Caribbean Sea to Patagonia.

LAC is nestled along the expanses of the Americas. Diversity begins with the ecological and topographical heterogeneity of the chain of continents. The physical topography across the 20 million square-kilometre area comprising the Region is the point of departure of variety. It is a mosaic of deserts, grassy plains, timberlands and rainforests, with highlands ascending to mountain ranges across almost all of the Pacific range of the Sierras and the Andes. It is bounded by largely tropical waters of the Pacific and Atlantic. Highlands and mountain residence became attractive for human residence to avoid the ravages of insect-borne febrile diseases, with the trade-off being adaptation to the lower oxygen tension in breathing at higher altitude.

In the pre-Columbian era, the inhabitants were indigenous groups who ranged from fisher-peoples on the Caribbean islands and towards the polar south to hunter-gatherers in the plains and forests to agrarians of maize and tubers in the established civilizations of Aztecs and Maya of Mesoamerica and Quechua-speakers of the Andes. In the wake of Columbus, the original inhabitants suffered a feeding frenzy of invading soldiers of fortune seeking to plunder their treasure and the missionaries dedicated to saving their souls. And in this, the Spanish and Portuguese were joined by the French, the Dutch and the English on insular and continental lands bordering the Caribbean Sea. Settlers from across Europe sought to exploit the coasts for fish, the forests for timber and furs, and the fertile soils for crops such as tobacco, sugar cane and cotton. With the latter came plantation agriculture and the enslavement of Africans dragged to LAC as field hands. So, from its dawn in the sixteenth and seventeenth centuries, the seeds of further diversity in an ethnic and cultural context were sown.

Human nutrition begins within the food supply. The geographic and topographical contours of the Region have shaped the food supply and dietary practices across the region with animal-sourced foods being different inland as compared on the coasts, with fruits and vegetables differing in subtropical versus overtly tropical climes, and with staple crops varying with lower or higher altitudes above sea level. In terms of nutritional impacts in the Region, we have the convergence of cuisines and dietary preferences from indigenous inhabitants, explanted Africans and Europeans, with the latter two seeking to adapt with the flora and fauna of the "New World". Over time, wheat, oats, barley, cattle and poultry, coffee, cheese, garlic, eggplant, grapes, apples and citrus fruits among others migrated to the Americas and became established. Meanwhile, maize, potatoes and cacao, along with common and broad beans, squash, cassava, peanuts and a host of tree nuts, expanded the food selection back in the Old World. Of course, dietary intake sets the bases for the nutritional status of populations. The abundance of calories, and to some extent the food sources, will determine the body weight and composition, whereas the variety of foods and food groups influences the adequacy of vitamins and minerals for an individual.

Growth has long been linked with what is eaten during childhood, but the dimensions of juvenile growth are quite distinct. There is ponderal (weight-related) growth and linear (height-related) growth. Concepts as fundamental as the Law of Thermodynamics and the Cell Theory of biology tell us clearly that the growth in mass and the maintenance of a body mass are supported by nutritional elements of the diet. Normal hydration depends on dietary water from beverages and solid foods. Muscles and organ systems require dietary protein. The most determinant component of human weight, that of the body fat mass, is related to the storage in the adipose tissue reserves of the energy from fat and carbohydrate. In a very basic manner, the dynamics of ponderal growth depends on the nutritional make up of an individual's diet.

Several of the chapters on growth in this compendium reject the universality of the WHO Growth Standards and opt in favour of national reference values to judge their respective population of children and adolescents. An attitude that the United Nations norms are not the universal guidelines for healthy growth has become heretical to most nutritional scientists and policymakers across the globe. However, in the specific contexts of the present authors, the applications of locally or nationally derived references have a strong rationale for the issues of interest.

Refreshingly, endemic short stature (stunting) is treated very consistently and appropriately across the authorships of the diverse chapters. It is either ignored as being negligible and non-existent, and no longer is a population issue, or it is ascribed more to environmental, ecological or social adversities. But the erroneous notion that linear growth faltering is largely determined by any dietary circumstance is not widely expressed in this book.

Notwithstanding any confusion from the title of the volume combining "growth" and "nutrition", the great predominance of interest and emphasis in growth was on ponderal growth, that is, the appropriateness of body mass and the ubiquitous tendency towards excess body weight conditions throughout the distinct sites in LAC reached by the authors.

This book was written and edited in a context of thoughts and observations of the LAC of today. As this book is released, upwards of 670 million persons inhabit the 20 million square-kilometre extent of the Region. More than half of these are resident in Brazil (213 million) and Mexico (129 million). The Editor's Preface outlines the content and contributions in extensive detail. Suffice it to say, it consists of 20 single- or multiple-authored chapters including specific content from ten countries: Argentina, Brazil, Bolivia, Chile, Cuba, El Salvador, Guatemala, Mexico, Peru and Venezuela. Several were represented on more than one occasion. The roster is too small to represent all of the diversity of the Region, but North American and South American sites are nicely balanced.

We have reviewed the diversity issues of the LAC but in contemporary times changes in knowledge and technology as well as a major trend in migration modify how the catalogue of diversity operates in nutrition and growth. The ethnic and national-origin descendants across the LAC have become largely delinked from their ancestral traditions and are amalgamated into societies undergoing rapid transitions and changes. The various traditional fruits, garden vegetables and staple crops still form part of the diets, but from more distant origins, often in processed formats and in competition with imported foodstuffs. The vast topographical diversity of the Region, described above, plays a diminishing role in contemporary times as fewer persons live in a countryside location and transportation has been expedited by air, rail and modern highway connections.

The major commonality throughout the Region – and a factor which has both driven and modulated influences on growth and nutrition – is urbanization. An urban zone is defined as an entity with 20,000 or more inhabitants. As a region, over 80% of the population is urban, with an incremental increase year on year. Only Haiti, Honduras and Guatemala remain with majority rural populations. Sao Paulo (22,237,472 inhabitants) is the fourth largest of the world's metropolises and number 5 is Mexico City (21,918,936 inhabitants), both in LAC. Also among cities with greater than 5 million residents, there are six more in the Region: Buenos Aires (15,257,673); Rio de Janeiro (13,293,000); Lima (10,391,000); Santiago (6,680,000); Belo Horizonte (5,972,000) and Guadalajara (5,023,000). If there is anything approaching monolithic to be found regarding LAC, it is its high degree of urbanization.

For the theme of the book, growth and nutrition, the factor of massive urbanization of the LAC has a Janus-headed influence. Since the populaces are no longer rural, the protective factors of physical activity of agricultural pursuit, the availability of abundant fresh produce and the scarcity of commercial processed food and drinks are buried in the past. Conversely, the mechanization of transportation and sedentary nature of life-style pursuits, the ebbing of the cuisine heritage and the dependency on commercial, retail dispensers of foods and beverages combine to favour a positive energy balance for the body. Ready-to-eat formats of street vendors, fast-food outlets, cafeterias and restaurants form an increasing proportion of people's diets in urban settings. With Latin America being the most intensely urbanized of all regions, the prevalence of excess body weight as a focus of the chapter, contributors should not be surprising.

Relatively few studies report quantitative intakes of macro- or micronutrients from contemporary diets in the sites of study, and even rarer are reports on biomarkers of vitamin or mineral status. However, studies representing Cuba and Mexico reported dietary habits of children, seasonal variation and macro- and micronutrient deficiencies. Anthropometry is almost the sole domain of "nutritional status" assessment. Although this is amply justified by the degree of overweight and obesity revealed, the "hidden hunger" component of the triple burden of malnutrition is virtually unexplored.

It was a major challenge to aspire to encompass contemporary aspects of growth and nutrition for the entire LAC region in a single volume given the extensive historical diversity of all dimensions across the area; indeed, navigating the combination of growth and diet between the same book-covers represented a delicate task. In many ways, this collective of authors and chapters assembled here largely got it correct, insofar as the wide diversity in almost all domains is reflected in the variety of approaches and focuses on a nation-by-nation basis. In general, the effort highlights the challenge in generalizing across a heritage of historical and contemporary diversity. We see the degree that influences from society and the environment often supersede dietary intake per se as factors in growth and nutritional status; this would be a message for all Regions of the globe. The major commonality across the Region is that of urbanization of the LAC population. Living in cities brings modernity, and with the demographic consolidation, this is the majority rule in the Region. The nature of stunting in the Region is put into modern perspective. It is noted that stunting is generally uncommon in the LAC with the notable exception of Guatemala and the indigenous populated regions of Mexico and the Andean nations. It has been recognized that social and environmental adversities, more than any dietary deficiencies, are responsible for the early-life restriction in elongation of the lower extremities, producing the short stature.

This is a valuable contribution to proper understanding. Finally, overweight and obesity are major risk factors for mortality and morbidity. If the attention to "growth" in the title comes down to the expansion of the girth of the body, and that of nutrition be the dietary practices fostering excess weight, this will be a beacon for useful policy development across the LAC.

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Preface

This book is a pioneering one that covers diverse aspects of physical growth, maturation, and nutritional status of children and adolescents in Latin American and Caribbean (LAC) countries. Publications are available on human growth, representing countries and ethnic groups of this part of the world. However, articles covering major areas of child growth and nutrition that are published in a book form is not common. Huge ethnic diversity, culturally determined lifestyle, dietary habits, and activity patterns altogether influence biological variations in the Latin American populations that can be analyzed in the perspective of human ecology. Here lies the novelty of this book (edited volume) that will encompass biological and sociocultural factors associated with human growth and nutrition in the background of environmental conditions. Events of child growth, maturation, and nutrition are also explained and interpreted using the theories of human biology.

The principal objective of editing this volume was to handover a book to the students, young researchers, and teachers who are interested to understand human growth and nutrition in the background of ethnic and environmental diversities of LAC countries. Scholars from other corners of the world will also be interested to read this book to explore LAC culture, physical and social environment, and human biological variation through the lens of human growth and nutrition.

The book reflects the major areas of research done by the human biologists representing different LAC countries. This will open a forum for the researchers to discuss about the emerging areas of investigation on human growth, nutrition, and maturation and create opportunities to collaborate among colleagues from the region.

This book is dedicated to the memory of Professors Napoleón Wolanski and Anna Siniarska-Wolańska who made valuable contributions in the areas of research on auxology and human ecology, intergenerational changes in developmental rhythm and sexual dimorphism in children, changes in body size in terms of the secular trend, ethnic and socio-economic inequalities, interrelationships between birth parameters and maternal and environmental factors, and changes in the state and biological dynamics of Yucatan populations, among others. They were associated with the Human Ecology Department of the Center for Research and Advanced

Studies of the National Polytechnic Institute (Cinvestav-IPN) in Merida, Mexico in the 1990s.

This edited book carries twenty chapters that are divided into three parts. Chapters are contributed by the renowned scientists who explain human growth and nutrition in the evolutionary and environmental backgrounds. The first part titled "Nutritional and Epidemiological Aspects of Child Growth in Latin American and Caribbean Countries" includes five chapters. Chapter 1 by Barry Bogin shows how human life history biology, especially the stages of human growth, development, and maturation, are shaped by the nutritional requirements and human social-economic-political-emotional (SEPE) factors. Biocultural systems in LAC countries determine the availability and use of food that consequently fulfil their nutritional needs. Coexistence of short stature (stunting) and excess weight are explained in terms of SEPE factors. Chapter 2 by Hugo Melgar Quiñonez deals with the availability of nutritionally adequate foods corresponding to the cultural values and preferences of a society that establish dietary habits and help people to get an active and healthy life. The author reviews the interrelationships between inappropriate food choice and food insecurity that consequently increase risk for dual burden of malnutrition in Latin American countries. Chapter 3 by Amanda Veile focuses on globalization and nutrition transition and their effects on diet, growth, and health of infants and children representing rural Latin American indigenous communities: Tsimane forager-farmers in the Bolivian Amazon, Venezuelan Pumé hunter-gatherers, and Yucatec Maya subsistence farmers. Globalization of food and modernization of breastfeeding shape early life environmental conditions of infants and children that have long-term negative consequences on health and nutrition. Chapter 4 by Anaximandro Gómez Velasco et al. deals with how far tuberculosis affects human growth that may have long-term impacts on growth and nutrition in children and adolescents with negative consequences for health in the adulthood. The authors explained the phenomenon using data from Latin American countries and in the perspectives of theories of human biology. Chapter 5 of this section by Lawrence M. Schell shows how non-nutritional components of food that include metals, herbicides, pesticides, insecticides, and industrial chemicals can have adverse effects on human health and development.

The second part of this book focuses on "Methods of Human Growth and Development" that covers four major areas of research and includes four chapters. Chapter 6 by Javier Rosique Gracia and colleagues shows how a growth reference curve is developed using the algorithm of LMS method and its importance for a country. The study used nutritional surveillance database of "National Survey of the Nutritional Situation (ENSIN 2015)" in Colombia to construct curves for height, weight, and body mass index (BMI) of children and adolescents. The chapter further compares the results with that of ENSIN 2005 and shows a secular trend in child growth and changes in nutritional status. Chapter 7 by Lidia Moreno-Macias et al. explains how triple burden of malnutrition-undernutrition, hidden hunger, and overweight develops major risk factors for premature death and physical disabilities in children of Mexico and Latin American countries. This study calls for the use of new anthropometric parameters, such as waist-to-height ratio, that will narrow the gap between malnutrition and cardiovascular risk assessment in children and adolescents. The authors also mention the urgent need to develop nationally representative nutrition reference values in Mexico to monitor child well-being. Chapter 8 by Joni J. S. Beintema and colleagues demonstrates how to apply photographic imaging technique to measure standing height and thereby estimate length of trunk and legs with an aim to calculate trunk-to-leg ratio. The authors used this novel imaging technique to evaluate environmental influences (socio-economic status) on growth and body proportion of preschool children in the Western Highlands of Guatemala. Chapter 9 by César Octavio Ramos-García et al. presents the interrelationships among physical, physiological characteristics of adolescent athletes and biomechanics and kinematics that are inherent to the physical fitness and sports performance. Biological maturation and its association with physical growth, puberty, metabolism, and exercise are discussed.

The third part titled "Biocultural Impacts on Child Growth and Nutrition in Latin American and Caribbean Countries" covers diverse areas of child growth and nutrition representing the region. Altogether eleven chapters represent data from Argentina, Brazil, Chile, Cuba, Dominican Republic, El Salvador, Guatemala, Mexico, and Peru. Chapter 10 by Alicia B. Orden reports series of cross-sectional studies carried out between 1990 and 2016 in Argentina and shows the secular trend of height, changes in BMI-based nutritional status of school-going children, and their variations in different socio-economic groups. A conspicuous secular change in the obesity rate among children from the lower socio-economic groups has been observed. The study also predicts the possible effects of COVID-19 pandemic on child growth and nutrition that calls for new research. Chapter 11 of this book, contributed by Bárbara Navazo and Silvia L Dahinten, also represents Argentina and reports nutritional status of schoolchildren in Puerto Madryn, the northeast of Chubut. Height and weight-for-age of two groups of 6–14-year-old boys and girls from different neighborhoods of Puerto Madryn, surveyed in 2001–2006 and 2014–2016, were evaluated and compared. Socioeconomic vulnerability increased with the expansion of informal settlements in the region with simultaneous rises of health burden and obesity. The interesting Chapter 12 by María Laura Bergel Sanchís and colleagues deals with the household socio-economic and environmental information (HSEI) of native Argentine and migrant Bolivians living in La Plata of Argentina and their association with nutritional status in children between 3 and 7 years of age. Children of the immigrants were in situations of greater social vulnerability than their native neighbors; higher rate of excess weight (56.0%) was recorded among the former group in comparison with the natives (44.8%). Chapter 13 by Hilton Pereira da Silva et al. representing Brazil, describes secular trend of anthropometric indicators (stunting, obesity) over the last 50 years. Data from Brazilian national surveys were used, and a comparative study was done with rural populations from the Amazon basin. The next Chapter 14 by Pablo A. Lizana et al. describes the trends of obesity in children and adolescents, based on Chilean national nutrition surveillance data. The authors suggest use of body composition assessment and somatotype criteria to evaluate absolute and relative body fatness, respectively, instead of using BMI only to evaluate obesity as an indicator of malnutrition. Chapter 15 by María Elena Díaz Sánchez and colleagues discussed feeding practices, growth, nutritional status, body composition characteristics, and physical activity patterns of Cuban infants, children, and adolescents. The review of literature shows excess weight (overweight and obesity) rather than undernutrition (stunting) is a public health concern related to human growth in the country. In a semi-longitudinal study, normalized data of height, weight, and BMI of school-going children and adolescents from Bajo Lempa region of El Salvador were compared with WHO growth reference and data from Dominican Republic (Chapter 16 by Roberto Pedrero Tomé and colleagues). A longitudinal study from Guatemala among infants and children under 5 years of age, evaluated how chronic malnutrition affects physical growth that is presented in Chapter 17 by Laura Medialdea Marcos and Jessica Alejandra Coronado. The authors reported how anthropometric indicators of weight, height mid-upper arm circumference (MUAC)-for-age, and weight-for-height were used to evaluate growth and nutritional status of infants and children. Chapter 18 by Francisco Gurri et al. reports the interrelationships between seasonal changes and diet quality that influence nutritional status and body composition characteristics of children in rural Yucatan, Mexico. Results showed that store-bought foods did not solve the macronutrient deficiencies but may have contributed to modify the composition of their gut microbiota. Seasonal differences were reflected in the formation of bacterial population clusters for lipids and overall age group differences in Firmicutes/Bacteroidetes (F/B) ratio. Increased dependence on store-bought foods may have modified the structure and composition of gut microbiota by substituting the intake of locally harvested food with industrialized and packaged consumables. Chapter 19 by Olga P. García Obregón et al. shows associations between intestinal parasites, micronutrient deficiencies, and obesity in Mexican children. Coexistence of obesity, parasitic infection, and micronutrient deficiencies among children is a public health concern in Mexico. The last chapter of this book by Achsah Dorsey reports on anemia among preschool children living in San Juan de Lurigancho, Peru, their growth patterns coupled with immune activation, and seasonality with iron status and associated factors. The study showed different patterns of response to iron supplementation between children with high and low central adiposity and total body fat and how fat distribution can impact immune function and nutritional status.

Empirical studies on child growth and nutrition, their analyses, and interpretations in the backgrounds of diverse ethnic, socio-economic, and environmental conditions of different LAC countries offer a valued discourse in the particular area of applied research in human biology, nutrition, and health. Methodological aspects of the evaluation of physical growth and maturation further enrich this volume. The book carries important information that is useful for the public health and nutrition policy makers of the government and non-government agencies at national and international levels.

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Part I
Nutritional and Epidemiological Aspects of Child Growth in Latin American and Caribbean Countries

Chapter 1
Anthropological Perspectives on Child Growth and Nutrition in Latin America

Barry Bogin

1.1 The Anthropological Perspective

An anthropological perspective includes evolutionary/historical and biocultural contexts. Both contexts require an appreciation of human life history biology, especially the stages of human growth, development, and maturation and how these stages have been shaped by nutritional requirements and, simultaneously, how these nutritional requirements are impacted by human social-economic-political-emotional (SEPE) factors. This chapter focuses on the life history stages of human growth, development, and maturation after birth – neonatal, infancy, childhood, juvenile, adolescence, and young adult. Each of these stages is defined, in part, by nutritional needs and style of feeding. The biology of the life history stages are human universals, that is, found in all members of the living human species, *Homo sapiens*. Variation in the pattern of growth, development, and maturation between human groups, and within each group, is in large part due to interactions between nutritional and SEPE factors. Historically and bioculturally, the human populations of the Americas have both shared and distinct characters. This chapter focuses on some of the biocultural and historical factors that define patterns of physical growth and nutrition in Latin America, especially Guatemala. The examples discussed are based on research by the present author and colleagues.

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S. Datta Banik (ed.), *Human Growth and Nutrition in Latin American and Caribbean Countries*, https://doi.org/10.1007/978-3-031-27848-8_1

1.2 Evolution/History of Humans in the Americas

Archaeological and genomic data indicate that the human occupation of the Americas occurred, most likely, within the past 36,000 years before present (BP) (Gannon, 2019; Raff, 2022). Two or more species of hominins may have existed in regions of Europe and Asia during that time, such as *Homo neandertalensis* and *Homo sapiens* (Hublin, 2017), but the skeletal/genomic data indicate that the only hominin migrating into the Americas was *Homo sapiens*. The genomic signature of the most ancient founding populations remains detectable in Native Americans (Posth et al., 2018). Changes within the Native American genome, such as novel single nucleotide polymorphisms (SNPs) and allele copy number variation attest to on-going evolution by natural selection and adaptation to diet, cold, and high altitude (Reynolds et al., 2019). It is beyond the scope of this chapter to discuss the evolution of SNPs and other genomic elements. Suffice it to state here that all Native Americans and all post-Conquest migrants to the Americans (after the year 1500 CE) are members of the single panmictic human species.

1.3 Human Life History Biology

Life history theory is a field of biology concerned with the strategy an organism uses to allocate its energy toward growth, body maintenance, defense against infection, reproduction, raising offspring to independence, and avoiding death (Bogin & Smith, 2012). For a mammal, it is the strategy of when to be born, when to be weaned, how many and what type of pre-reproductive stages of development to pass through, when to reproduce, and when to die. The life history approach attempts to unravel the reasons why different species of animals follow distinctive sequences of development and why new life stages evolve, such as the juvenile stage of the social mammals (e.g., most African/Asian monkeys and apes) and the childhood and adolescence stages of humans. I have discussed in detail elsewhere how some "mysteries" of human growth, such as the nature of the human childhood and adolescence stages and the vigorous post-menopausal stage of women, are best understood in terms of life history strategies for efficient reproduction and offspring survival (Bogin et al., 2018b; Bogin, 2021b).

1.3.1 Overview of Human Postnatal Life History Stages[1]

The biocultural life history stages of human growth, development, and maturation are found in all members of the human species. One of the many possible ordering of events is given in Table 1.1, in which growth periods are divided into

[1] This overview is based on material published in (Bogin et al., 2018b; Bogin, 2021b). These sources provide more detailed discussion, and supporting references, of the stages of human life history.

developmentally functional stages. For convenience, the life cycle may be said to begin with fertilization and then proceed through prenatal growth and development, birth, postnatal growth and development, maturity, senescence, and death. The timing of growth events is presented in Table 1.1 as mean, median, or modal ages. The reader should bear in mind that these ages indicate the central tendency and not the normal range of variation that occurs naturally in the timing of many growth events. Research may find, for example, that the median age at menarche (first menstruation) is 12.6 years in a sample of girls. The actual age at menarche for individual girls in the sample may range from 8.0 to 15.0 years, and both the earliest and latest ages represent perfectly normal individuals. When the range of variation in the timing of growth events is important in terms of the focus of this chapter, then it will be given.

A wonderous amount of growth and development takes place before birth (prenatally). Here the focus is on the postnatal stages of life – from birth onwards. In Fig. 1.1, average distance and velocity curves of growth in height are shown for healthy, well-nourished boys and girls. The distance curves, the amount of growth achieved from year to year, are in panel A. The velocity curves, representing the rate of growth during any 1 year, are below in panel B. The velocity curve is labeled with symbols indicating the average duration of each stage of development. From inspection of the velocity curves, it is apparent that changes in the rate, tempo, and amplitude of growth are associated with each stage of development. The rate of growth is often expressed as the change in size for a given amount of time, for example, centimeters per year. The tempo of growth is a concept derived from music theory. Tempo expresses the pace, or "time signature", of development and maturation. A fast tempo is characteristic or an early-maturing person, while a slow tempo characterizes the late maturer. Amplitude is the maximum rate of growth at a specific state of maturity, for example, the peak of the adolescent growth spurt. Another definition of growth amplitude is size at a given time, such as a 12 year old girl being tall or short (Hermanussen, 2011). The human pattern of growth is not unusual in terms of amount (many living things are much larger or smaller than people) but is unusual, even unique, in terms of change in rate, tempo, and amplitude. These aspects of growth and development are described further elsewhere (Hermanussen & Bogin, 2014; Tanner, 1971). The emphasis in this chapter is on the rapidly changing velocity during infancy, the steady rate of growth in childhood, a mid-growth spurt at the transition to the juvenile period, and the adolescent growth spurt.

The Neonatal and Infancy stages (Birth to ~36 months) are characterized by the most rapid velocity of growth of any of the postnatal stages. During the first year of postnatal life infants may add 28 cm in length and 7 kg in weight, which represents more than 50% of birth length (about 50 cm) and 200% of birth weight (about 3.4 kg). The rate of decrease in velocity, or deceleration, is also very steep, which makes Infancy the life stage of most rapidly changing rate of growth. The infant's curve of growth, rapid velocity and deceleration, is a continuation of the fetal pattern, in which the rate of growth in length reaches its peak in the second trimester and then begins a deceleration that lasts until Childhood.

The Neonatal period (birth to day 28) is a critical and stressful transition from intra- to extra-uterine environments. Discussion is limited to full-term (37–42 weeks

Table 1.1 The stages of human growth, development, and maturation

Duration/age	Biological signs	Socio-cultural and cognitive signs
Neonatal stage		
Birth to 28 days	Extrauterine adaptation of cardio-vascular, pulmonary, digestive, excretory systems from maternal dependence; Motor skills characterized by automatic inborn behaviors (reflexes) and gross motor activity ***End:*** maturity of mother's breast milk at no sooner than 28 days	Preference for visually following human faces more than other objects Visual acuity is best at a distance of about 19 cm, about the distance between faces when nursing. All senses operational, preference for sweet taste, able to distinguish the odor of mother's breast milk Reflexes orient neonate's attention toward sound and light
Infancy		
Month 2 to end of lactation (usually by 30–36 months in traditional societies**)	Rapid growth velocity with steep deceleration in velocity with time Many developmental milestones in physiology Feeding by total or partial lactation in traditional societies, or by human breast milk-like formulas in industrial societies, complimentary foods added by 6–12 months	Rapid motor-sensory, behavioral and cognitive development
Early infancy		
Month 2 to 12 month	Eruption of some deciduous teeth ***End:*** bipedal walking typical by the end of the stage (at ~12 months)	Feeding by lactation with addition of complementary foods after 6 months of age Learning first motor skills, training of sensory systems, social relationship
Late infancy		
Month 12 to 30–36 month	***End:*** deciduous tooth eruption is complete (2nd deciduous molar erupts at 20–35 months), weaning (termination of breast-feeding) between 30 and 36 months	Development of verbal skills associated with more intense social and cognitive development Use of shared intentionality and theory of mind

(continued)

Table 1.1 (continued)

Duration/age	Biological signs	Socio-cultural and cognitive signs
Childhood		
3.0–6.9 years	Moderate growth rate Mature level of bipedal walking Relatively fast rate of brain growth and synaptogenesis, near completion of brain volume growth by end of stage ***End:*** eruption of first permanent molar and incisor complete, mid-growth spurt in many children, adrenarche	Dependency for feeding End of the *kindchenschema* in physical appearance and behaviors Language improvements in phonology, vocabulary, and sentence length Greater independence in feeding, self-care, and care of others
Juvenile		
Pre-pubertal		
7–9 years in both sexes	Slower growth rate Adult-like energy efficiency in bipedal walking	Capable of self-feeding Cognitive transition leading to learning and practice of economic and social skills (apprenticeships in traditional societies, formal schooling in many societies)
Puberty		
Neuroendocrine change in reproductive system: 9–10 years Somatic signs: Girls, 11.0 years, boys 11.6 years	Neuro-endocrine: ***Event*** in the regulation of the hypothalamic-pituitary-gonadal axis from negative feedback to positive feedback of the sex steroid hormones. ***Short*** duration (1–2 months) that reactivates the hypothalamic GnRH pulse generator leading to a massive increase in sex hormone secretion. Somatically: First appearance of secondary sexual characters (darkening and increased density pubic or axillary hair, development of the breast bud in girls, genital changes in boys) Beginning of the adolescent growth 10–11 girls +12–14 boys	In traditional societies, and many industrial societies, pubertals contribute increasing amounts of time and labor toward food production, food processing, infant and child care, and wage-earning activities; in post-industrial nation's most juveniles attend formal school, intensify friendships and social activities and are protected from physical labor Brain growth rate declines in volume, but cognitive organization continues Additional syntactic advances in language use, an increase in speech-breathing capacity and further increases in speech fluency Greater socially relevant use of language from gossip to storytelling and greater use of language and cognitive skills in social competition

(continued)

Table 1.1 (continued)

Duration/age	Biological signs	Socio-cultural and cognitive signs
Adolescence		
Girls: 11–18 years Boys: 12–22 years	adolescent growth spurt in height and weight Further development of secondary sexual characteristics	Intensification of interest and practice in adult social, economic and sexual activities, Further development & organization of brain associated with changes in language usage, risk-taking behavior & other cognitive capacities.
Pre-fertile		
Girls: 11–13 years Boys: 12–13 years	Increasing velocity of growth in height and weight until PHV ***End:*** Menarche (~12.5–13 years) Spermarche (~13–13.5 years)	Continuation of juvenile behaviors, but with greater skill
Fertile		
Girls: 13–18 years Boys: 14–22 years	Decreasing velocity in height, weight velocity is variable Low fecundity in girls due to 1–3 years of irregular ovulations (phase of 'adolescent sterility'), sex-specific fat/muscle changes ***End:*** permanent tooth eruption complete (molar 3 eruption at ~18 years, if present) ***End:*** epiphyseal fusion of long bones, adult target height achieved	Improvements in physical and cognitive levels of work capacity Post-fertile adolescents may be self-sufficient in physical terms but become more socially-emotionally dependent on peers Linguistic content, including vocabulary, becomes more nuanced, grammatical operations and idiomatic phrases (slang) become commonplace More refined logical expression of thought as well as joking, deceiving, mollifying, negotiating, persuading, and the use of sarcasm
Adulthood		
Prime (maximal performance age)		
Women: 18–20 years Men: 20–23 years to about age 30–35 years in both sexes	Commences with completion of skeletal growth Homeostasis in biology Optimal reproductive performance and resilience to insults from injury and illness	Cognitive, physical, social and economic skills achieve maximum performance Linguistic abilities in all aspects of spoken language are fully mature, written language (when present) may improve throughout the adult stage All physical, social, economic, linguistic and cognitive abilities are applied to success in mating, reproduction and care of offspring

(continued)

Table 1.1 (continued)

Duration/age	Biological signs	Socio-cultural and cognitive signs
Gradual decline		
~35 to ~50 years, menopause	First signs of physical degeneration are clinically detectable Decrease of reproductive performance, fertility cessation ***End for women:*** menopause by age 50; decline of sperm quality for men	Both sexes still capable of physical and cognitive work; most women and men can compensate for the degeneration by new biobehavioral strategies.
Transition (degeneration age)		
Age ~ 50 years to senescence	Decline in the function and repair ability of many body tissues or systems Decrease of body muscle and bone Increase of relative or absolute percentage of body fat	Decline in cognitive functions Women may adopt a strategy investment in younger generations to enhance reproductive success and human capital, 'grandmother effect' Men may also do this or continue with their own reproduction, but risk of unhealthy offspring increases
Senescence (old age)		
Variable time of onset and progression, depends on prior level of somatic and cognitive reserves	Decline in the function and repair ability of many body tissues or systems Decrease of body muscle and bone; Decrease of relative or absolute percentage of body fat	More rapid decrease of physical and cognitive working ability and decline in the ability for to adopt biobehavioral strategies for compensation
Death (age dependent physiological death)		
Variable	Reduction of the performance of somatic tissues and organs below that required for life support	

The table is based on material published in Bogin et al. (2018b) and Bogin (2021b). 'Duration/age' given in the table are approximate, representing the average or modal ages for the onset of a stage or its range of duration. The essential biological, socio-cultural and cognitive signs of each stage or period are given in the table. **Anthropologists define traditional societies as hunter-gatherer (forager), horticultural and pre-industrial agricultural and pastoral societies. The people of these societies may best represent human history and the evolutionary forces that shaped life history biology and behavior.

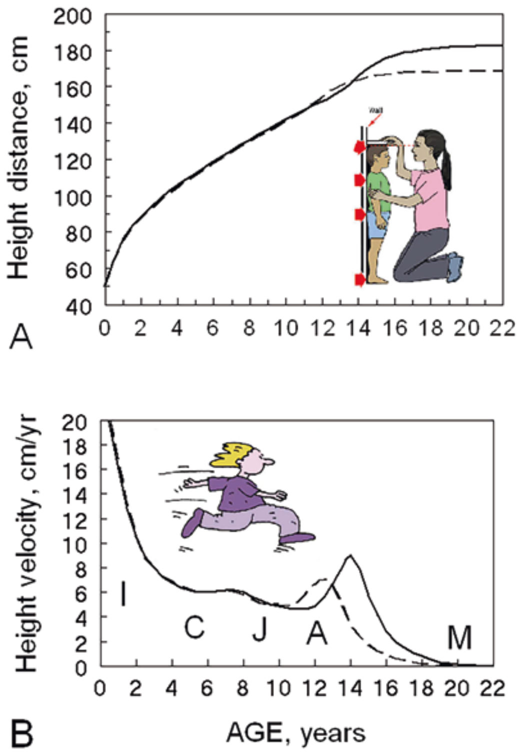

Fig. 1.1 Average distance (**a**) and velocity (**b**) curves of growth in height for healthy girls (dashed lines) and boys (solid lines). Distance is the amount of height achieved at a given age. In part **a**, the image shows a child's height being measured. Velocity is the rate of growth at a given time, in this case shown as centimeters per year. In part **b** the running figure represents "velocity." The velocity curves show the postnatal stages of the pattern of human growth. Note the spurts in growth rate at mid-childhood and adolescence for both girls and boys. The postnatal stages: *I* infancy, *C* childhood, *J* juvenile, *A* adolescence, *M* mature adult. (Original figure of the author)

gestation) neonates of normal birth weight (2.5–4.3 kg) because preterm, low-, or high-birth weight neonates are at elevated risk of mortality. The medical technology needed to sustain such neonates was unlikely to be available for most of human evolutionary history. The neonate must quickly adjust her own metabolism to the extra-uterine environment, and this involves temperature regulation, breathing, sleeping, eating, digestion, elimination, and other autoregulatory processes. Even with these adjustments, the human neonate is altricial, that is, born in an undeveloped state and requiring care and feeding by the other, older and more capable, people. Human neonates have a large body relative to other apes, a small brain size relative to the human adult, and a prolonged period of extreme motor immaturity relative to other ape neonates. These three traits are an unusual combination for a primate newborn. This combination makes the human infant a costly creature to carry around, protect, and feed – burdens usually falling on the mother. Maternal commitment to the neonate has important behavioral, economic, political, and emotional implications for the social group in which the mother lives. These implications are detailed below in the context of the evolution of hominin/human biocultural reproduction.

The relatively large body of the neonate is in part due to the fact that human infants are born with a greater reserve of fat than any other mammal (Kuzawa, 1998). The human fat reserve not only allows for survival during the first few days after birth, but also fuels a rapid brain growth. By day 5 after birth human milk composition begins to mature in terms of energy and other nutrient content and is fully mature by 4–6 weeks postpartum. The maturity of human milk at no sooner than 28 days after birth is a compelling reason to define the duration of the Neonatal period.

The next stage of growth is Infancy. Overall, Infancy is defined as the period of breast feeding, which in traditional societies usually terminates by 30–36 months. Anthropologists define traditional societies as hunter-gatherer (forager), horticultural and pre-industrial agricultural and pastoral societies. The people of these societies may best represent human history and the evolutionary forces that shaped life history biology and behavior. Early Infancy ends as the first bipedal steps are taken. With the transition to the Late Infancy period, motor development of walking, running, object manipulation and other skills continues to take place in a, mostly, gradual manner for many years. In contrast, some cognitive skills, especially language, develop more rapidly. In Table 1.1, there is an emphasis on linguistic development, as it is the outcome of interactions between physical growth, motor-sensory development and control, brain development, and cognitive maturation. By the end of Late infancy, at the age of 36 months, "…the rudiments of a structural linguistic system, and basic components of a functional communicative system, are operative" (Locke & Bogin, 2006, pp. 261–262).

The infant's language skills are centered on the ability to infer the intentions of others and the disposition to align these intentions with the infant's own physical and emotional states. These abilities are called "theory of mind" or "shared intentionality" (Povinelli & Preuss, 1995; Tomasello et al., 2005). Human infants develop this skill to a greater degree than any other species and refine it throughout the growing years and into adulthood. Some scholars suggest that the intensity of shared intentionality is the basis of the evolution of the human brain and mind (Hrdy, 2009). The end of the Late Infancy period is marked for most youngsters by completion of the eruption of all deciduous teeth, the transition from breast-feeding to complementary foods (i.e., specially prepared foods that are easy to ingest and nutritionally dense), motor abilities such as walking forward and backward easily, and language/cognitive skills such as understanding "same and different", counting, sorting objects by shape and color, speaking more than 250 words, often in sentences of five to six words, and telling stories with elements of pretense and fantasy.

The next period of growth and development is Childhood, encompassing, approximately, the ages of 3.0–6.9 years. This stage is characterized biologically by a moderate growth rate of about 5–6 cm/year and characterized behaviorally by feeding independence from the mother (i.e., weaning), but feeding dependence on other members of the child's social group. There is no society in which children survive if deprived of this care provided by older individuals. So-called wolf children, referring to children reared by non-human animals or children living "wild" on their own, and even "street children," who are sometimes alleged to be living on their own, are either myths or, in fact, not children at all. A search of the literature finds no case of a human child, that is a youngster under the age of six, living alone either in the wild or on urban streets (Bogin, 2006). The feeding dependence of children is due, in part, to their immature deciduous dentition, with thin enamel and shallow roots. This prevents mastication of many of the food items of the adult diet of traditional societies. Another reason for feeding dependency during Childhood is that energy requirements peak, measured as resting metabolic rate per kg body weight, or as daily energy requirement expressed in grams of glucose per day per kg body weight. The brain, which grows rapidly during Infancy and Childhood, is especially greedy for energy. According to the data presented by Kuzawa and colleagues (Kuzawa et al., 2014), the life history transition from Infancy to Childhood takes place when brain glucose uptake exceeds 100–110 g day.

The end of Childhood and the transition to the Juvenile stage is characterized by a mature level of bipedal walking and a brain volume that is nearly complete, although the organization of the brain and learning will continue for more than four decades. By the end of Childhood, the youngster is less dependent on older people for feeding due to the eruption of the first permanent molar teeth (M_1 or the "6-year-molar") and central incisors. Permanent tooth eruption, along with increasing body size and behavioral maturation, make a life history transition to more adult-like features. These changes result in end of *kindchenschema* (baby schema or "cuteness") in physical appearance and behaviors. Cuteness is a subjective term describing a type of attractiveness commonly associated with youth, but it is also a scientific concept and analytical model in ethology, first introduced by Konrad Lorenz (Lorenz, 1971). Lorenz proposed the concept of *kindchenschema*, a set of facial and body features that make a creature appear "cute" and activate ("release") in others the motivation to care for it (Glocker et al., 2009). The human *kindchenschema* helps to promote the human style of caring for infants and children, called human biocultural reproduction. In essence, biocultural reproduction is the set of marriage, kinship-based, and societal rules for extra-maternal cooperation in the production, feeding, and care of women and their offspring. Many people are needed for successful human reproduction and the care and education of offspring. Elsewhere, the nature of human biocultural reproduction is described in greater detail (Bogin, 2021b; Bogin et al., 2014).

One of the endocrine events that occurs at the Childhood/Juvenile transition is adrenarche. This is the postnatal onset of secretion of the androgen hormones dehydroepiandrosterone (DHEA) and DHEA sulfate (DHEA-S) from the zona reticularis of the adrenal gland. Among the primates, the zona reticularis is an evolutionarily novel histological region for the production of these hormones. Adrenarche is one of the events that ends the *kindchenschema* of Childhood. In humans, the adrenal androgens seem to cause the appearance of a small amount of axillary and pubic hair and may be associated with a small acceleration in skeletal growth velocity called the mid-growth spurt in height and deepening of the voice. The changes produce the more "adult-like" physique of the juvenile. Adrenarche may also promote a transition to a more adult-like brain and behavior, called the "5- to 7-year-old shift" by some psychologists, or the shift from the preoperational to concrete operational stage, using the terminology of Piaget. This shift leads to new learning and work capabilities in the older child. There is more abstract thinking and inhibition of impulsive behaviors. In traditional societies, older children learn and practice important economic and social skills, such as food gathering, food preparation, and "baby-sitting", that is, the care of infants and younger children. In many industrial societies, older children may also engage in these economic-social activities and may enter formal school education.

Juvenile non-human mammals are, for the most part, responsible for their own feeding and protection. Juveniles are also not sexually mature, though may engage in some mating behavior, but rarely, if at all, produce offspring. In contrast to other mammals, human juveniles tend to be supported by social groups and receive care and feeding from many older individuals. This care of juveniles is part of the structure of human biocultural reproduction. Like other juvenile mammals, human juveniles are not sexually mature, but may engage in some mating behavior. The scheme of Table 1.1 divides the Juvenile period into two parts. The first part is the Prepubertal stage, from about the ages of 7.0–9.0 years in both girls and boys. This time is characterized by the slowest rate of growth since birth. The second part of the Juvenile period is Puberty, which is defined here as an event of relatively short duration (1–2 months). Other researchers may consider Puberty to be a life history stage of several years duration or use the words 'puberty' and 'adolescence' interchangeably. Here a distinction is made between Puberty as a life history transition event and Adolescence as a life history stage of growth and development.

Puberty, as defined here, is the reactivation of the hypothalamic GnRH (gonadotropin releasing hormone) pulse generator leading to a massive increase in sex hormone secretion. The production of GnRH and its release in a pulsatile fashion is active in the mammalian fetus and neonate. In primates studied, including rhesus monkeys and humans, that activity declines after birth and the system is "turned-off" by about age 2 years. It is reactivated at puberty. Puberty leads to changes in physiology, anatomy, behavior, social interests, emotional attitudes, and moral values. The Puberty transition takes the person from the immaturity of the child and early juvenile to the incipient adult-like phenotype of the young adolescent. Due to the biocultural importance of the Puberty event and the transition to Adolescence, there is a long history of research and scholarship by anthropologists, sociologists, psychologists, life history biologists, physicians, epidemiologists, and other human scientists, as well as economists and philosophers. Several key sources are (Bogin, 2011; Levesque, 2011; Schlegel & Barry, 1991).

The biosocial mechanisms that control the onset of Puberty are not well understood, but the consequences of this life history event are noted in the phenotype of the late juvenile by the first appearance of secondary sexual characters. These include darkening and increased density of pubic or axillary hair, development of the breast bud in girls and genital changes in boys. Skeletal growth rate transitions from deceleration to acceleration and the point of this change marks the beginning of the adolescent growth spurt and, in the Table 1.1 scheme, the Adolescence stage of growth and development.

Human Adolescence may be defined by a suite of physiological and behavioral characteristics, many of which are sex specific and appear in a different sequence for each sex. The production of viable spermatozoa, for example, occurs relatively early in the adolescent development of boys (a fast tempo), but the production of mature oocytes is a relatively late event in the adolescence of girls (a slow tempo). In contrast, girls have a fast tempo in breast development and height amplitude, which makes them appear to be more sexually mature than boys, who have a slow tempo in terms of the amplitude of height and muscularity. The sex-specific human patterns of reproductive development and associated behavioral changes are discussed in detail elsewhere. Sex-specific differences in the tempo and amplitude of various body parts and systems are part of the reason that human adolescence is considered a unique life history stage – one not found in any other species of mammal (Bogin, 2021b; Bogin & Varea, 2017).

The adolescent growth spurt starts at an average age, depending on population health, of 10 years in girls and 12 years in healthy boys. For both girls and boys, Adolescence starts with the change in growth velocity of height from negative to positive, proceeds through a rise in growth velocity to its maximum amplitude since childhood, called peak height velocity (PHV), and then ends with a decline in height velocity that reaches zero velocity when final adult height is achieved. The rise and fall of height velocity is the adolescent growth spurt. The spurt is typically detectable by members of the social group (without anthropometric measurement) and experienced by almost all boys and most girls. Another reason why the adolescent growth spurt is human species-specific trait is that all long bones as well as several cranial bones and the mandible have an adolescent spurt. The human adolescent spurt is associated with a high growth velocity of arm and leg length. These global skeletal changes in growth velocity are not known for other mammals, not even for chimpanzees and other non-human apes. During the adolescent period girls and boys have, in relation to total stature, the longest legs of any period of the life course, and, on average, the whole body becomes slimmer.

As noted above, the adolescent stage also includes development of secondary sexual characteristics, such as the external genitalia, sexual dimorphism in body size and composition, and deepening of the voice in boys. Adolescent girls and boys express greater interest and practice of adult patterns of sociosexual behavior and economic behavior, such as food production in traditional societies. Some of these physical and behavioral changes occur with puberty in many species of social mammals. What makes human adolescence unique are two important differences. The first, as noted above, is that both boys and girls experience a rapid acceleration in the growth velocity of virtually all skeletal tissue – the adolescent growth spurt (see Fig. 1.1). The second is the length of time between puberty and adulthood, that is, full reproductive maturity. Humans take 5–10 years for this transition. Monkeys and apes take less than 3 years and most non-primate mammals take only months.

Human boys begin producing spermatozoa at median ages that cluster between 13.4 and 14.5 years. This event, called spermarche, often occurs before the appearance of any secondary sexual characteristics (e.g., facial hair). Whether this event marks the onset of fertility is not known. It is well-documented in the cross-cultural ethnographic and demographic literature that few adolescent boys/men successfully father children. Where reliable data exist, less than 4% of live-born infants are known to be fathered by men under 20 years of age. Human girls achieve menarche (first menstruation) at median age range of 12.0–13.0 years in the higher income nations. Menarche does not equate with fecundity (able to make a baby) or fertility (becoming pregnant or a parent). Girls usually experience 1 year or more years of irregular and anovulatory menstrual cycles following menarche. This time is often called "adolescent sub-fecundity", as there is a low probability of pregnancy. Indeed, the median age of first birth for women in traditional societies, regardless of their sexual practices, clusters at 19 years, which is after growth in height ends. Individuals, of course, may mature and give birth several years earlier or later than this median age. The adolescent time gap between spermarche/menarche and parenthood is of value to the individual in terms of its apprenticeship for adulthood, that is, the learning, practicing, and perfecting technical, social, sexual, and political skills, and the emotional maturation required to successfully apply these skills. Adolescence is also of critical value to the social group of the teenager, as adolescent girls and boys supply needed physical labor and other support in terms of food production and care of children and juveniles (Bogin et al., 2014). Adolescents can contribute more energy (food) to their social group than they consume. Even so, adolescents need the physical and emotional support of their social group to survive.

Adolescence became part of human life history because it conferred significant reproductive advantages to our species, in part, by allowing the adolescent to learn and practice adult economic, social, and sexual behaviors before reproducing. In equal measure, adolescents contribute to the well-being of their social group and enhance the survival of individuals younger and older than themselves. The basic argument for the evolution and value of human adolescence is this: girls best learn their adult social roles while they are infertile but perceived by adults as mature; whereas, boys best learn their adult social roles while they are sexually mature but not yet perceived as such by adults. This is exactly the way girls and boys mature sexually and are expected to behave by adults. Without the adolescent growth spurt, and the sex-specific timing of maturation events around the spurt, this unique style of social and cultural learning could not occur. The biology of adolescence is a human universal. Over the course of time and space, the styles of adolescent learning and practice of behaviors have come to vary considerably cross-culturally. The evolution of human adolescence, therefore, must be studied and understood from a biocultural perspective.

Adolescence terminates at about the same age as M_3 (third permanent molar or "wisdom tooth") eruption, which is 18–21 years, if that tooth is present. About 15% of humans worldwide never form the third molar (Jung & Cho, 2013). M_3 agenesis is a sign of on-going human evolution due to natural selection. M_3 impaction is a common dental pathology and can debilitate or kill the victim. Prior to the advent of modern dental interventions, including antibiotics and surgery, adolescents and young adults with M_3 impaction would have reduced fertility and increased mortality; hence, the selection for agenesis. The implications of M_3 agenesis for future human life history evolution are unknown.

Adulthood is subdivided into the separate stages of Prime (also referred to as Maximum Performance Age), Transition or Degeneration age, and Senescence or old age. Description of these stages is given in Table. Prime age adults can produce enough food and other resources to survive on their own, but such solitary persons are uncommon. Even prime adults need social/emotional interaction with other people. Moreover, successful human reproduction requires a community, composed of biological and social kinship partners (Bogin et al., 2014). Within this community, nutritional support comes from people of many ages and life history stages, including juveniles, adolescents, and Transition-age adults.

The reproductive aging of women in the Transition-age is another unusual feature of human life history. In healthy, well-nourished women, fertility declines after age 40 years and ceases by about the age of 50 years with menopause. The decline and termination of reproduction usually occurs before other obvious physiologically signs of degeneration or senescence. Although men have an age-dependent decline in reproductive function, they do not experience the termination of fertility as abruptly as women. Possible evolutionary reasons for menopause have been discussed for decades. In our view, the cause of menopause is that the addition of the Childhood and Adolescence stages of development results in a slowing of the pace of human maturation and aging. With proper care, feeding, and social and emotional support, the value added by the additional life course stages allows for greater adult homeostasis, resistance to disease, and the potential to live longer than most other mammals, especially other Primates. One trade-off of greater longevity is that women outlive their supply of primary oocytes, which is determined during their gestation and is reduced to a non-functional level by ~50 years of age. The decline of ovarian reserves with age causes primary unresponsiveness of the ovaries to hypothalamic-pituitary stimulation and, eventually, menopause. A few other species of mammals, such as killer whales (*Orcinus orca*) and short-finned pilot whales (*Globicephala macrorhynchus*), live past the age of 50 years in the wild also experience menopause (Brent et al., 2015; Croft et al., 2017). Wild-living chimpanzees almost never survive past age 50 years, but may do so in captivity. Two chimpanzee females that did so also experienced marked decline in reproductive function and then menopause (Herndon et al., 2012).

Knowing the reason for menopause does not explain why women remain vigorous and productive in other ways for decades after fecundity ends. Old chimpanzees degenerate rather quickly in virtually all physical and cognitive aspects. Importantly, the two species of whales mentioned above are similar to human women in that female whales may have healthy lives for up to 30 years after menopause. These older female whales assist in food acquisition and provide knowledge of long-term ecological variability. Similar value from post-menopausal women has been well described in hunter-gatherer and other traditional populations and is often called the “grandmother effect” or “grandmother hypothesis” (Hawkes

& Coxworth, 2013). Along with value added by Childhood and Adolescence, contributions of post-reproductive women and whales may have provided part of the selection for their slower senescence, even in the face of reproductive termination.

1.4 Nutrients and Food

Just as all human beings share the biocultural life history stages of human growth, development, and maturation, all members of the human species share the same fundamental nutritional requirements. In the growing human being, the multiplication of cells or their enlargement in size depends upon an adequate supply of nutrients. Nutritional biochemists have determined that the are about 50 essential nutrients required for growth, maintenance, and repair of the body. The imprecision of the phrase 'there are about 50' is used here because some biochemical substances, such as cobalt, may be essential in relatively small amounts but a minimally required amount has not been determined. Essential nutrients are those substances which the body needs but cannot manufacture. The 50 essential substances are divided into six classes: protein, carbohydrate, fat, vitamins, minerals, and water. Shown in Fig. 1.2 are the essential nutrients in these categories. Why we have so many essential nutrient requirements is related to the evolutionary history of the human species, a topic that I have written about elsewhere (Bogin, 1998, 2001).

One way that nutrients are shown to be essential is via experiments with nonhuman animals. A young rat, pig, or monkey is fed a diet that includes all the known nutrients except the one being tested. If the animal gets sick, stops growing, loses weight, or dies it usually means that the missing nutrient is essential for that animal. Such experiments do not prove that the same nutrient is needed for people, but due to the close biological relationship between monkeys, apes, and people it is likely that nutrient requirements are similar, if not identical. This does not mean that all primate species should eat the same diet as, for example, a diet as high in animal protein as eaten by many human groups will kill chimpanzees (Finch & Stanford, 2004). The primate similarity means only that monkeys, apes, and humans share the same 50 essential nutrients requirements. Another way to discover essential nutrients is that certain medical conditions deprive people of one or more nutrients and the consequence of deficiency helps to prove the essential nature of those nutrients. Finally, controlled experiments were done in the twentieth century with humans, such as with children at orphanages, patients at psychiatric hospitals, people incarcerated in prison, and with residents of villages in colonized or low-income nations. Most of these experiments were unethical as they were usually performed without informed consent and often without any understanding or knowledge by the participants. Examples are the unethical nutrition experiments performed on Canadian Aboriginal children at six residential schools between 1942 and 1952 (Macdonald et al., 2014) and the experiments performed on Guatemala rural people in the 1960s (Read & Habicht, 1992). In the latter case, "…concern centred on whether a nonnutritive placebo could be used in villages known to have extensive childhood

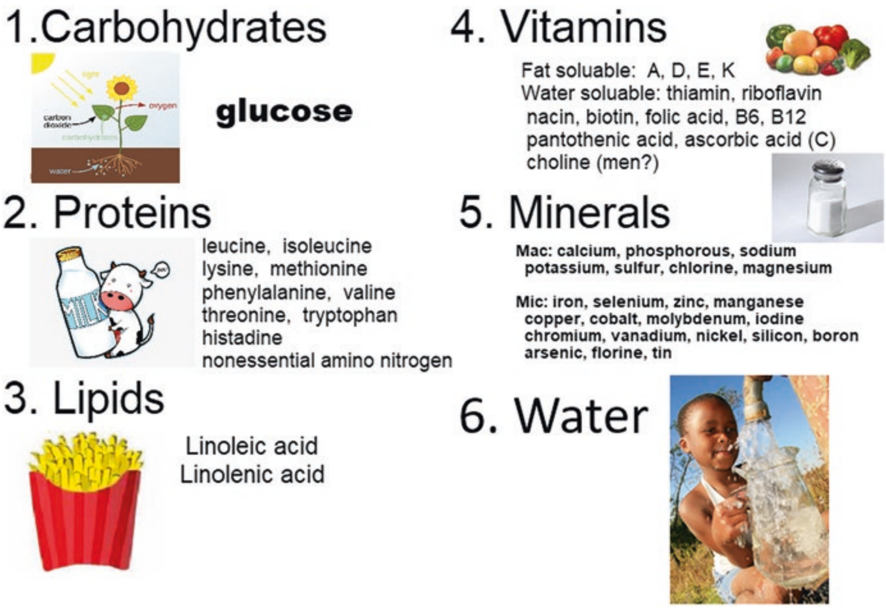

Fig. 1.2 Essential nutrients grouped into six categories. The image under "Carbohydrates" is a cartoon of photosynthesis. Under "Proteins" are the nine essential amino acids required during the years of body growth. Under "Lipids" is a container of fried potatoes which due to the absorption of the frying oil provides most of its energy from lipids. The image under "Vitamins" is of fruits and vegetables which are sources of the essential vitamins. The image of a saltshaker indicates that table salt provides calcium and phosphorous. "Mac" is an abbreviation for macromineral and "Mic" is an abbreviation for micromineral. The "Water" image indicates that safe tap water is needed for all people. When safe to drink, tap water is preferred to plastic bottles and is often of higher quality. (Original figure by the author, the photosynthesis cartoon is from https://en.wikipedia.org/wiki/Photosynthesis#/media/File:Photosynthesis_en.svg (open source); the 'tap water' image is from https://lisadewberry.wordpress.com/2012/02/03/urban-areas-produce-world-quality-water/ (open source))

malnutrition" (Read & Habicht, 1992, p. 6). Such a placebo was used during the first years of the INCAP[2] Four Village study in Guatemala, from 1969 to 1971. The initial hypothesis of the study was that a deficiency of protein caused poor physical growth and mental deficiency. To test this hypothesis, a low-energy placebo drink, with only 59 kcals per 180 ml from carbohydrate and no protein, vitamins, or minerals, was given to people in two 'control' villages. In contrast, people in the two 'experimental' villages were given a high energy supplement beverage with 163 kcal per 180 ml from protein and carbohydrate, as well as a host of vitamins and minerals. Only in 1971 was it decided, on scientific and ethical grounds, to fortify both the low energy placebo and the high energy supplement with minerals and vitamins in equal concentrations. That decision was not only ethical in terms of human

[2] Institute of Nutrition of Central America and Panama.

nutritional well-being, it lead to the discovery that the initial hypothesis was incorrect – it was the extra energy (kcals) in the supplement that made the difference in physical growth and cognitive development (Stein et al., 2008). More detail on this nutritional experiment is given below.

1.4.1 People Eat Food, Not Nutrients

People do not usually eat the essential nutrients directly as pure chemicals, rather we eat food. This was certainly true for our animal ancestors throughout evolutionary history. Human foods come from five of the traditionally defined six Kingdoms of living organisms: 4 plants, animals, fungi (e.g., mushrooms), protists (e.g., species of algae referred to as "seaweed") and eubacteria (e.g., bacteria used in fermented foods). The sixth Kingdom, archaebacteria, are not eaten directly, but are essential in the diet of other species that people do eat. Herbivores, for example, have archaebacteria in their guts to digest plant cellulose. Some people eat the herbivores, such as cows, horses, sheep, deer, goats, and the like. Furthermore, every human society creates a cuisine, that is, a list of acceptable food items, the style of preparing these items, the rules for serving and sharing food, food taboos against the consumption of certain foods based on age, sex, gender, state of health, religious beliefs, and other culturally defined reasons (Pelto & Pelto, 1983). In addition, people use food for non-nutritional purposes, such as for medicine to cure or cause disease and as offerings in ritual or religious activities. In these contexts, food may have physiological functions due to their ideological and symbolic meaning. All people have the same nutrient requirements, but the biocultural nature of human nutrition makes the connection between food, growth, development, and maturation hugely complicated to study.

1.5 Patterns of Growth and Development for Guatemalans at Different Life History Stages

Velocity curves in height are presented in Fig. 1.3 for four groups of boys: two samples from Guatemala, one of high SES urban-living Ladino boys and one of low SES rural Maya boys, a sample of low SES boys from rural Gambia, West Africa, and a sample of low SES boys from rural India. The velocity curves were calculated from longitudinal measurements of height by fitting the measurements to the Preece–Baines model 1 function (Bogin, 2021b, pp. 276–289; Bogin et al., 1992 provide details of the samples and methods of analysis). The Maya, the rural Indians (from the Hyderabad region of India), and the rural Gambians were described as suffering from poor living conditions, including high rates of disease and chronic undernutrition. In contrast, the high SES urban Ladino boys are generally healthy

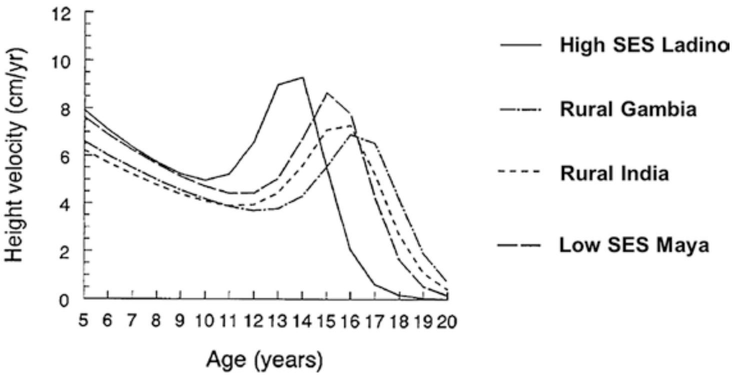

Fig. 1.3 Velocity curves of height growth, estimated by the Preece–Baines model 1 function, for high SES urban Ladino and low SES rural Maya boys from Guatemala, rural Indian boys, and rural Gambian boys. The curves are based on mean-constant values estimated by the Preece–Baines model 1 function. (Author's original figure)

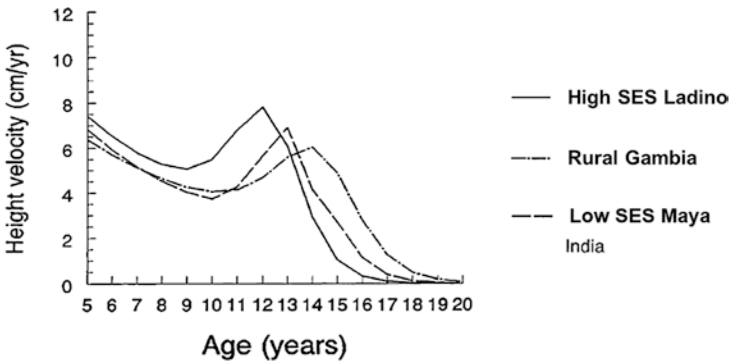

Fig. 1.4 Velocity curves of height growth, estimated by the Preece–Baines model 1 function, for high SES urban Ladino and low SES rural Maya girls from Guatemala, and rural Gambian boys. The curves are based on mean-constant values estimated by the Preece–Baines model 1 function. (Author's original figure)

and well nourished. Compared with the Ladinos, the Maya, rural Indian, and rural Gambian boys have slower velocities of growth during all stages of life history. These three slower growing groups also have a longer period of childhood, juvenile, and adolescent growth; note that the Preece–Baines function estimates that growth continues beyond age 20 years. Despite this the Maya, rural Indians, and rural Gambians end up significantly shorter than the high SES Ladinos (estimated mean adult heights are: high SES Ladino, 176.9 cm; Maya, 169.15 cm; rural Indians, 158.2 cm; Gambians, 170.8 cm).

Velocity curves for high SES Ladina girls, Maya girls, and rural Gambian girls are shown in Fig. 1.4. Compared with Ladina girls, the Maya and Gambian girls show a general pattern of slower growth and delayed maturation, although this is more pronounced for the Gambians. An exception to this general pattern is that Maya girls grow more rapidly than the Ladina girls at age eight. Despite that anomaly, Maya and Gambian girls are shorter at all ages, including adulthood, than Ladina girls (the estimated mean adult heights are: high SES Ladina, 162.95 cm; Maya, 151.8 cm; Gambian, 158.8 cm).

The difference in height between Maya and Ladinos may be due, in part, to genetic determinants of amount of growth. However, it is not possible to assess that determination in these samples. Moreover, an explanation that relies heavily on the genetic limitation of Maya growth (or rural Indians and Gambians) is not particularly useful, as shown by the enormous plasticity in growth of Maya, Indian, African, and other migrants to the United States and other high-income nations (Bogin et al., 2001, 2018a; Smith et al., 2002). The low SES of the Maya of Guatemala correlates with their chronic mild-to-moderate undernutrition as measured by body composition, with their higher rates of disease, and with their generally unfavorable environment for growth. The result is shorter stature at all virtually all life history stages of growth for the Maya, rural Indians, and Gambians compared with the high SES Ladinos. Puberty and sexual maturation are, on average, delayed and the adolescent stage is prolonged for the lower SES groups. Because of the wide geographic, ethnic, and sociocultural differences between these groups, and despite possible genetic differences, it seems that it is the shared negative environment for growth that produces the similar pattern in amount and rate of growth in height in the Maya, Indian, and Gambian samples.

In populations where food shortages are present growth delays occur, and people of all ages are shorter, lighter, and mature later than in populations with adequate or overabundant supplies of food. Guatemala, where I have worked since 1974, has the one of the highest prevalence of stunting of all nations, affecting 46.7% of all infants and children <5 years old. The word "stunting" is used to describe very short height, technically a girl or boy whose height-for-age is among the shortest 2.3% (less than 2 standard deviations) of a healthy reference group of same the sex and age. In rural communities of Maya people (the indigenous ethnic group of Guatemala) the prevalence of stunting exceeds 60% of all infants and children. For adults, the total Guatemalan population ranks 12th shortest for men (mean height = 163.4 cm) and 1st shortest for women (mean height = 149.4 cm) of the 200 nations surveyed by the NCD Risk Factor Collaboration (NCD Risk Factor Collaboration (NCD-RisC), 2016). The prevalence of stunting for Guatemalans across all quintiles of family income is illustrated in Fig. 1.5. High rates of stunting are present for all economic groups, with up to 17% stunting for infants and children from the highest income quintile families of Guatemalans (i.e., the richest 20%). A deficit of food energy is unlikely for families with incomes in the middle, rich, and richest quintiles. So, what factors might account for such high rates of stunting for the rich? There are many reasons unrelated to food for the very short average stature of all Guatemalans. These reasons likely include infection with bacteria, viruses, and parasites as well as a variety of Social-Economic-Political-Emotional (SEPE) factors. Especially important are the emotional stresses that result from a constant exposure to high levels of violence and insecurity that pervade the entire country.

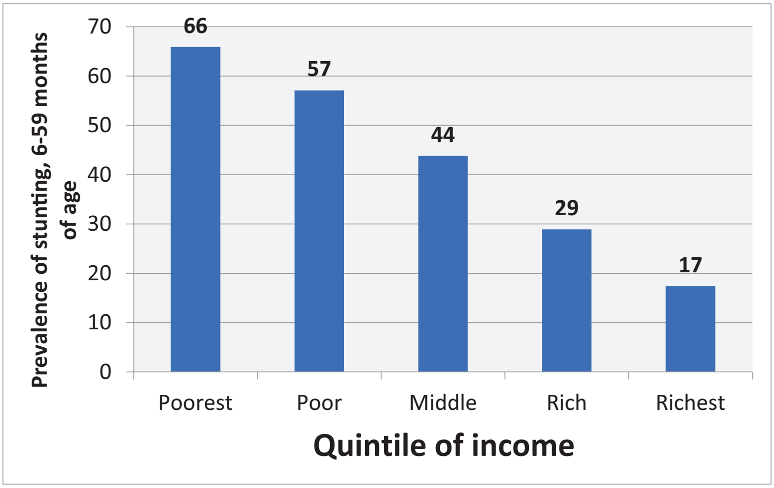

Fig. 1.5 Guatemala: prevalence of stunting by quintile of family income. The data come from the Guatemala DHS Key Indicators Report, 2014–2015 available at https://dhsprogram.com/what-we-do/survey/survey-display-440.cfm. This is the most recent report for Guatemala. (The figure is based on a World Bank presentation, 'Desnutricion en Guatemala' (Malnutrition in Guatemala), January 2016)

First, I wish readers to understand clearly that nutritional deficiencies can certainly result in delayed growth and poor health. Nutritional deficiencies, especially food shortages, along with infections and psychosocial stress, are more likely for the families in the poor and poorest income quintiles. The poor constitute the 56–64% of the Guatemalan population that survive on an income of US$2/day/person. The poorest constitute 21.5% of the population and suffer from an income of US$1/day or less per person (Bogin, 2021a). The World Bank provides estimates of food shortages in a country via a statistic called "the depth of the food deficit." This statistic indicates how many kilocalories would be needed to lift the undernourished to a status of adequately nourished, everything else being constant (such as no infection, no increase in workload, and no psychosocial stress). The average intensity of food deprivation of the undernourished is estimated as the difference between the average dietary energy requirement and the average dietary energy consumption of the undernourished population. The depth of the food deficit in Guatemala was reported at nearly 140 kilocalories per person per day in 2001 and 101 kcal/person/day in 2016, according to the World Bank collection of development indicators.[3]

In addition to the total energy deficit, the poor in Guatemala suffer micronutrient deficiencies of iron, vitamin A, and iodine.[4] A shortage of any one of these nutrients,

[3] https://knoema.com/WBWDI2019Jan/world-development-indicators-wdi?tsId=2592780

[4] http://documents.worldbank.org/curated/en/485361468251183980/Guatemala-Nutrition-at-a-glance

before or after birth, will reduce body growth and brain development of the fetus or young person. It is estimated that worldwide the most common nutrient deficiencies are iron, iodine, vitamin A, folate, and zinc. Vitamin B12 may also be in widespread shortage. Undoubtedly, many infants, children, pregnant women, and others in Guatemala and elsewhere are deficient in one or more of these nutrients. However, precise estimates for specific nutrient deficiencies are made difficult in that the intake requirements are set at a level above the known biological requirement. The US National Institutes of Health sets the average daily requirement for iron, for example, at 13.7–15.1 mg/day in people aged 2–11 years. In the United States the average daily iron intake from foods is 11.5–13.7 mg/day in this age group. Nearly all these people should be iron deficient, but the prevalence of iron deficiency for this age group is less than 3.5% as assessed by blood tests for anemia (Le, 2016). It is unlikely that the other 96.5% take iron supplements. Why the discrepancy? The recommended intakes of nutrients are purposefully set high so if consumed at that level that at least 98% of the human population will be adequately nourished. But, setting the recommendations so high means that deficiency misdiagnosis will also be high. This is one reason why nutrient supplementation interventions to prevent or overcome stunting and underweight so often fail – the people were not, in fact, deficient for that nutrient (Goudet et al., 2019).

1.5.1 An Experimental Study of Nutrition and Growth

Some nutrition interventions do work when the reason for growth failure is a real deficiency of total food or specific nutrient intake. The INCAP "Four Village Study" was described briefly above. The original study ran from 1969 to 1977 and involved the supplementation of pregnant women and all infants and children with either a high energy drink, with protein, carbohydrates, vitamins, and minerals, or a low energy drink with essentially little carbohydrate and no protein, but after 1971 the drink contained the same vitamins and minerals.

The study took place in a rural region of eastern Guatemala in two large (~900 residents) and two small (~500 residents) *ladino*[5] villages. INCAP personnel screened 300 communities to identify these four villages, which were chosen because they met the criteria of "…appropriate size, compactness, ethnicity and language, diet, access to health care facilities, demographic characteristics, nutritional status and degree of physical isolation" (Martorell, 1995, p. 716). The criteria of "appropriate" diet meant that the villagers suffered from a chronic shortage of

[5] Guatemala is composed of two major ethnic groups – Maya and *ladino*. Maya are the cultural descendants of the pre-Conquest Maya, speak a Maya language and Spanish, wear traditional non-Western clothing (especially during social and religious rituals), and claim Maya ancestry or heritage. Ladinos are defined as the cultural descendants of the Spanish conquerors of Guatemala, speak Spanish as their primary language, wear western-style clothing, and deny Maya ancestry or heritage.

food intake. The study focused on protein because in 1969 it was assumed that protein deficiency was the most important nutritional problem facing the poor in the developing countries. "Appropriate" nutritional status meant that most infants and children were very thin and stunted. The four villages chosen for the study suffered from extreme economic poverty which caused hunger and growth failure. "Appropriate" ethnicity and language meant that participants were *ladinos* speaking Spanish and not Maya speaking one of the many Maya languages.

One large and one small village received the experimental supplement called *atole*, which is the local name of a thick, corn-based beverage, and the other two villages received *fresco*, the local name of a drink made from watered-down fruit juice. The *atole* used in the intervention was a gruel-like drink made from Incaparina, a proprietary formula developed at the INCAP laboratories. Incaparina is composed of a vegetable protein mixture (a cereal), dry skimmed milk, and sugar. In the other two villages, residents were given an INCAP formulated *fresco*, a drink that contained energy from sugar, but no protein and at the start of the study no other nutrients.

The study participants were pregnant women, infants, and children who were given the drinks twice a day at feeding stations in the villages. The participants could consume all they wished, and intake was carefully monitored. The infants and children participating in this original INCAP study were followed until they were 7 years old. Results of this study showed that pregnant women receiving the *atole* drink gave birth to newborns with higher birth weights and lower infant mortality. Infants receiving the *atole* had greater weight and length-for-age until age 3 years (Martorell, 1995). Analysis of these findings showed clearly that it was the total energy (kcal) added by the *atole* supplement, and not the amino acids of the protein per se, that was associated with the greater weight and length. Based, in part, on the findings of the INCAP study, the early 1970s recommended amounts of protein intake for infants dropped from more than 3 grams per kilogram body weight per day (g/kg/day) to the current estimated average requirement 1.52 g/kg/day for infants 0–6 months, 1 g/kg/day for infants 7–12 months, and 0.87 g/kg/day for infants 13–36 months old.

Several follow-up studies have been conducted with the original INCAP participants. One follow-up took place from 1988 to 1989 to assess participants who were then 11–27 years old (Martorell, 1995). The reason for the follow-up was to see if nutritional supplementation up to age 7 years had long-term effects. The answer is yes! There are several long-term effects of the *atole* drink, including greater stature and fat-free mass (the weight of the skeleton, muscles, and organs of the body), especially for girls and women. *Atole* users also showed improved work capacity in the men and higher scores on tests of intellectual performance in both males and females. The *atole* group did not experience a faster tempo of maturation, as measured by either skeletal development or age at menarche, compared with the *fresco* group. More recent follow-ups reported that the *atole* group had higher scores on both a measure of reading comprehension and on the Ravens' Progressive matrices, a type of cognitive performance (IQ) test. Participants receiving *atole* between 0 and 24 months of age had a 46% increase in net wages as adults (Stein et al., 2008).

Some researchers concluded that the INCAP intervention study showed clear benefits of improved nutrition at all stages of the life cycle and that these results should apply to all human groups. But, as mentioned above, most nutrition interventions have no such effects and some even have negative effects on physical; growth (Scheffler et al., 2020). Another interpretation of the INCAP study is that providing more food to the clearly underfed people of the four fastidiously selected villages had beneficial effects. Would the same atole supplement improve growth and development in the 296 villages not selected? Would the intervention have a similar effect in Maya villages? These questions are not possible to answer, but it is known that the height growth status of the adult Guatemalan population has changed little in the past 100 years despite many interventions by other research groups and charitable organizations and despite the general improvement of the Guatemalan economy (NCD Risk Factor Collaboration (NCD-RisC), 2016).

1.6 Infection and Psychosocial Stress in Guatemala

The WHO states that in addition to malnutrition, repeated infection and inadequate or inappropriate psychosocial stimulation can cause stunting. Between 1960 and 1996 Guatemala suffered from both repeated bouts of infections and an inappropriate psychosocial environment due to civil war. The civil war of the twentieth century was preceded by much violence in Guatemala during the 500 years since the arrival of Spanish *conquistadores* in the year 1500 CE. There are several accounts of Guatemala and its violent history (e.g., Handy, 1984). I have written on the insecurity and fear that the Guatemalan violence creates and its association with stunting and poor health (Bogin, 2021a). Here I present some of the main points.

The civil war (1960–1996) resulted in more than 200,000 deaths and millions of displaced people, especially from rural villages that were targeted for destruction by the military (Lovell, 2010). In addition, the 1976 earthquake of moment magnitude 7.5 killed at least 23,000 and injured at least 76,000 people. Many thousands were left homeless, especially in rural areas. The civil war and the earthquake forced many rural families to migrate to Guatemala City to live in slums and other informal settlements as there were no other places to live. It is estimated that Guatemala City had a population of 285,000 inhabitants in 1950; 573,000 in 1964; 1,202,536 in 2006; and 2,450,212 in 2018. The total population in Guatemala was estimated at 17.3 million people in 2018. About 42%, or about 7.2 million people, live in the greater metropolitan region. Guatemala City's population continues to increase with the influx of predominantly indigenous migrants from the other departments as well as people from other countries. By the year 2003 the city was characterized by a large horizontal expansion, an inefficient public transportation system, a decrease in state attention to housing needs, and a proliferation of precarious settlements (slums). Of Guatemala City's 2.45 million inhabitants, approximately a third live in precarious settlements.

The civil war was most intense from 1978 to 1985 and led to a decline of the Guatemalan economy, massive urban migration, the growth of urban slums, and an increase in infectious disease. The Pan-American Health Organization (PAHO) country profile for Guatemala in 1991 (www.paho.org) reported that for the years 1988–1990 the two leading causes of death were respiratory infections and intestinal infections. The death rate from measles rose during the years 1989–1990 and the number of malaria cases rose from 41,711 in 1990, to 57,560 in 1992. There was an "alarming rise" of acute malnutrition for infants and children under 5 years old as assessed by weight-for-height. In 1979 the prevalence of endemic goiter due to iodine deficiency was 8% of the Guatemalan population but by 1989 had increased to 20.4% as a consequence of notable deterioration in the salt iodization program (Bogin & Keep, 1999).

The rural, especially rural Maya, population was affected most strongly by these generally negative changes in health and nutrition during the 1980s and 1990s. However, the civil war and the collapse of the Guatemalan economy after the war brought a decline in health and nutrition to the urban population as well. Even the children of the wealthy may have suffered as the safety of the water and food supply of the country was compromised during the most intense periods of social, economic, and political instability during and after the civil war. The quality of urban water and food did decline in Guatemala during the 1980s and was associated with the outbreak of cholera in the 1990s. Quoting again from the PAHO country report for Guatemala: "In response to the cholera epidemic that struck the country in 1991, the use of chlorine in municipal water systems has doubled. In 1991, 48 systems were chlorinating their water supplies and by 1992 the number increased to 94; nevertheless, only 45% of the total urban population is served by those 94 systems."

The PAHO report concludes that in addition to cholera contaminated water, the food supply was a source of infection: "With regard to food sold by street vendors, 52% of the samples from the departments [rural areas] and 48% of the samples from the capital [Guatemala City] were found to be microbiologically acceptable in 1992." Those figures represent an improvement over the 34% level of acceptability found in 1991. Street vendor food is consumed by all segments of the Guatemalan population, especially school-aged children of all economic levels. Even with some improvement, the 1992 data indicate that about one-half of this food was contaminated. Thus, Guatemalans of all ages, ethnicities, sexes, and family income levels were subjected to risks for health from food and water. My ethnographic experience in Guatemala provides ample evidence that people know of these risks. This knowledge, as well as the biological contaminants, create a climate of insecurity that compromised growth and resulted in the high prevalence of stunting for the nation.

Following the end of the civil war in 1996 there was a rise in organized crime and corruption related to drugs and human trafficking. The crime and gang violence were, and still are, symptoms of much larger structural problems in the government and society, "…including deepening economic inequalities, the erosion of political and social infrastructures and disparate access to healthcare and education" (Thomas

& Benson, 2008, p. 39). The murder rate of women in Guatemala is the third highest in the world with an average of 755 violent deaths/year of women in the years 2014–2016. Between 1991 and 2001 the rate was about 200 murders of women per year. The number of killings increased to just over 600 by 2006, according to a 2007 study by UN Rapporteur Philip Alston who noted that "…the death toll is only the beginning of the cost, for a society that lives in fear of killing is unable to get on with its life and business in the ways that it wants." (Sanford, 2008, p. 21). Life and business in Guatemala have been insecure for everyone due to crime at the highest levels of government. In 2015 the Guatemalan president and vice-president were arrested for crimes of corruption and money-laundering. The Guatemalan National Postal Service was suspended for 2 years following its involvement in similar crimes, resuming some services in April 2019.

In addition to the crime and corruption suffered by the poorest to richest in Guatemala, the wealthy live under the threat of kidnappings for ransom. These kidnappings are so common that in my personal experience every richer Guatemalan family I know has had at least one family member kidnapped. Rich and richest families send their children to school in bullet-proof vehicles accompanied by armed guards. The stress of real and threatened violence is pervasive and is part of the lives of people of all ages.

1.6.1 It Is All About Stress

These insecurities from endemic corruption, violence, and kidnappings are forms of inadequate and inappropriate psychosocial stimulation, commonly referred to as toxic emotional stress and adverse childhood experiences (ACEs).[6] This type of stress takes a toll on human health, including the physical growth of people, as much as do food shortages and infection. ACEs and toxic emotional stress are associated with susceptibility to disease, dysregulated gene expression, and low birthweight (Bogin, 2021a). Too often the toxic emotional stress is exacerbated by food shortages, infection, and other health problems, a combination that is especially harmful – even deadly.

The "C" in ACEs places emphasis on the childhood phase of life but toxic stress impacts people of all ages and persists across generations. Several researchers with a focus on Maya people and on Guatemala noted the effect of toxic stress on pregnant and lactating women and their newborns. This research group collected and interpreted biocultural data using anthropological fieldwork methodology of participant-observation, newer methods of participatory action research and socio-ecological frameworks to construct questionnaires (Chomat et al., 2015). The research was based on a sample of 155 Maya women living in rural communities in the Western Highlands of Guatemala. Women were enrolled during pregnancy and

[6] https://developingchild.harvard.edu/ACEs

followed for between 6 and 9 months. Mother-infant dyads were assessed between 0 and 6 weeks after birth (early postpartum) and again at 4–6 months after birth (later postpartum). In addition, two cross-sectional samples of mother-infant dyads were assessed at early postpartum (n = 60) or later postpartum (n = 56). Participant engagement with the research team did not influence study outcomes based on comparisons between longitudinal and cross-sectional cohorts.

The researchers collected information on household and social factors, including an appropriate index of household wealth, the mother's nutritional and infectious disease status, the mother's obstetric history and care during pregnancy; place and type of delivery, and psychosocial stressors of the mother assessed from the perspective of the researchers and as reported by the mothers in their local idioms of distress. By "local idioms of distress" the researchers meant that the women used their own Maya language and meaning to describe and interpret illness and emotional status. The researchers also collected newborn and infant characteristics such as birthweight and length. The researchers' interpretation of findings was based on a sociocultural model that distinguished three broad categories of stressors – (1) nutrition, (2) infection, (3) psychological – that, "…cumulatively impact the health of the maternal–infant dyad" (Chomat et al., 2015, p. 417, see their Fig. 1.1 for details of the model). Subsistence farming and extreme poverty characterized 68% of families and an additional 19% lived in poverty. Based on a 24-h diet recall, only 20% of women had a sufficient diet diversity score during pregnancy and early postpartum and only 9.9% had adequate diet diversity by later postpartum. Only 38% of mothers reported food security. Most women (81%) reported low maternal autonomy, 70% reported high paternal support, but 22% of women also reported experiences of domestic violence. In general, the women's social support networks were small (mean of 2.7 ± 1.3 individuals). While the women reported high trust in family (88%), trust in community-based institutions was moderate (61–65%), and trust in government services was low (6%).

The mean height of the mothers was 146.5 ± 5.2 cm, and 33% were <145 cm which the authors designated as adult stunting. Low birth weight (LBW) was reported for 8.6% of the longitudinal sample, which received frequent antenatal care visits (7.5 + 3.8), but LBW was 21.6% for the later postpartum cross-sectional sample. Premature birth (<37 weeks gestation) was 21.7% for the longitudinal sample. Infant stunting was common, at 33.8% for the longitudinal sample despite the frequent antenatal care visits. The researchers noted that these data contradict the "conventional wisdom" in the literature is that there is little to no growth retardation in length at birth and that such growth restriction is believed to occur after age 6 months (Solomons et al., 2015). The conventional belief is based on the fact that few reliable measurements of length growth are available prior to age 6 months and the WHO length growth standards begin at age 6 months. The authors' research found that for their Maya participants growth delay began in utero. The infants' small size at birth seems to be related to a combination of short gestation length, mother's short-stature, and maternal stress during pregnancy. The stress likely includes physical environmental insults such as recurrent infection and exposure to indoor woodfire smoke, but also persistent psychological and emotional stress.

Maya mothers reported on three types of stress disorders defined by local idioms of distress. These were *susto*, *enojo*, and *nervios*. The researchers explain that: "*Susto* is believed to result from a frightening or startling experience, ranging from an accidental fall or physical trauma to witnessing an accident or human suffering, which, sometimes only after a significant time lapse, affects the normal equilibrium of the human body and manifests as a diverse array of symptoms and pathologies. *Enojo* is described as an anger that upsets the body's equilibrium and leads to headaches, stomach pains, weakness or fatigue, and chronic illness. *Nervios* is an illness due to experiencing strong emotions, particularly anxiety, grief, and sorrow…" (Chomat et al., 2015, p. 424). *Susto* or *enojo* were reported by 69% of women during pregnancy and by 52% during later postpartum. Less than 5% of women reported *nervios* at any time. *Susto* was always the most common complaint. Mothers reported that their infants also suffered from *susto*. Mother state that infants with *susto* have poor appetite, discoloration, irritability, and fatigue. Some Maya mothers state that *susto* may be transferred from the mother during pregnancy or via breast milk and these women are less likely to breastfeed their infants (Wren et al., 2015) and the infant may suffer poor growth. These traditional Maya beliefs have support in western science and biomedicine in terms of the intergenerational transmission by epigenetic processes (reviewed in Bogin, 2021a, b, pp. 372–375).

1.6.2 How Stress Gets into the Skeleton and Delays Growth

The Maya women's use of *susto* and *enojo* as a local idiom of distress, and their explanation that *susto* is transferrable to their fetus and infant, are both accommodated by western biomedicine's concerns with infection, nutrition, and physiological stress. One member of the research team in Guatemala, Noel Solomons, has long proposed that infections, more than inadequate nutrition, are primary causes of growth failure in Guatemalan infants and children (Solomons et al., 1993). Solomons and colleagues based their proposal on the "dirty chicken" hypothesis, that, "…continuous activation of the acutephase [immune] response with the consequent mediation of catabolic and antitrophic metabolic processes is responsible for the antibiotic-responsive growth impairment of chicks raised in unhygienic environments" (p. 327). Subsequent research by Solomons and others in Guatemala reports that breastfeeding Maya women with subclinical mastitis (an inflammatory condition of the breast) produce milk with proinflammatory cytokines and dysregulated mineral content (Li et al., 2018). The infection, the cytokines, and other hormonal signaling factors – due to the chronic toxic stresses of *susto*, *enojo*, and their underlying causes in poverty, insecurity, and violence – may be transferred from mother to infant via breastfeeding (Solomons, 2019). Coupled with deficits or excesses in minerals and other nutrients the outcome may be growth faltering in infant length (Wren-Atilola et al., 2019).

Whether called *susto* or ACEs, the impacts of stress and illness begin to act early in life and have powerful, persistent correlations with poor outcomes later in life, including dramatically increased risk of heart disease, diabetes, obesity, depression, substance abuse, smoking, poor academic achievement, time out of work, and early death. Too often exposure to ACEs and toxic emotional stress in Guatemala is exacerbated by food shortages, infection, and other health problems, a combination that is especially harmful – even deadly (Bogin, 2021a, pp. 423–425).

Toxic stress and ACEs increase the production of cortisol, the catecholamines dopamine, norepinephrine, and epinephrine (adrenalin), and glucagon. Recent experimental evidence with rodents and clinical observations with human patients indicate that various types of physical and emotional stress also cause a rapid rise in osteocalcin (OC) release into the blood stream and that this OC is needed for the acute stress response (Berger et al., 2019). Higher serum levels of these hormones induce a hypermetabolic state of catabolism – the breakdown body cells to liberate amino acids, fatty acids, and glucose from body cells and tissues for a response to the stress. This hypermetabolic state is called the acute stress response (ASR). In the short term, the catabolism of the ASR may be beneficial for immune response, wound repair, and dieting for weight loss. In the long term the consequences are harmful because a chronic stress response results in permanent loss of tissue and growth stunting (Bogin, 2021a). The relationship of toxic stress and ACEs to bone growth is illustrated in Fig. 1.6. Also shown in the figure is the impact of stress on adipose tissue and body fatness. The result is a human phenotype that is short in stature and overfat. This phenotype is increasingly common in countries similar to Guatemala – lower income nations with high toxic stress. The phenotype is often ascribed to a nutritional dual-burden, that is, a deficit of some essential nutrients with a surplus of energy. While nutrition may be one contributor, the dual-burden phenotype, with short-stature/high fat, is also likely due to SEPE factor that create an ecology of chronic fear, insecurity, and hopelessness.

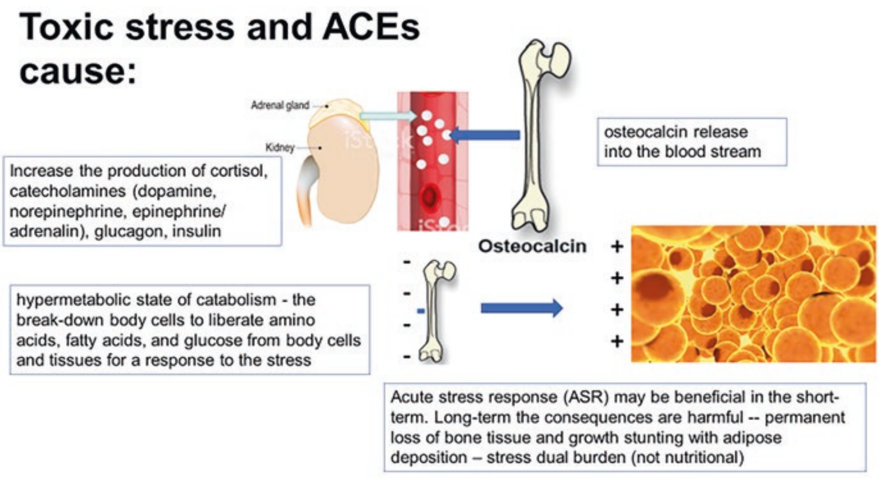

Fig. 1.6 The relationship of toxic stress and ACEs to bone growth and body fatness

1.6.3 Material and Emotional Security Are Old Problems and Continue Today

The recent history of Guatemala is, unfortunately, repeated in many parts of the world. There are daily news reports of civil war, violence, exposure to infection, disruption of food supplies, and toxic emotional stress in dozens of nations. To have health, happiness, and hope people require material and emotional security, and these are based on the reliability of an adequate diet, protection from infection, safe housing, protection from forced migration, and a meaningful livelihood. Material and emotional security are the basis of successful human biocultural reproduction, family care, and healthy growth, development, and maturation of young people of all ages before and after birth. The need for these factors has been known for hundreds if not thousands of years. The foundations of modern public health research, for example the work on human growth by René Villermé in 1829 with French military conscripts and by Edwin Chadwick in 1833 with English factory children emphasized the harmful impact of poor social conditions on healthy systems of biocultural reproduction, and not just hunger, as causes of poor growth. In his 1842 Report on the sanitary conditions of the laboring population of Great Britain, Chadwick found that there was a link between poor living standards, the spread of disease, feelings of hopelessness, and poor physical growth. He reported that unsanitary conditions in Britain's urban slums, into which rural peoples had been forced to migrate due to evictions from their homesteads, had a demoralizing effect on the families affected. The Health Foundation, a UK charity, explains that Chadwick recommended, "…the government should intervene by providing clean water, improving drainage systems and enabling local councils to clear away refuse from homes and streets." To persuade the government to act, Chadwick argued that the poor conditions endured by impoverished and ailing laborers were preventing them from working efficiently.[7] Chadwick explained that it was in the selfish interest of the wealthy factory owners to eliminate poverty.

Chadwick's advice is as pertinent today as it was 181 years ago. Despite many important historic improvements to public health in Britain, the United States, and other industrial nations during the past two centuries, poverty, unsanitary conditions, and hunger persist today in the low-income regions of all nations. Residents of impoverished cities and rural areas in the United States suffer persistent food insecurity and unsafe drinking water – the most notorious recent example is Flint, Michigan (Clark, 2018). Nationally, an estimated 11.8% of US households, totaling 40 million people, were food insecure at least some time during the year in 2017, meaning they lacked access to enough food for an active, healthy life for all household members.[8] People in the US and other wealthy nations with high prevalence of food insecurity have higher risk for overweight, diabetes, and some form of physical or emotional/psychological disability. These health risks are inter-related in that the food insecurity

[7] https://navigator.health.org.uk/theme/report-sanitary-conditions-labouring-population-great-britain

[8] www.ers.usda.gov/publications/pub-details/?pubid=90022

leads to emotional stress and unhealthy food choices of energy-dense but nutrient poor foods (diets with lots of carbohydrates and fats with few fruits and vegetables). In the low-income nations of Africa, Asia, and Latin America the quality of life for the poor, and often for the middle-class, is even worse. Both rural and urban poor, especially those families living in slums, face insecurities from inadequate water and sanitation and inadequate amounts, quality, and diversity of foods.

1.7 Conclusion

This book focuses on diverse aspects of physical growth, maturation and nutritional status of children and adolescents in Latin American countries. Much effort and money has been spent by Latin American governments, by governments of the high-income nations, and by charitable organizations to improve water, sanitation, and nutritional status throughout Mexico, Central America, and South America. These efforts were, and still are, needed. But more is required. Researchers and policy makers must embrace theory and applications that focus on the upstream, structural factors of the social-economic-political-emotional (SEPE) systems that systematically deprive lower class families of hope, dignity, and a belief that they can better themselves economically and socially. Subramanian and colleagues propose that we move away from nutrition and WASH intervention strategies to prevent stunting and move toward support-led strategies that offer integrated policies to reduce SEPE risks for stunting. Support-led strategies are a type of intervention that creates "…equitable public policies and provisions that matter for nutrition" (Subramanian et al., 2016, p. 233). Greater equity in social, economic, and political conditions creates greater emotional security and these associate with taller average adult height, as shown by a systematic analysis across 169 countries (Bogin et al., 2017). To implement the recommendations of Subramanian and colleagues requires a multifactorial approach such as combining a strong food distribution system with investments in water and sanitation infrastructure, health services, and quality education leading to meaningful employment. These are the type of support-led strategies that the currently high-income, industrialized nations implemented in the past 150 years to overcome some of their inequalities and insecurities. Stunting in these wealthy nations is relatively rare, affecting 2.5% of all infants and children. The low and lower middle-income countries have prevalences of stunting of 35.6% and 32.2%. The contrast in the material and moral conditions of life between these two worlds could not be more starkly presented.

Theorists in economics and public health policy describe economic, social, and political inequalities as a "pollutant" which causes emotional stress and disempowers people from the resources needed for their own healthy growth and development and for the health and good growth of their children (Marmot, 2015; Pickett & Wilkinson, 2017; Sen, 2002; Wilkinson & Pickett, 2009). In Guatemala and many other nations, the pollution of inequality combined with high level of persistent violence creates an ecology of fear and biocultural stress that inhibits healthy growth and causes stunting for people of all income levels.

Acknowledgements I thank Dr. Sudip Datta Banik for the invitation to prepare this chapter. My appreciation to Sudip, and to all of my colleagues and students in Guatemala, Mexico, and other Latin American nations, for their support of my research.

References

Berger, J. M., Singh, P., Khrimian, L., et al. (2019). Mediation of the acute stress response by the skeleton. *Cell Metabolism, 30*(5), 890–902.e8.

Bogin, B. (1998). From caveman cuisine to fast food: The evolution of human nutrition. *Growth Hormone & IGF Research, 8 Suppl B*(Supplement 2), 79–86.

Bogin, B. (2001). *The growth of humanity*. Wiley.

Bogin, B. (2006). Childhood begets children: Human reproductive success in life history perspective. In É. B. Bodzsár & C. Susanne (Eds.), *Human evolution: Facts and factors, biennial B* (pp. 87–98). Eötvös University Press.

Bogin, B. (2011). Puberty and adolescence: An evolutionary perspective. *Encyclopedia of Adolescence, 1*, 275–286. https://doi.org/10.1016/B978-0-12-373951-3.00033-8

Bogin, B. (2021a). Fear, violence, inequality, and stunting in Guatemala. *American Journal of Human Biology, 34*, e23627.

Bogin, B. (2021b). *Patterns of human growth* (3rd ed.). Cambridge University Press. https://doi.org/10.1017/9781108379977

Bogin, B., & Keep, R. (1999). Eight thousand years of economic and political history in Latin America revealed by anthropometry. *Annals of Human Biology, 26*(4), 333–351.

Bogin, B., & Smith, B. H. (2012). *Evolution of the human life cycle. Human biology: An evolutionary and biocultural perspective: Second edition*. https://doi.org/10.1002/9781118108062.ch11

Bogin, B., & Varea, C. (2017). Evolution of human life history. In J. Kass (Ed.), *Evolution of nervous systems* (Vol. 4, 2nd ed., pp. 37–50). Elsevier.

Bogin, B., Wall, M., & MacVean, R. B. (1992). Longitudinal analysis of adolescent growth of ladino and Mayan school children in Guatemala: Effects of environment and sex. *American Journal of Physical Anthropology, 89*(4), 447–457.

Bogin, B., Kapell, M., Varela Silva, M., Orden, A., Smith, P., & Loucky, J. (2001). How genetic are human body proportions? In P. Dasgupta & R. Hauspie (Eds.), *Perspectives in human growth development and maturation*. Kluwer Academic Publishers.

Bogin, B., Bragg, J., & Kuzawa, C. (2014). Humans are not cooperative breeders but practice biocultural reproduction. *Annals of Human Biology, 41*(4), 368–380.

Bogin, B., Scheffler, C., & Hermanussen, M. (2017). Global effects of income and income inequality on adult height and sexual dimorphism in height. *American Journal of Human Biology, 29*(2). https://doi.org/10.1002/ajhb.22980

Bogin, B., Hermanussen, M., & Scheffler, C. (2018a). As tall as my peers – Similarity in body height between migrants and hosts. *Anthropologischer Anzeiger, 74*(5), 363–374.

Bogin, B., Varea, C., Hermanussen, M., & Scheffler, C. (2018b). Human life course biology: A centennial perspective of scholarship on the human pattern of physical growth and its place in human biocultural evolution. *American Journal of Physical Anthropology, 165*(4), 834–854.

Brent, L. J. N., Franks, D. W., Foster, E. A., Balcomb, K. C., Cant, M. A., & Croft, D. P. (2015). Ecological knowledge, leadership, and the evolution of menopause in killer whales. *Current Biology: CB, 25*(6), 746–750.

Chomat, A. M., Solomons, N. W., Koski, K. G., Wren, H. M., Vossenaar, M., & Scott, M. E. (2015). Quantitative methodologies reveal a diversity of nutrition, infection/illness, and psychosocial stressors during pregnancy and lactation in rural mam-mayan mother-infant dyads from the Western Highlands of Guatemala. *Food and Nutrition Bulletin, 36*(4), 415–440.

Clark, A. (2018). *The poisoned city: Flint's water and the American urban tragedy*. Picador.

Croft, D. P., Johnstone, R. A., Ellis, S., et al. (2017). Reproductive conflict and the evolution of menopause in killer whales. *Current Biology, 27*(2), 298–304.

Finch, C. E., & Stanford, C. B. (2004). Meat-adaptive genes and the evolution of slower aging in humans. *The Quarterly Review of Biology, 79*(1), 3–50.

Gannon, M. I. (2019). The Knotty question of when humans made the Americas home. *Sapiens*. Retrieved from https://www.sapiens.org/archaeology/native-american-migration/

Glocker, M. L., Langleben, D. D., Ruparel, K., et al. (2009). Baby schema modulates the brain reward system in nulliparous women. *Proceedings of the National Academy of Sciences of the United States of America, 106*(22), 9115–9119.

Goudet, S. M., Bogin, B. A., Madise, N. J., & Griffiths, P. L. (2019). Nutritional interventions for preventing stunting in children (birth to 59 months) living in urban slums in low- and middle-income countries (LMIC). *The Cochrane Database of Systematic Reviews, 6*, CD011695.

Handy, J. (1984). *Gift of the devil*. South End Press.

Hawkes, K., & Coxworth, J. E. (2013). Grandmothers and the evolution of human longevity: A review of findings and future directions. *Evolutionary Anthropology, 22*(6), 294–302.

Hermanussen, M. (2011). Tempo and amplitude in growth. *Georgian Medical News, 196–197*, 83–88.

Hermanussen, M., & Bogin, B. (2014). Auxology – An editorial. *Italian Journal of Pediatrics, 40*(1), 8.

Herndon, J. G., Paredes, J., Wilson, M. E., Bloomsmith, M. A., Chennareddi, L., & Walker, M. L. (2012). Menopause occurs late in life in the captive chimpanzee (Pan troglodytes). *Age (Dordrecht, Netherlands), 34*(5), 1145–1156.

Hrdy, S. B. (2009). *Mothers and others: The evolutionary origins of mutual understanding*. The Belknap Press of Harvard University Press.

Hublin, J.-J. (2017). The last Neanderthal. *Proceedings of the National Academy of Sciences, 114*(40), 10520–10522.

Jung, Y.-H., & Cho, B.-H. (2013). Prevalence of missing and impacted third molars in adults aged 25 years and above. *Imaging Science in Dentistry, 43*(4), 219–225.

Kuzawa, C. W. (1998). Adipose tissue in human infancy and childhood: An evolutionary perspective. *American Journal of Physical Anthropology, Suppl 27*, 177–209.

Kuzawa, C. W., Chugani, H. T., Grossman, L. I., et al. (2014). Metabolic costs and evolutionary implications of human brain development. *Proceedings of the National Academy of Sciences, 111*(36), 13010–13015.

Le, C. H. H. (2016). The prevalence of anemia and moderate-severe anemia in the US population (NHANES 2003-2012). *PLoS One, 11*(11), e0166635.

Levesque, R. J. R. (2011). *Encyclopedia of adolescence* (R. J. R. Levesque, Ed.). Springer New York. https://doi.org/10.1007/978-1-4419-1695-2

Li, C., Solomons, N. W., Scott, M. E., & Koski, K. G. (2018). Subclinical mastitis (SCM) and proinflammatory cytokines are associated with mineral and trace element concentrations in human breast milk. *Journal of Trace Elements in Medicine and Biology, 46*, 55–61.

Locke, J. L., & Bogin, B. (2006). Life history and language: Selection in development. *Behavioral and Brain Sciences, 29*(3), 301–311.

Lorenz, K. (1971). *Studies in animal and human behavior*. Harvard University Press.

Lovell, W. G. (2010). *A beauty that hurts: Life and death in Guatemala* (2nd ed.). University of Texas Press.

Macdonald, N. E., Stanwick, R., & Lynk, A. (2014). Canada's shameful history of nutrition research on residential school children: The need for strong medical ethics in aboriginal health research. *Paediatrics and Child Health, 19*(2), 64.

Marmot, M. (2015). The health gap: The challenge of an unequal world. *Lancet, 386*(10011), 2442–2444.

Martorell, R. (1995). Results and implications of the INCAP follow-up study. *Journal of Nutrition, 125*, 1127S–1138S.

NCD Risk Factor Collaboration (NCD-RisC). (2016). A century of trends in adult human height. *eLife, 5*, 1–29.

Pelto, J., & Pelto, G. (1983). Culture, nutrition, and health. In L. Romanucci, D. Moerman, & L. Tancredi (Eds.), *The anthropology of medicine* (pp. 173–200). Praeger.

Pickett, K. E., & Wilkinson, R. G. (2017). Immorality of inaction on inequality. *BMJ (Clinical Research Ed.), 356*, j556.

Posth, C., Nakatsuka, N., Lazaridis, I., et al. (2018). Reconstructing the deep population history of Central and South America. *Cell, 175*(5), 1185–1197.e22.

Povinelli, D. J., & Preuss, T. M. (1995). Theory of mind: Evolutionary history of a cognitive specialization. *Trends in Neurosciences, 18*(9), 418–424.

Raff, J. (2022). *Origin: A genetic history of the Americas*. Twelve Books.

Read, M. S., & Habicht, J.-P. (1992). History of the incap longitudinal study on the effects of early nutrition supplementation in child growth and development. *Food and Nutrition Bulletin, 14*(3), 1–7.

Reynolds, A. W., Mata-Míguez, J., Miró-Herrans, A., et al. (2019). Comparing signals of natural selection between three Indigenous North American populations. *Proceedings of the National Academy of Sciences, 116*(19), 9312–9317.

Sanford, V. (2008). Feminicide in Guatemala. *REVISTA: Harvard Review of Latin America, Winter*, 20–21.

Scheffler, C., Hermanussen, M., Bogin, B., et al. (2020). Stunting is not a synonym of malnutrition. *European Journal of Clinical Nutrition, 74*(3), 377–386.

Schlegel, A., & Barry, H. (1991). *Adolescence: An anthropological inquiry*. Free Press.

Sen, A. (2002). Why health equity? *Health Economics, 11*(8), 659–666.

Smith, P. K., Bogin, B., Varela-Silva, M. I., Orden, B., & Loucky, J. (2002). Does immigration help or harm childrens health? The Mayan case. *Social Science Quarterly, 83*(4), 994–1002.

Solomons, N. W. (2019). Vision of research on human linear growth. *Food and Nutrition Bulletin, 40*(4), 416–431.

Solomons, N. W., Mazariegos, M., Brown, K. H., & Klasing, K. (1993). The underprivileged, developing country child: Environmental contamination and growth failure revisited. *Nutrition Reviews, 51*(11), 327–332.

Solomons, N. W., Vossenaar, M., Chomat, A.-M., Doak, C. M., Koski, K. G., & Scott, M. E. (2015). Stunting at birth: Recognition of early-life linear growth failure in the western highlands of Guatemala. *Public Health Nutrition, 18*(10), 1737–1745.

Stein, A. D., Melgar, P., Hoddinott, J., & Martorell, R. (2008). Cohort profile: The Institute of Nutrition of Central America and Panama (INCAP) Nutrition Trial Cohort Study. *International Journal of Epidemiology, 37*(4), 716–720.

Subramanian, S. V., Mejía-Guevara, I., & Krishna, A. (2016). Rethinking policy perspectives on childhood stunting: Time to formulate a structural and multifactorial strategy. *Maternal & Child Nutrition, 12*, 219–236.

Tanner, J. M. (1971). Sequence, tempo, and individual variation in the growth and development of boys and girls aged twelve to sixteen. *Daedalus, 100*(4), 907–930.

Thomas, K., & Benson, P. (2008). Dangers of insecurity in postwar Guatemala: Gangs, electoral politics, and structural violence. *REVISTA: Harvard Review of Latin America, Winter*, 39–41.

Tomasello, M., Carpenter, M., Call, J., Behne, T., & Moll, H. (2005). Understanding and sharing intentions: The origins of cultural cognition. *The Behavioral and Brain Sciences, 28*(5), 675–691. discussion 691–735.

Wilkinson, R. G., & Pickett, K. E. (2009). *The spirit level: Why more equal societies almost always do better*. Allen Lane.

Wren, H. M., Solomons, N. W., Chomat, A. M., Scott, M. E., & Koski, K. G. (2015). Cultural determinants of optimal breastfeeding practices among indigenous mam-Mayan women in the Western Highlands of Guatemala. *Journal of Human Lactation, 31*(1), 172–184.

Wren-Atilola, H. M., Solomons, N. W., Scott, M. E., & Koski, K. G. (2019). Infant growth faltering linked to subclinical mastitis, maternal faecal–oral contamination, and breastfeeding. *Maternal & Child Nutrition, 15*(3). https://doi.org/10.1111/mcn.12756

Chapter 2
The Complex Relationship Between Food Insecurity and Malnutrition

Hugo Melgar-Quiñonez

2.1 Historical Background and Development of the Food Security Concept

Food insecurity represents nowadays one of the most challenging issues faced by human society. The fight against this phenomenon, particularly expressed in its severe consequence of hunger, has been the focus of international attention and programming for several decades. Furthermore, having access to adequate food and to be free from hunger is considered a human right, as stated in the International Covenant on Economic, Social and Cultural Rights (ICESCR), adopted 16 December 1966 by the United Nations (UN) General Assembly, entering into force in 1976.

In his book "The Geography of Hunger", published the first time in 1946 and considered a foundational intellectual assessment of an ancestral plague that continues affecting human and social development and growth, Josué de Castro shares a preface by André Mayer starting with a reflection about hunger as "a problem as old as life itself" (Castro, 1967). Mayer continues stating that hunger "is one of those problems that put at risk the survival of the human species, which to guarantee its perpetuity has to fight against assaulting illnesses, seek shelter against bad weather, and defend itself from its enemies". Hunger is a daily reminder that overall, human beings must seek for food to survive, something that no one is allowed to ignore. In fact, hunger has been a threat to all forms of life and particularly to our species since prehistoric times. The need for food drove the homo sapiens and other hominids to migrate out of its initial territories and finally to populate the whole planet. The first human beings to move into the American landmass seem to have followed both

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S. Datta Banik (ed.), *Human Growth and Nutrition in Latin American and Caribbean Countries*, https://doi.org/10.1007/978-3-031-27848-8_2

terrestrial and maritime preys as they migrated into and along the coasts of this continent. The first permanent settlements took place in regions where agriculture provided people with news ways of accessing foods, beyond hunting and gathering, and novel agriculture systems started to be developed in synchrony with the development of the largest indigenous societies in America. The Milpa system allowed Mesoamerican societies to build complex political, cultural, economic, and social structures. The combination of crops, such as corn, beans, and squash, delivered an enhanced nutritional content supportive of human growth and development. Other crops, native to the Americas, expanded with the time to other continents greatly impacting the gastronomic culture of various countries and even continents, as it is the case of tomatoes, peppers, potatoes, cassava, and chocolate. Energy-dense foods such as cassava and potatoes constitute some of the most important caloric sources in Africa and in Europe. The exchange of crops and goods, which did not occur without huge losses of human life due to conquer, slavery and colonialism, brought to this continent other kind of products that increased the variety of foods potentially available to the increasing population. In other latitudes, agriculture and animal husbandry sustained also large societies, each with its own culinary traditions, giving our species the largest diversity of food sources across the animal kingdom.

Despite the great advances made by humanity in its effort to produce food, hunger continued to be of great concern shaping the relationships between nations and regions. During the times of the British colonialism in India, the imperial authorities held the Codes of Famine, which were in place by the end of the nineteenth century to secure effective information channels to timely detect the proximity of scarcity and famine, collecting information of food prices, weather conditions, agricultural production, and social indicators (Waal, 1996). Over half a century later and once the second World War was over, the United Nations Food and Agriculture Organization (FAO) was founded in Quebec City, Canada, sponsored by 34 countries. In 1946, only a year after the foundation of FAO, Josué de Castro elaborated on the linkages between the foods consumed in five different food regions in Brazil and the prevalence of hunger, undernutrition, and protein and micronutrient deficiencies (Castro, 1967). Freedom from hunger and malnutrition was declared a basic human right in the 1948 Universal Declaration of Human Rights: “Everyone has the right to a standard of living adequate for the health and well-being of himself and his family, including food ...” (Assembly General, UN, 1948). By 1961 the XI FAO conference resolved to create the Codex Alimentarius, a compilation of norms, codes, directions, and recommendations about food (Pothisiri & Kongchuntuk, 1996). Nevertheless, it was not until the hunger crisis that hit Africa in the 1970’s that the focus turned towards the association between food supply and nutritional status, which propelled the development of the Food Balance Sheets and the Nutrition Surveillance System (FAO, 1984; Tuffrey & Hall, 2016).

The human right to food, which expresses the preferred relationship between the individual and the State, was reiterated in the International Covenant on Economic, Social and Cultural Rights (United Nations General Assembly, 1966). As a result, states recognize the right to be free from hunger and malnutrition: “Every man, woman and child has the inalienable right to be free from hunger and malnutrition in order to develop fully and maintain their physical and mental faculties". The elimination of hunger and malnutrition was one of the six goals of the Third United Nations Development Decade, as well as a goal of the WHO Declaration on "Health for All by the Year 2000" (WHO, 1978). This conference recommended the adoption of an international commitment for food security and proclaimed the right of every man, woman, and child to be free from hunger or undernutrition to reach the full development of its physical and mental capacities. Five years later the World Conference about Agrarian Reform and Rural Development put in place a declaration and an action plan, incorporating to the discussion the importance of land property and use, access to water and to natural resources (Michalski, 1980).

In 1981 the celebration of the World Food Day took place for the first time, establishing October 16th as its official annual date, in remembrance of FAO's foundation 36 years earlier. By the mid-eighties the attention moved from food availability to access to food, recognizing that agriculture was producing an increasingly amount of food and that the main problem was not necessarily a low quantity of food available, but the lack of access to that food. The importance of timely data is highlighted by the creation of the AGROSTAT, later FAOSTAT, system to compile agriculture information and statistics from all United Nations' member countries (FAO, 2008).

The 90's represent the time at which food security started to be explicitly linked to the nutritional value of food. In fact, it was actually a definition of food insecurity the one that embraced in 1990 that relationship as follows: "limited or uncertain availability of nutritionally adequate and safe foods or limited or uncertain ability to acquire acceptable foods in socially acceptable ways", including the importance of acceptable foods, recognizing the relevance of culinary traditions. That same year the United Nations Children's Fund (UNICEF) release a foundational paper describing what nowadays is known as the UNICEF Conceptual Framework on the Determinants of Maternal and Child Nutrition (UNICEF, 1990). Besides basic causes of malnutrition related to structural, superstructural, and institutional causes, as well as immediate causes regarding deficient dietary intake and disease, this framework recognizes insufficient household food security as one of the underlying causes of malnutrition and death (Fig. 2.1). The other two underlying causes of malnutrition refer to inadequate care and insufficient health services, along an unhealthy environment.

As a result of the previous developments, in 1994 FAO put in place the "Special Program for Food Security" focusing on poor families through national and regional programs to be executed by the governments, while FAO provided them with technical assistance (FAO, 2003). It was in November of 1996 at the World Food Summit in Rome, that a consensual definition of food security was approved, which entails the economic and physical access by all people at all times, not only to sufficient food, but also to safe and nutritionally adequate foods that correspond to cultural values and preferences and that allow everyone to meet her or his dietary needs in terms of macro and micronutrients in order to enjoy an active and healthy life (FAO, 1996).

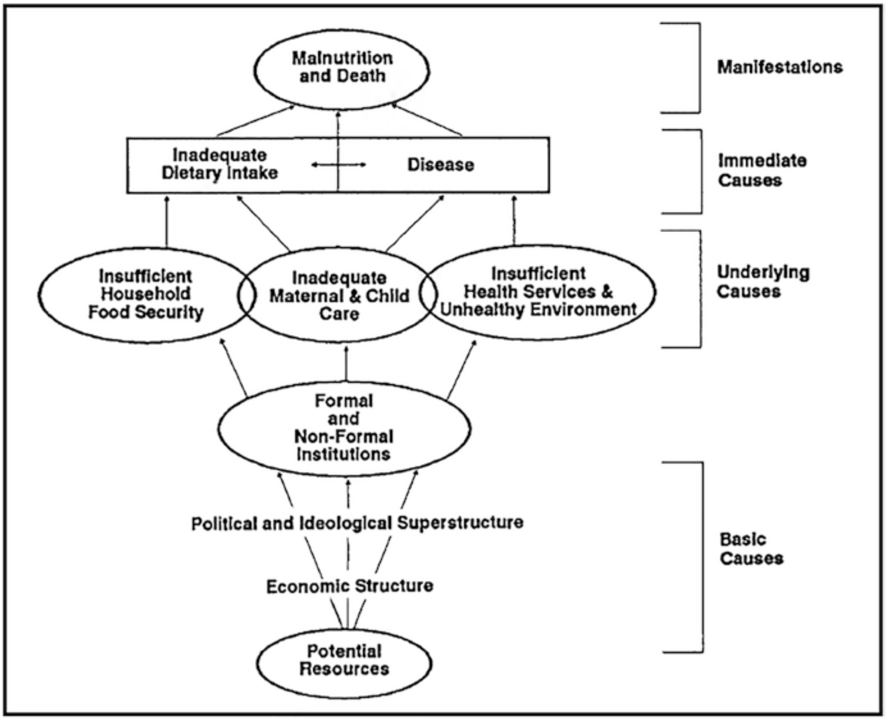

Fig. 2.1 UNICEF Conceptual Framework on the Determinants of Maternal and Child Nutrition. (Picture taken from United Nations Children's Fund, 1990). Strategy for improved nutrition of children and women in developing countries

2.2 More Integrative Approaches in the Twenty-First Century

By the beginning of a new millennium in the Gregorian calendar the Millennium Development Goals (MDG) were set by the United Nations General Assembly, putting together under the MDG#1 the fight against extreme poverty and hunger, as a recognition of poverty as one of the key determinants for food insecurity and therefore of its consequences. More explicitly, MDG#1 recognizes that tens of millions of children under 5 years of age in the developing world are undernourished and underweight. In addition, MDG#4 (Reduce Child Mortality) brought international agencies to recognize that child mortality in the developing world is strongly linked to undernutrition and to food insecurity. As a result, in 2008 United Nations put in place a program under the name of Renewed Efforts against Child Hunger (REACH) lead by FAO, UNICEF, the World Food Programme (WFP), the World Health Organization (WHO), and the International Fund for Agricultural Development

(IFAD), with the goal of assisting governments to "accelerate the scale-up of food and nutrition actions" (WHO, 2014a, b). Once the due date set for the MDG's was reached in 2015, the new Sustainable Development Goals (SDGs) were agreed upon at the United Nations General Assembly. As a comparison to the 8 MDGs, the 17 SDGs were to be complied not only by so called developing countries, but also by all UN member countries. Regarding food insecurity and undernutrition, this time a specific goal was set; SDG#2 Zero Hunger, or by its full name: End Hunger, achieve Food Security and improved Nutrition and promote Sustainable Agriculture. Even though SDGs are considered indivisible and are all related to each other in a way that achieving one of them requires compliance with the other 16 goals, SDG#2 contributes to a better understanding about the direct association between food security and nutrition, which are also linked to sustainable agriculture. The first two out of 8 targets related to this SDG call to end hunger by ensuring access by all people to safe, nutritious, and sufficient food all year round, and to end all forms of malnutrition, including the internationally agreed targets on stunting and wasting in children under 5 years of age. Such approach puts an end to the narrower view of keeping apart issues that are intrinsically related to each other. In fact, with the inclusion of a specific target in the SDG#3 (Good Health and Wellbeing) calling for a reduction of the mortality related to non-communicable diseases an implicit (unfortunately not explicit) incorporation has been made about other forms of malnutrition, such as those caused not by the lack of food but by unhealthy eating habits that result in an increasing rate of obesity around the world.

Another important action has been taken in what could be called a transformation in the way food security has been reported internationally. Until 2015 the annual report by the UN was named The State of Food Insecurity in the World (SOFI), which changed to The State of Food Security and Nutrition in the World, but still known by the same acronym (FAO, IFAD and WFP, 2015). In fact, until 2008 SOFI was released only by FAO, joined later by IFAD and the WFP. In 2017, UNICEF and WHO joined as coauthoring agencies which certainly results in a more integral approach on the topics of food security and nutrition (FAO, IFAD, UNICEF, WFP and WHO, 2017). In addition, the last three SOFI reports (2020, 2021, 2022) emphasize the importance of healthy diets as a key element linking food security to good health and nutrition (FAO, IFAD, UNICEF, WFP and WHO, 2020, 2021, 2022). In this regard, the nutritional value of foods was highlighted by the 2020 United Nations (UN) report on the "State of Food Security and Nutrition in the World" (SOFI2020), which discusses the importance of nutrient adequate and healthy diets, beyond the concept of energy sufficient diets (FAO, IFAD, UNICEF, WFP and WHO, 2020). Thanks to the support given to SOFI2020 by different UN organizations, the report includes valuable information on various indicators that go across phenomena closely related to food insecurity from caloric availability to undernutrition and anemia (FAO, IFAD, UNICEF, WFP and WHO, 2020). The focus has been similar in the SOFI reports of 2021 and 2022 (FAO, IFAD, UNICEF, WFP and WHO, 2021, 2022).

2.3 Beyond the Definition of Food Security

The 1996 definition of food security depicts a complex phenomenon that incorporates the importance of accessing not only sufficient, but also safe and nutritious foods that correspond to people's preferences, meaning food and culinary traditions. Furthermore, food security has been described as a phenomenon composed by four dimensions, which have been also depicted as pillars supporting a protective roof of food security (Peng & Berry, 2019). The usual picture of a temple with those four columns gives similar status to each of the food security dimensions. Alternatively, as illustrated below we propose that the roof of food security, which protects people from hunger and undernutrition, is sustained by three columns and one foundation. Each column is located here in a position that shows its relationship to other dimensions. Thus, the dimension of food availability is located as the first column to the left since food requires to be produced, stored, and imported before it can be accessed by people. The central column corresponds to the access dimension corresponding to the relevance it has within the food security definition.

This column precedes the third dimension of utilization, which can be practiced after the food has been accessed. Nevertheless, in spite of its location in the picture each of these dimensions keeps a determining relationship with the nutritional content of the food. The nutritional value of the food consumed by people is determined among other factors by the type of foods that are produced and made available in the market. In addition, the differential price of various kinds of foods (e.g., energy dense and micronutrient-dense) determines the access. Thirdly, the dimension of utilization refers to the way the body makes the most of various nutrients in the food, in dependence of the sufficiency of energy and nutrients, the food diversity, its preparation, and its intrahousehold distribution. Finally, the foundation of this construction is represented by the dimension of stability or sustainability. This dimension incorporates social, economic, environmental, and political elements, which sustain the three columns. Natural catastrophes (e.g., earthquakes, hurricanes) or human-made crises (e.g., war, coups d'état), or economic factors (e.g., inflation, bankruptcy) affecting such components might put at risk the stability of at least one of the other three dimensions (Fig. 2.2).

It is certainly very important to keep in mind that the well-functioning of each of the four dimensions is key to the long-term sustainability of food security, as well as to its resilience to confront and overcome inevitable challenges.

2.4 Determinants and Consequences of Food Insecurity

As well as the 1990 UNICEF framework for nutrition, the conceptual context in which food insecurity emerges is very complex. Several are the determinants that must be considered to better understand the conceptual framework within which food insecurity exists. Figure 2.3a illustrates the importance of various kinds of

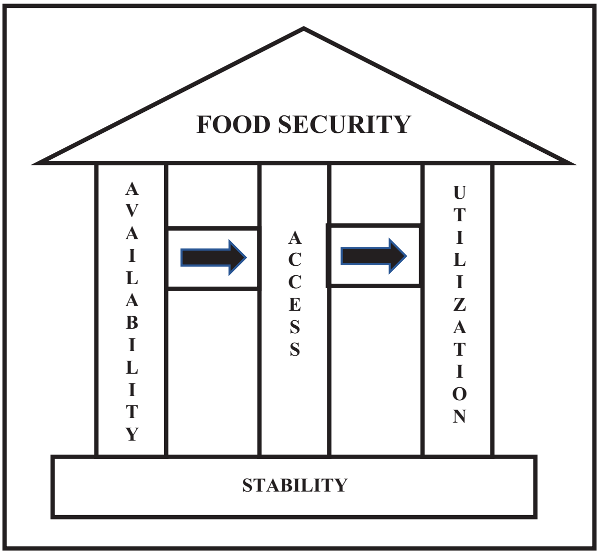

Fig. 2.2 Dimensions of food security

environmental layers such as the ecological environment, the economic, and the political environment, which are often contaminated, deteriorated and unpopular. Such environments affect subsequently the stocks of accumulated materials and information that can be used or transformed to generate goods and services needed for social development, economic growth, wellbeing, and for the growth and thriving of the human population. The figure lists several capitals that play an important role to sustain society, playing each of them a more or less direct role in generating food security. The lack or the weakness of such capitals would therefore set up the conditions for growing unemployment, inequalities, lack of fertile soils and adequate water for food production and human consumption. and poverty. The deterioration of an environmental layer or the weakness in one type of capital will inevitably affect the other environmental layers or types of capita in a negative way, causing a vicious circle of determinants, seemingly impossible to overcome.

Regarding the consequences of food insecurity, as illustrated in Fig. 2.3b, they are primarily reflected in the lack of access to socially acceptable, sufficient, safe, and nutritious food. An insufficient dietary intake results then in macro and micronutrient deficiencies, overconsumption of energy-dense and low-nutrient foods, and in the development of social conflicts at the family, community, and societal level. Such physical and psychosocial deteriorations are in direct relationship with public health problems reflected in undernutrition, hidden hunger (vitamins and minerals deficiencies), overweight and obesity, and depression. Once food insecurity established itself in a chronic way, its consequences turn into long-term factors that negatively feed back into the environmental layers and types of capital, strengthening the vicious circle that characterizes food insecurity and hunger.

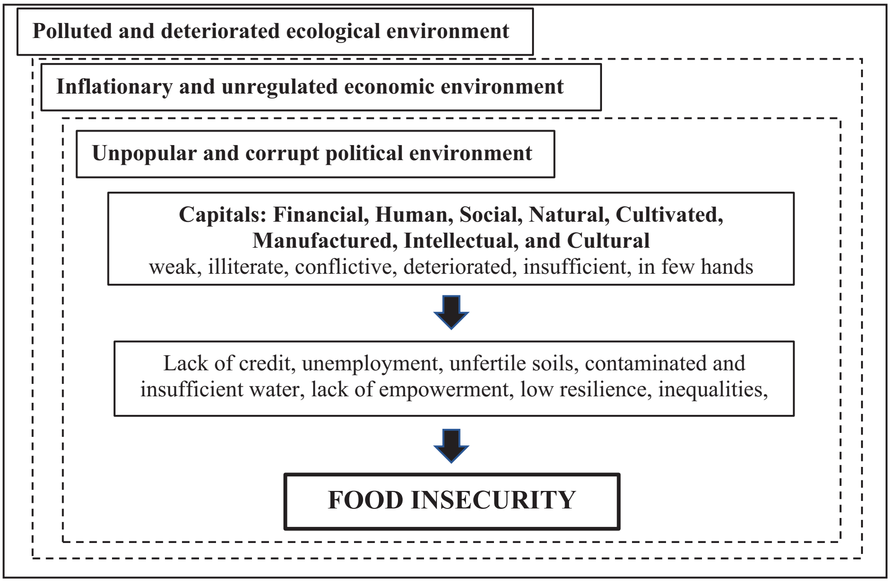

Fig. 2.3a Determinants of food insecurity

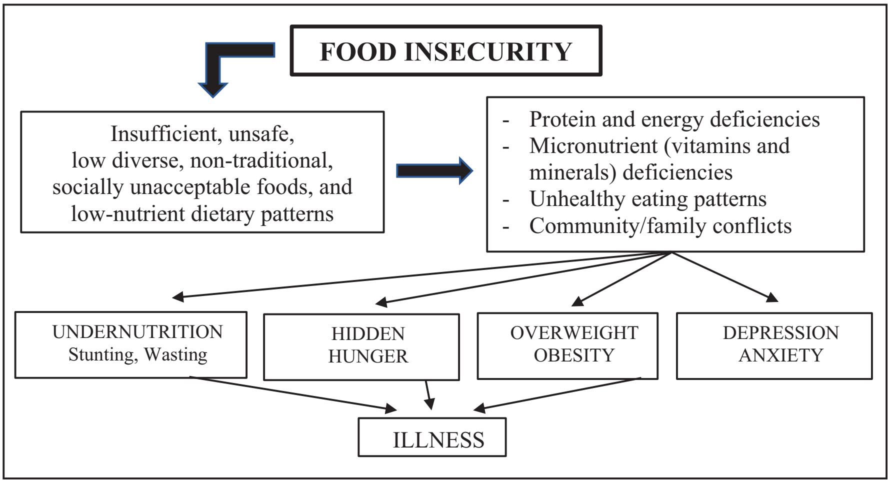

Fig. 2.3b Consequences of food insecurity

Even though the frameworks shared here on determinants and consequences of food insecurity illustrate the complexity of both phenomena, the reality in which they exist and therefore the number of factors related to them are even more intricated and extensive. If we just bring into the equation the increasingly recognized importance of water security, it turns evident how much of the variability of these problems we are missing. As reported by Spears (2013) when assessing the causes of chronic undernutrition in India, between one third and half of the variability in stunting could be explained by open air defecation. Given the magnitude of stunting in that country (30% of children under 5 years of age by 2020), it is impossible to avoid thinking how many millions of children could grow and develop without such burden by solving an issue seemingly unrelated to food insecurity. Still, it is unavoidable to remember that those who still lack access to adequate sanitary services belong to the same population groups who suffer poverty and hunger. Open air defecation is clearly related to contaminated water and foods, and subsequently to infections (viral, bacterial, or parasitic) of the gastrointestinal tract, causing malfunctioning of the intestinal mechanisms for the absorption of nutrients, vomiting, diarrhea, and micro bleedings of the intestinal wall. Furthermore, the consequences of food insecurity go beyond the ones listed above, such as the loss of knowledge on traditional eating practices and even on how to cook, as well as the lack of family and community interactions related to sharing meals. In fact, some evidence shows that some of the consequences depicted in Fig. 2.3b don't act in isolation. Cumulative evidence is showing the association of food insecurity with the so-called double burden of undernutrition and obesity. Such double burden might in fact turn into a triple burden that incorporates low dietary diversity and micronutrient deficiencies, to which one could add the burden of mental illness, and even of unsafe foods, presenting to human development and growth a challenge that includes at least 5 burdens as illustrated in Fig. 2.4. Evidence will be shared later in this chapter on the existence of the association between food insecurity and undernutrition or obesity separately and in coexistence. The relationship of food insecurity with low dietary diversity and micronutrient deficiencies, as well as with symptoms of mental illness has been also explored by some researchers. Still, as far as we know no relationship has been examined so far between food insecurity and unsafe foods (contaminated with chemical or biological agents), even though access to safe foods corresponds to the world definition of food security.

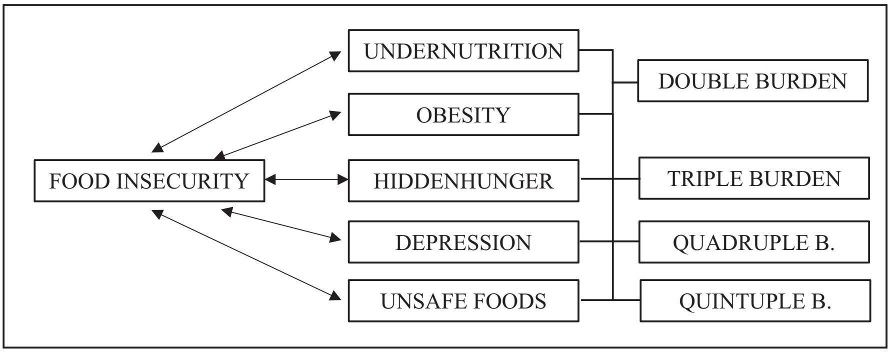

Fig. 2.4 The multiple burdens of food insecurity

2.5 Methodologies for the Assessment of Food Insecurity and Undernutrition

Given that food security is in itself a very complex phenomenon, one of the major challenges to accurately determine its status relates to the validity and reliability of the indicators to be applied in its assessment. Thus, before describing the current status of food security in the world, it is important to reflect upon the fact that there is no one measure that can by itself capture all of the elements embedded in its definition or all of its dimensions. As a result, a large number of tools have been proposed and applied, in some cases without knowing how valid they are and as a consequence ignoring if they are actually measuring what is intended to be measured. In 2002 though, an international scientific symposium under the sponsorship of FAO took place in Rome, under to discuss the "Measurement and Assessment of Food Deprivation and Undernutrition"; note that the term food insecurity was not mentioned in the conference title. Still, in the proceedings preface it was stated that the goal was to bring "…together those who deal scientifically with methods and applications of those methods for the measurement of hunger would greatly enhance FAO's mandate to measure and monitor progress." Five methodologies were discussed, recognizing the inexistence of a "gold standard", since each of the methods measures "…different aspects of hunger." In Fig. 2.5 the five methodologies, which will not be discussed in detail here, are presented with some of the respective indicators, keeping in mind that other indicators can be generated through such methodologies. For example, anthropometry is used to generate the body mass index, which is used to determine obesity. Undernourishment is the resulting indicator of an assessment focused on the availability of dietary energy in a given country in regard to the country's population caloric requirement (size, sex and age composition). This indicator has traditionally been the central indicator in the SOFI reports and was used to monitor the hunger component of the MDG#1. It does not inform about the nutritional quality of the available foods. The direction of the arrows in the figure represents the theoretical position of the indicators with regards to food

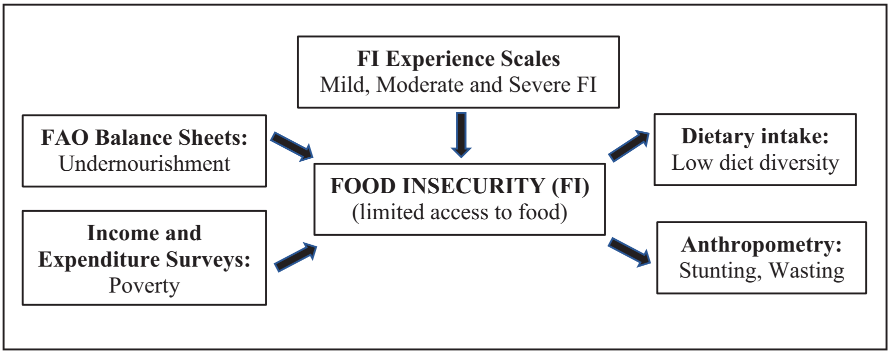

Fig. 2.5 Methodologies for the assessment of food insecurity

insecurity, and in the case of undernourishment and poverty it shows that before accessing food people would require to have food available (calories in this case) and money to purchase the food. From such perspective, undernourishment and poverty would be proxies of food insecurity determinants. By the way, with regards to poverty measurement methodologies were developed for a multidimensional assessment of this phenomenon, which also incorporate a food related component. On the right side of the figure, the indicators on low dietary diversity and undernutrition would be proxies on consequences of the limited access to food. Various methods are used to in the assessment of the diet such as 24 h-recall and food frequency questionnaires, to mention only the two most commonly applied. More recently, the dietary diversity score is be promoted as a low-cost, easy to apply and to analyze tool. Regarding anthropometry, the assessment of height and weight are the most common measures, along with a wide range of other measures such as skinfold measurements, circumferences of the middle-upper-arm, hip, and waist, among many others. The fifth methodology represented by the food insecurity experience scales are based on short lists of questions based on experiences people go through at different severity levels of food insecurity, such as eating the same kinds of foods, skipping meals, running out of food, or experiencing hunger, all due to the lack of money or other resources to access food. These scales have been considered the most direct form to assess food insecurity as defined in 1996. By no means they are considered the gold standard, and certainly do not include all components of the definition. Nevertheless, since its initial development in the early 90's their use in research and program evaluation and monitoring has grown exponentially and are being applied yearly in more than 150 countries since 2014. Out of the three levels of food insecurity (mild, moderate, and severe) SOFI currently reports on the two more severe categories.

Finally, with regards to nutritional status other methodologies are in place following the acronym ABCD, for Anthropometry, Biochemical tests for nutrient status, Clinical signs and symptoms of nutritional deficiencies, and Dietary intake. All of them involved different kinds of techniques with various levels of complexity, which will not be discussed in this chapter.

2.6 The Magnitude of Food Insecurity and Undernutrition

Despite the long-term consensus about the importance of food security, SOFI 2022 unfortunately informs about a global increasing trend in the prevalence of food insecurity as measured by some of the different indicators. Even though the estimates through diverse methodologies provide different magnitudes in prevalence of the same problem, all of them show that humanity is far from finally liberating itself from the calamities that determine or are a consequence of food insecurity and undernutrition. Before sharing estimates generated through methodologies such as the FAO balance sheets, dietary intake assessments, anthropometric measures, and food insecurity experience scales, is worth mentioning that poverty, the determinant considered the most direct cause of hunger is on the rise, apparently due to the COVID-19 pandemic. Now, very important to keep in mind is how poverty is defined. For example, in UN reports a person is extremely poor if she lives on 1.90 US$ per day or less. Any one above that cut-off point would not be considered extremely poor. Nevertheless, with the money such person has available per day, she will need to pay not only for food, but also for shelter, transportation, clothing, housing and utilities, health related costs, and education. Even though 1.90 US$ are far from being enough for covering at least the costs of the most basic needs, extreme poverty still affects more than 750 million individuals. Regarding food insecurity, the World Bank states that the current "food inflation can have a particularly devastating impact on poor families.", thus an adjustment to the global poverty line has been proposed raising it to 2.15 US$ per person per day. This might have some implications of the global prevalence on extreme poverty. Other poverty lines apply to other countries based on the countries' income classification. Despite the World Bank statement that poverty was steadily decreasing until the arrival of the COVID-19 pandemic, other reports show a different previous trend. For example, the Latin American Economic Commission reported that after an important decline between 2002 and 2014, poverty was on the rise again in the region, reaching in 2018 levels similar to those observed between 2008 and 2012 (CEPAL, 2019). When discussing the costs of a healthy diet below, we will be able to better understand how poverty relates to food insecurity.

2.6.1 Undernourishment

In terms of undernourishment ("condition in which an individual's habitual food consumption is insufficient to provide the amount of dietary energy required"), the estimates on the number of people facing this severe form of food insecurity are on the rise since 2017 (SOFI, 2022). In fact, by 2011 FAO statistics showed for the first a number of undernourished people below 600 million, remaining that way until the estimate for 2019 went up to 618 million, higher than the estimate for 2010. This indicates that in the best-case scenario things remained at the same level between 2010 and 2018. Such increasing trend became more worrisome during the first year of the COVI-19 pandemic, when undernourishment affected more than 720 million people. The average estimate for 2021 brings that number to where it was 15 years earlier. But it is not only the number of undernourished people that is on the rise. The 2021 projected average prevalence of almost 10% brings humanity back to where it was in 2019. Given that SOFI considers undernourishment as a synonymous for hunger, it is worth reminding us that the hunger can be defined in different ways. In 1990, Anderson defined food insecurity as the limited or uncertain availability of nutritionally adequate and safe foods or limited or uncertain ability to acquire acceptable foods in socially acceptable ways. With regards to SOFI, "hunger is an uncomfortable or painful physical sensation caused by insufficient consumption of dietary energy". This is what currently at least one in ten members of the global human society experience regularly, but as it will be described below it is only the peak of the iceberg.

2.6.2 Malnutrition

Even though malnutrition has usually been applied to conditions related to conditions related to deficient consumption of nutrients, such as wasting, stunting and hidden hunger, the etymology of the terms shows that it would actually mean bad (mal) nutrition. As such, we assume that it also incorporates other physiological conditions related to unbalanced and excessive intake nutrients, resulting in overweight and obesity. Thus, here we will briefly discuss the global magnitude of malnutrition as referred to all of those conditions.

With regards to children under 5 years of age, the anthropometric measures related to impaired physical development shows that at least two out of ten children are stunted. Given that stunting (chronic undernutrition; low-height-for-age) has long-term effects one should consider what does it mean to human growth and development that millions of children under five might be sentenced to a life of poor cognition and educational performance, which will have immense consequences in their ability to generate adequate wages to sustain themselves and their families. The individual tragedy of stunting in terms of human growth and development will also translate negatively at the societal level due to the loss in productivity, and perhaps in public health costs due to the increase risks for obesity and nutrition related chronic diseases. On this indicator, SOFI2022 reported that even though in decrease stunting still affects 22% of children under 5 years of age, meaning almost 150 million individuals. In Sub-Saharan Africa stunting was reported for almost one-third of the children, while in Latin America and the Caribbean the prevalence was of 11%, with a very concerning estimate for Guatemala, which showed a prevalence of 42.8%, by far the largest in the region. Regarding the undernutrition indicator wasting (low-weight-for-height), considered by UNICEF "the most immediate, visible and life-threatening form of malnutrition", SOFI reports a global prevalence of 6.7%, more than 45 million children. The highest prevalence was reported for India where the prevalence of wasting affected 17%, representing 20 million children under five (almost half of the children worldwide).

At this point, and with the goal of making a sound interpretation of the numbers shared here, it is critical to keep in mind that some of the data supporting these estimates are affected by the capabilities of some countries to timely assess and report on such public health problems. In addition, given the political implications of the estimates reported by the UN agencies, some countries do not allow their own statistics to be reported upon. Technical arguments are also being used to question the validity of the methods used, in an effort to remain away from the political spotlight that SOFI represents every year. In any case, what the statistics show is that food insecurity and hunger are far away from disappearing since most of the indicators show either a stagnation or an increasing trend in the prevalence. The exception refers to stunting with a world-wide decrease from 26% to 22% from 2012 to 2020.

Regarding obesity, it is well known that this is a problem that do not affect only population groups in high-income countries, and it has been increasingly impacting the nutritional status of people in other latitudes turning itself into a public health issue of pandemic scale. Even though some differences exist in how obesity is determined in adults and children, the cut-off points are based on a function that incorporated the weight by the height of individuals. An et al (2019) reported that the prevalence of obesity (BMI $\geq$ 30) more than tripled between 1975 and 2016, reaching 19% of the adult population. SOFI 2022 reports that in Latin America and the Caribbean, the prevalence was 24%, while the regional mean prevalence was very similar for Northern and Southern Africa, Western Asia and North America and Europe (around 27%). Regarding children under 5 years of age, almost 6% (39 million) were overweight in 2020. A much higher prevalence can be observed in diverse countries around the world, such as Lebanon (20%), Australia (18%), South Africa and Argentina (13%), and Barbados and Indonesia (11%). When adding adolescents to the children estimates, WHO reports a global increase of overweight and obesity from 4% to 18% between 1975 and 2016.

2.6.3 Healthy Diets and Micronutrient Deficiencies

The international food security definition and the dimension of utilization incorporate the central role of nutritious foods in order to consider an individual or a household to be food secure. Reiterating a statement made earlier, food security goes beyond having access to enough food, the quality of such is also of great importance. The role of all macro and micronutrients for human growth and development is beyond the purpose of this chapter; all and each of them plays a crucial role for human life. A balance and diverse diet is considered key to health and therefore the term "healthy diet" has been also used to portrait the current status of food security and nutrition in the world. On the contrary, a poor diet would increase the risk for undernutrition, and also for overweight and obesity, and related illnesses. A summarized definition of a healthy diet refers to a balanced and diverse food selection, consumed over a period of time that ensures covering the needs for all nutrients, following certain recommendations on the proportions allocated to fat, protein, and carbohydrates. In addition, it should include the consumption of adequate amounts of fruits and vegetables, and limited amounts of saturated fats, salt, and free sugars. Adequate breastfeeding practices for infants and young children are also part of a healthy diet. As part of the efforts for presenting a more integrative picture of food security and nutrition in the world, the United Nations started in 2020 to report on the affordability of a healthy diet. The results of such analysis are unfortunately less encouraging, to say the least, in terms of the magnitude of the problem humanity is confronting. Overall, SOFI2022 indicates that more than 40% of the world population are unable to afford a healthy diet, a percentage that reaches almost 80% in Africa. Worldwide, the number of people in such situation has increased since 2017. It is worth mentioning that the increase in the costs of a healthy diet were on the rise already before the COVID-pandemic. As expected, the percentage of people unable to afford a healthy diet is much lower in high-income countries (1.4%) than in low-income countries (88%), easily explain by the higher incomes in the first group of countries. Now, as reported in SOFI2022 it might also be a matter of the difference in the cost of such diet. Worldwide, a healthy diet for one person per day is 3.54 US$, but in Latin America is 3.89 US$, in Asia 3.72 US$ and in Africa 3.46 US$, while in North America and Europe where income is higher than in the other regions the cost of a healthy diet is 3.19 US$. Nevertheless, such inequality affects an important number of human beings in the last region; almost 20 million individuals are not able to pay for a health diet. Important to keep in mind also that food costs represent only part of all expenditures people need to live and thrive.

The consequences of not having access to a healthy diet relates directly to several micronutrient deficiencies, such iron deficiency anemia, which globally affects almost one in three women aged 15–49 years, with prevalence close or above 50% in Haiti, India, Yemen, and various African countries. Multiple studies report on the detrimental impact of iron deficiency anemia in cognitive development, productivity, and physical development. Understanding the role that iron plays in critical metabolic functions helps to understand the tremendous affection its deficiency causes to people. For the purposes of this chapter a brief reminder about the presence of iron in the hemoglobin, responsible for oxygen transport to the tissues. Low iron levels in the human body translates in impaired ability to work, to learn and to grow; it's like an engine lacking the ability to use its for combustion fuel when needed.

Other micronutrient deficiencies affect human growth and development as well, such as vitamin A deficiency, considered one of the most important deficiencies affecting globally around 30% of children under 5 years of age (Wirth et al., 2017). It is considered also a major cause for preventable child blindness. The role of vitamin A for an adequate immunological response is well known, and the implications of its deficiency have major negative impacts in the ability of children to fight and survive infectious diseases.

Given the increasing prices of some of the most important food sources of iron and vitamin A it is not difficult to understand the relationship that such micronutrient deficiencies have with food insecurity and hunger.

2.6.4 Food Insecurity Experiences

The search for a more direct measure of food insecurity started in the early 90's in the United States, where research showed the validity of a questionnaire including items related to various experiences reported by low-income women and families when facing different severity levels of this phenomenon. In 1995 such a questionnaire was applied for the first time in a national survey (Bickel, 1997). In 1998 after some adjustments to the questionnaire, the Economic Research Services at the US Department of Agriculture assumed the sponsorship of the food security measure, reporting since then on an annual basis on "Household Food Security in the United States" (Coleman-Jensen et al., 2021). Thanks to this effort, food insecurity can be tracked back more than 20 years in the US, allowing to argue with sound data about the importance of programs against hunger in that country. The last estimate corresponding to 2021 showed that food insecurity affects 10.5% of US households (13.8 million, representing more than 38 million individuals). The highest prevalence ever reported was in 2011 with 14.9% of US households, more than 50 million people facing food insecurity, still a result of the financial crisis when food insecurity jumped from 11% in 2007 to 14.6% in 2008. It took 10 years to go back to the 2007 estimate. The US estimates do not include a category corresponding to mild food insecurity.

In Canada the most recent survey showed that in 2021 almost 16% of the households in 10 provinces experienced food insecurity, which includes the less severe category of marginal food insecurity (Tarasuk et al., 2022). Changes in the sampling design make it difficult to compare this result with previous measures, but there is some indication that the problem has been increasing over the last decade.

Such questionnaire, along other research efforts was applied, adapted, and adopted in other countries providing the platform for national and regional food security scales such as the Brazilian Food Insecurity Scale (EBIA – Escala Brasileira de Segurança Alimentar) or the Latin American and Caribbean Food Security Scale (ELCSA – Escala Latinoamericana y Caribeña de Seguridad Alimentaria) (Segall-Correa & Marin-León, 2009; Segall Corrêa et al., 2012). Thanks to the involvement of academic institutions in Latin America and elsewhere, rigorous research showed the validity of such scales, setting the ground for the adoption of the 8-questions Food Insecurity Experiences Scale (FIES) sponsored by FAO and applied yearly since 2014 in around 150 countries (Sainte Ville et al., 2019). All questions refer to situations experienced due to the lack of money or resources to access food. Such development had immense implications for further research on the validity and reliability of FIES when exploring the relationship between food insecurity and various other public health issues, such as undernutrition, obesity, chronic diseases, or mental illness. The literature on this matter basically skyrocketed, allowing the international community to better understand the conceptual framework of determinants and consequences of food insecurity. More importantly, such scales are and will increasingly allow better identifying of those suffering of food insecurity and to better focalize resources and interventions to fight hunger. These measurement approach help us to remember that hunger has an address, has a name, and even has a racial, ethnographic, and a social background.

Food security experience scales allow the generation of four categories of households or individuals as follows: food secure are those who have responded negatively to all the questions; mildly food insecure are those who worry about not having enough food and are not able to consume a diverse and nutritious diet; moderately food insecure are people who must skip meals, eat less than usual, and ran out of food; and severe food insecurity refers to the experience of hunger and not been able for a whole day or longer. Globally, although initially SOFI reported only on severe food insecurity, since 2019 it also includes the moderate category. National institutions in countries like Brazil, Canada, Colombia, or Mexico do report on mild/marginal food insecurity. Regarding its validity and reliability researchers have stated the following: "On the basis of the evidence we have reviewed, we conclude that experience-based food insecurity measures are the most promising tools among those currently available and constitute a valuable instrument that can be applied together with other indicators to better understand the determinants and consequences of household and individual food insecurity" (Cafiero et al., 2014).

Now to the question about the magnitude of food insecurity when assessed using FIES the following results highlight the importance of such assessment. As reported in SOFI2022, the very first measure done globally with this tool showed that in 2014 21% of the world population suffered moderate or severe food insecurity. That prevalence increased to 25% in 2018 and to 29% in 2020. This estimate remained pretty much unchanged in 2021, probably due to a decrease observed in Asia (from 25.8% to 24.6%), which experienced the previous increases. In contrast, Africa and Latin America continued experiencing increases of in the best case a stagnation in the prevalence. Africa went from 44.4% in 2014 to 57.9% in 2021, and Latin America went from 24.6% in 2014 to 40.6% in 2021. Similar increases had been reported earlier for Latin American countries. Even though America and Europe in average remained under the 9% mark, FIES allowed for the first time the identification of food insecurity in most high-income countries in this regional group. In terms of the number of affected individuals experiencing hunger, skipping meals, eating less than usual, or running out of food, SOFI reported that in 2014–2016 1.61 billion people suffered food insecurity, while in 2019–2021 that number went up to 2.19 billion persons. As stated earlier, these estimates do not include those who were not able to consume a nutritious or a diverse diet, which relates to the difficulty related in generating cross-country comparable estimates of mild food insecurity.

COVID-19 synchronic increases were observed in all the regions, except for the later. Given that FIES is being applied globally at the individual level, the estimates allowed also to differentiate food insecurity experiences when comparing men with women. As expected, and reported earlier by others, SOFI showed that women experienced more often food insecurity than men; this "gender gap" is particularly large in Latin America, although can be observed globally as well. Earlier was also reported that in the "global south" the food insecurity prevalence is larger in the rural areas when compared to the urban settings.

2.7 The Relationship Between Food Insecurity and Health

Some decades ago, the 1998 Nobel Prize awardee for Economic Sciences Amartya Kumar Sen stated that a lot is pretty obvious with regards to poverty and that no elaborated criteria, or complicated measurements and analyses were needed to recognize severe hunger and to understand its determinants (Sen, 1981). Nevertheless, he continued, not everything is that simple and the mere identification of those who are poor becomes less obvious as we move away from the most extreme and severe situations. We paraphrased Dr. Sen's statement with the goal of stating that the estimates shared in this document, even though supported by elaborated methodologies and analyses, do show something that is pretty obvious: food insecurity conceived as the limited or uncertain access to food coexists hand-in-hand with poverty, therefore with the inability of consuming a healthy diet that would allow human life to grow and thrive. In the countries and regions where the food insecurity prevalence is the highest, there is where stunting and anemia show the highest estimates. As if this was not enough of a burden for the poorest countries and even for the poorest populations in the Northern Hemisphere, overweight and obesity growingly show their presence, probably in part due to the fact that an energy-adequate diet is way more affordable than a healthy diet. Obesity is certainly a phenomenon that is way more complex than the classical approach of "calories in and calories out", but some the following findings show that those who are food insecure are more likely to face obesity and its consequences.

It is certainly not the soundest epidemiological approach, but the fact is that there are regions and countries where all of those problems coexist, along with low levels of school education, weak and insufficient health services, scarce infrastructure and very little opportunities of formal employment. Thus, more integral approaches are being used to assess poverty from a multidimensional perspective, incorporating to low-income and low expenditures the lack of access to school education, inadequate housing, unemployment, insufficient access to health and basic services, such as water, lack of social security, and food insecurity.

Thanks to the more than 20 years of annual report on household food security in the US, we know that the distribution of this problem follows the distribution of the inequalities that characterize that country (Coleman-Jensen et al., 2021). Thus, it is reported that in 2020 lowest prevalence by race and ethnicity corresponded to the non-Hispanic white population with a prevalence of 7.1%, while the non-Hispanic black population showed a prevalence three times higher (21.7%). The Hispanic population showed a prevalence of 17.2%. The higher the poverty level the higher food insecurity, and women headed households with children and no spouse presented a higher prevalence than their male counterparts (27.7% vs. 16.3%). In parallel to the statements by Josué de Castro's in his book, "Geography of Hunger", the highest prevalence of food insecurity in the US is found in those states with the highest rates of poverty.

The findings from the Canadian Community Health Survey show the same pattern as in the US, where the white population has a prevalence lower (13%) than the national average (15.9%), while minorities such as East/ Southeast Asians (19.8%), blacks (22.4%), Arabs/Western Asians (27.6%), and indigenous people (30.7%) show higher estimates of food insecurity (Tarasuk et al., 2022). This phenomenon shows also a differential geographic distribution across provinces.

In 1965 Goldblatt, in a paper on a study exploring social factors associated to obesity in Manhattan, reported a higher prevalence of obesity among low-income adults when compared to their higher income counterparts. Thirty years later, the Journal of Pediatrics published a letter by William Dietz (1995) under the title "Does hunger cause obesity?", reporting a case study of a 7-year-old African American girl with obesity whose family regularly ran out of food due to its poverty situation. As a result, the child was fed with unexpensive high-caloric foods in an effort to prevent hunger. In 2001, Townsend reported on the significant relationship between food insecurity and overweight in US women, presenting binge eating as a possible reaction to periodic monetary restrictions to buy food. The so called "Hunger-Obesity Paradox" became with the time an important center of research trying to explain such relationship (Kaiser et al., 2004; Dhurandhar, 2016). The association between food insecurity and obesity among women living in the US was examined in Ohio, and the potentially associated binging eating behavior in a sample of food insecure and obese women was reported at a conference (Ye et al., 2009). Studies confirming the relationship between food insecurity and obesity among adults and adolescents have been conducted in other countries as well (Shariff & Khor, 2005; Ortiz-Hernández et al., 2012; Kac et al., 2012; Mohammadi et al., 2013; Morales et al., 2014; Gubert et al., 2017; Ponce-Alcalá et al., 2021). Additionally, researchers have also reported on an association between food insecurity and chronic diseases, as well as with metabolic syndrome (Seligman et al., 2009; Pérez-Escamilla et al., 2014). Such association among children remains a matter of controversy with studies showing opposite results (Gundersen et al., 2009; Papas et al., 2016). Regarding children's health, Cook (2004) reported that food insecurity is significantly associated with diverse health problems affecting young children. The authors emphasize the need for ensuring food security towards reducing health problems and hospitalizations. A study in Brazil (Rezende Machado de Sousa et al., 2019) showed also an increasingly significant relationship between food insecurity and poor health status.

Even though the UNICEF conceptual framework on malnutrition recognizes since 1990 insufficient household food security as an underlying cause of undernutrition, few studies have generated evidence of the links between food insecurity and undernutrition, despite the obvious theoretical relationship between the two phenomena. This might be due to the complexity of both food insecurity and undernutrition, in terms of their causality and of their consequences. In a study conducted in Mexico, Vega-Macedo et al. (2014) characterized by food security status the foods purchased by Mexican households with children under 5 years of age, showing that food insecure households' food purchases were higher in energy-dense foods and less diverse than the purchases done by food secure households. Regarding dietary diversity, Mundo-Rosas et al. (2014) reported a significant relationship between food insecurity and low dietary diversity in Mexico. Both studies are in line with the SOFI statements on the low affordability of a diet that allows people to consume the nutrients needed for an active and healthy life. A previous study in Ecuador (Hackett et al., 2007) showed lower domestic food supplies among food insecure rural households when compared to food secure households. An association of food insecurity with anemia has been reported as well (Jones et al., 2017).

Research assessing the relationship between food insecurity and stunting seems to confirm a significant association, although the studies reporting on this show sometimes contradictory findings (Ali et al., 2013; McDonald et al., 2015; Baig-Ansari et al., 2006; Berra, 2020; Sarpong, 2022). In a study conducted in Colombia Hackett (2009) reported that the likelihood of child stunting increased across food insecurity categories as they turned more severe. An association with underweight was also found. Studies conducted in other countries confirm the results of this study, although the findings are not always exactly the same. More recently, Sansón-Rosas et al. (2021) confirmed using nationally representative data from Colombia that child stunting increased as food insecurity turned more severe. More recently, studies focusing mainly in Latin America have taken place to explore establish the existence of the double burden, defined as the coexistence of both obesity and stunting, and also its association with household food insecurity (Temponi & Velasquez-Melendez, 2020). In 2021, Sansón-Rosas reported a significant association between the double burden (stunted child and overweight/obese mother) and moderate food insecurity in rural Colombian households.

Beyond affecting physical health, food insecurity has shown to also affect the mental health status of individuals. Some of the most recent studies on this matter show significant associations between food insecurity and the presence of symptoms related to depression (Kolovos et al. 2020). Elgar (2021) reported on two studies with data from 160 countries that "individuals who live with constant worries about not getting enough food, have to skip meals, or face chronic hunger are deprived of material and social resources that support mental health and wellbeing". Furthermore, among young people (aged 15–24 years) "increased food insecurity was uniquely related to more mental health symptoms and reduced wellbeing". In 2005, Jyoti reported that food insecurity affects children in various ways on their academic performance, their social skills, and in their nutritional status.

Finally, given that billions of individuals suffer or are at risk of suffering limited of scarce access to water, it is critical to emphasize the importance of water security, understood as the regular access to enough and safe water for human use and consumption. Studies have shown an association between water and food security, and an extensive paper was recently published to highlight the importance of water security to ensure food security, good nutrition, and well-being (Brewis et al., 2020; Young et al., 2021).

2.8 Final Remarks

Governments around the world along with numerous international organizations have committed to an agenda for sustainable development that when achieved would represent a radical improvement in the lives of billions of individuals, who currently suffer from hunger, undernutrition, impaired physical growth and cognitive development, lack of safe water, and many other basic needs, globally recognized as inherent human rights. Food insecurity and hunger do not only impact the life of billions of people but are far from disappearing even though technologies and knowledge are more advanced than ever to produce, store, preserve, and distribute food around the world. Lack of action on this matter leaves at stake the sustainable development of a human society that should by now be able to leave behind the times of hunger. Recognizing that without solving the challenges inherent to hunger sound human growth and development are not possible represents still an imperative for action.

References

Ali, D., Saha, K. K., Nguyen, P. H., Diressie, M. T., Ruel, M. T., Menon, P., & Rawat, R. (2013). Household food insecurity is associated with higher child undernutrition in Bangladesh, Ethiopia, and Vietnam, but the effect is not mediated by child dietary diversity. *The Journal of Nutrition, 143*(12), 2015–2021.

Anderson, S. A. (1990). Core indicators of nutritional state for difficult-to-sample populations. *The Journal of Nutrition, 120*(suppl_11), 1555–1600.

Assembly, U. G. (1948). Universal declaration of human rights. *UN General Assembly, 302*(2), 14–25.

An, R., Guan, C., Liu, J., Chen, N., & Clarke, C. (2019). Trade openness and the obesity epidemic: A cross-national study of 175 countries during 1975–2016. *Annals of Epidemiology, 37*, 31–36.

Baig-Ansari, N., Rahbar, M. H., Bhutta, Z. A., & Badruddin, S. H. (2006). Child's gender and household food insecurity are associated with stunting among young Pakistani children residing in urban squatter settlements. *Food and Nutrition Bulletin, 27*(2), 114–127.

Berra, W. G. (2020). Household food insecurity predicts childhood undernutrition: A cross-sectional study in West Oromia (Ethiopia). *Journal of Environmental and Public Health, 2020*, 5871980.

Bickel, G. (1997). *Household food security in the United States in 1995* (Technical report of the food security measurement project). U.S. Department of Agriculture Food and Consumer Service.

Brewis, A., Workman, C., Wutich, A., Jepson, W., Young, S., & Household Water Insecurity Experiences–Research Coordination Network (HWISE-RCN). (2020). Household water insecurity is strongly associated with food insecurity: Evidence from 27 sites in low-and middle-income countries. *American Journal of Human Biology, 32*(1), e23309.

Cafiero, C., Melgar-Quiñonez, H. R., Ballard, T. J., & Kepple, A. W. (2014). Validity and reliability of food security measures. *Annals of the New York Academy of Sciences, 1331*, 230–248. https://doi.org/10.1111/nyas.12594

Castro Josué de. (1967). *Geografia da fome* (10ª. Edição). Brasiliense.

Coleman-Jensen, A., Rabbitt, M. P., Gregory, C. A., & Singh, A. (2021). *Household food security in the United States in 2020, ERR-298*. U.S. Department of Agriculture, Economic Research Service.

Comisión Económica para América Latina y el Caribe (CEPAL). (2019). *Panorama Social de América Latina, 2018 LC/PUB.2019/3-P, Santiago*.

Cook, J. T., Frank, D. A., Berkowitz, C., Black, M. M., Casey, P. H., Cutts, D. B., Meyers, A. F., Zaldivar, N., Skalicky, A., Levenson, S., Heeren, T. C., & Nord, M. (2004). Food insecurity is associated with adverse health outcomes among human infants and toddlers. *The Journal of Nutrition, 134*(6), 1432–1438.

Dhurandhar, E. J. (2016). The food-insecurity obesity paradox: A resource scarcity hypothesis. *Physiology & Behavior, 162*, 88–92.

Dietz, W. H. (1995). Does hunger cause obesity? *Pediatrics, 95*(5), 766–767. PMID: 7724321.

Elgar FJ, Sen A, Gariépy G, Pickett W, Davison C, Georgiades K, Hammami N, Da Silva MA, Gordon D, Melgar-Quiñonez HR (2021). *Food insecurity, state fragility and youth mental health: A global perspective. SSM-population health, 14*, p.100764..

FAO. (1984). *Food balance sheets, 1979–81 average*. Food and Agriculture Organization of the United Nations.

FAO. (1996). *Declaration on world food security*. World Food Summit.

FAO. (2002). Measurement and assessment of food deprivation and undernutrition. In *International scientific symposium*. FAO.

FAO. (2003). *Programa Especial para la Seguridad Alimentaria: Respuesta a los nuevos desafíos*. recuperado el 2 de marzo de 2015 de http://www.fao.org/docrep/006/ac828s/ac828s00.htm

FAO, AGROSTAT. (2008). *Agricultural statistics.*

FAO, IFAD and WFP. (2015). *The state of food insecurity in the world 2015. Meeting the 2015 international hunger targets: Taking stock of uneven progress*. FAO.

FAO, IFAD, UNICEF, WFP and WHO. (2017). *The state of food security and nutrition in the world 2017. Building resilience for peace and food security*. FAO.

FAO, IFAD, UNICEF, WFP and WHO. (2020). *The state of food security and nutrition in the world 2020. Transforming food systems for affordable healthy diets*. FAO. https://doi.org/10.4060/ca9692en

FAO, IFAD, UNICEF, WFP and WHO. (2022). *The state of food security and nutrition in the world 2022. Repurposing food and agricultural policies to make healthy diets more affordable*. FAO.

FAO, IFAD, UNICEF, WFP and WHO. (2021). The State of Food Security and Nutrition in the World 2021. Transforming food systems for food security, improved nutrition and affordable healthy diets for all. Rome, FAO. https://doi.org/10.4060/cb4474en.

Goldblatt, P. B., Moore, M. E., & Stunkard, A. J. (1965). Social factors in obesity. *JAMA, 192*, 1039–1044.

Gubert, M. B., Spaniol, A. M., Segall-Corrêa, A. M., & Pérez-Escamilla, R. (2017). Understanding the double burden of malnutrition in food insecure households in Brazil. *Maternal & Child Nutrition, 13*(3), e12347.

Gundersen, C., Garasky, S., & Lohman, B. J. (2009). Food insecurity is not associated with childhood obesity as assessed using multiple measures of obesity. *The Journal of Nutrition, 139*(6), 1173–1178.

Hackett, M., Melgar-Quiñonez, H., Zubieta, A. C., & Hernandez, K. (2007). Food security and household food supplies in rural Ecuador. *Archivos Latinoamericanos de Nutrición, 57*(1), 10–17.

Hackett, M., Melgar-Quiñonez, H., & Álvarez, M. C. (2009). Household food insecurity is associated with stunting and underweight among preschool children in Antioquia, Colombia. *The Pan American Journal of Public Health, 25*(6), 506–510.

Jones, A. D., Mundo-Rosas, V., Cantoral, A., & Levy, T. S. (2017). Household food insecurity in Mexico is associated with the co-occurrence of overweight and anemia among women of reproductive age, but not female adolescents. *Maternal & Child Nutrition, 13*(4), e12396.

Jyoti, D. F., Frongillo, E. A., & Jones, S. J. (2005). Food insecurity affects school children's academic performance, weight gain, and social skills. *The Journal of Nutrition, 135*(12), 2831–2839.

Kac, G., Velasquez-Melendez, G., Schlüssel, M. M., Segall-Côrrea, A. M., Silva, A. A., & Pérez-Escamilla, R. (2012). Severe food insecurity is associated with obesity among Brazilian adolescent females. *Public Health Nutrition, 15*(10), 1854–1860.

Kaiser, L. L., Townsend, M. S., Melgar-Quiñonez, H. R., Fujii, M. L., & Crawford, P. B. (2004). Choice of instrument influences relations between food insecurity and obesity in Latino women. *The American Journal of Clinical Nutrition, 80*(5), 1372–1378.

Kolovos, S., Zavala, G. A., Leijen, A. S., Melgar-Quiñonez, H., & van Tulder, M. (2020). Household food insecurity is associated with depressive symptoms: Results from a Mexican population-based survey. *Food Security*, 1–10. https://doi.org/10.1007/s12571-020-01014-1

McDonald, C. M., McLean, J., Kroeun, H., Talukder, A., Lynd, L. D., & Green, T. J. (2015). Household food insecurity and dietary diversity as correlates of maternal and child undernutrition in rural Cambodia. *European Journal of Clinical Nutrition, 69*(2), 242–246.

Michalski, K. J. (1980). Proceedings and results of the world conference for Agrarian reform and rural development-Rome, July 1979. *Beitrage zur Tropischen und Subtropischen Landwirtschaft und Veterinarmedizin, 18*(1), 3–10.

Mohammadi, F., Omidvar, N., Harrison, G. G., Ghazi-Tabatabaei, M., Abdollahi, M., Houshiar-Rad, A., et al. (2013). Is household food insecurity associated with overweight/obesity in women? *Iranian Journal of Public Health, 42*(4), 380.

Morales, M., Méndez, I., Shamah, T., Valderrama, Z., & Melgar, H. (2014). La inseguridad alimentaria está asociada con obesidad en mujeres adultas de México. *Salud Publica México, 56*(1), S54–S61.

Mundo-Rosas, V., Cruz-Góngora, V. D. L., Jiménez-Aguilar, A., & Shamah-Levy, T. (2014). Diversidad de la dieta y consumo de nutrimentos en niños de 24 a 59 meses de edad y su asociación con inseguridad alimentaria. *Salud Pública de México, 56*, s39–s46.

Ortiz-Hernández, L., Rodríguez-Magallanes, M., & Melgar-Quiñónez, H. (2012). Obesity, eating behavior, and food insecurity among adolescents in Mexico City. *Boletín Médico del Hospital Infantil de México, 2012*, 69. (6).

Papas, M. A., Trabulsi, J. C., Dahl, A., & Dominick, G. (2016). Food insecurity increases the odds of obesity among young Hispanic children. *Journal of Immigrant and Minority Health, 18*(5), 1046–1052.

Peng, W., & Berry, E. M. (2019). The concept of food security. *Encyclopedia of Food Security and Sustainability, 2*(1), 1–7.

Pérez-Escamilla, R., Villalpando, S., Shamah-Levy, T., & Méndez-Gómez Humarán, I. (2014). Household food insecurity, diabetes and hypertension among Mexican adults: Results from Ensanut 2012. *Salud Pública de México, 56*, s62–s70.

Ponce-Alcalá, R. E., Ramirez-Garcia Luna, J. L., Shamah-Levy, T., & Melgar-Quiñonez, H. (2021). The association between household food insecurity and obesity in Mexico. A cross-sectional study of ENSANUT MC 2016. *Public Health Nutrition*, 1–11.

Pothisiri, P., & Kongchuntuk, H. (1996). Codex alimentarius. *Nutrition Reviews, 54*(11), S149.

Rezende Machado de Sousa, L., Saint Ville, A., Maria Segall-Corrêa, A., & Melgar-Quiñonez, H. (2019). Health inequalities and well-being in times of financial and political crisis in Brazil, a case study. *Global Public Health, 15*, 1–14.

Saint Ville, A., Po, J. Y. T., Sen, A., Bui, A., & Melgar-Quiñonez, H. (2019). Food security and the food insecurity experience scale (FIES): Ensuring progress by 2030. *Food Security, 11*, 483–491.

Sansón-Rosas, A., Bernal-Rivas, J., Kubow, S., Suarez, A., & Melgar-Quiñonez, H. (2021). Food insecurity and the double burden of malnutrition in Colombian rural households. *Public Health Nutrition*, 1–13.

Sarpong, N. N. (2022). *Household food insecurity is a predictor of acute malnutrition but not chronic malnutrition among children (6–59 months old): A cross-sectional in Tamale South Constituency*.

Segall Corrêa, A. M., Álvarez Uribe, M. C., Melgar Quiñonez, H., & Pérez Escamilla, R. (2012). *Escala latinoamericana y caribeña de seguridad alimentaria (ELCSA): Manual de uso y aplicaciones*.

Segall-Corrêa, A. M., & Marin-Leon, L. (2009). A segurança alimentar no Brasil: proposição e usos da Escala Brasileira de Medida da Insegurança Alimentar (EBIA) de 2003 a 2009. *Segurança Alimentar e Nutricional, 16*(2), 1–19.

Seligman, H. K., Laraia, B. A., & Kushel, M. B. (2009). Food insecurity is associated with chronic disease among low-income NHANES participants. *The Journal of Nutrition, 140*, 304–310.

Sen, A. (1981). *Poverty and famines: An essay on entitlement and deprivation*. Clarendon Press.

Shariff, Z. M., & Khor, G. L. (2005). Obesity and household food insecurity: Evidence from a sample of rural households in Malaysia. *European Journal of Clinical Nutrition, 59*, 1049–1058.

Spears, D., Ghosh, A., & Cumming, O. (2013). Open defecation and childhood stunting in India: An ecological analysis of new data from 112 districts. *PLoS One, 8*(9), e73784.

Tarasuk, V., Li, T., & Fafard St-Germain, A. A. (2022). *Household food insecurity in Canada, 2021*. Research to identify policy options to reduce food insecurity (PROOF). Retrieved from https://proof.utoronto.ca/

Temponi, H. R., & Velasquez-Melendez, G. (2020). Prevalence of double burden on malnutrition at household level in four Latin America countries. *Revista Brasileira de Saúde Materno Infantil, 20*, 27–35.

Townsend, M. S., Peerson, J., Love, B., Achterberg, C., & Murphy, S. P. (2001). Food insecurity is positively related to overweight in women. *The Journal of Nutrition, 131*(6), 1738–1745.

Tuffrey, V., & Hall, A. (2016). Methods of nutrition surveillance in low-income countries. *Emerging Themes in Epidemiology, 13*(1), 1–21.

UNICEF. (1990). *Strategy for improved nutrition of children and women in developing countries*. Policy Review Paper E/ICEF/1990/1.6, UNICEF, New York; JC 27/UNICEF-WHO/89.4. New York.

United Nations General Assembly. (1966). *International covenant on economic, social and cultural rights*, December 16, 999 UNTS 3 (entered into force Jan 3, 1976).

Vega-Macedo, M., Shamah-Levy, T., Peinador-Roldán, R., Méndez-Gómez Humarán, I., & Melgar-Quiñónez, H. (2014). Food insecurity and variety of food in Mexican households with children under five years. *Salud Pública de México, 56 Suppl 1*, s21–s30.

Waal, A. D. (1996). Social contract and deterring famine: First thoughts. *Disasters, 20*(3), 194–205.

Wirth, J. P., Petry, N., Tanumihardjo, S. A., Rogers, L. M., McLean, E., Greig, A., Garrett, G. S., Klemm, R. D., & Rohner, F. (2017). Vitamin A supplementation programs and country-level evidence of vitamin A deficiency. *Nutrients, 9*(3), 190.

World Health Organization. (1978). *Declaration of Alma-Ata (No. WHO/EURO: 1978-3938-43697-61471)*. World Health Organization. Regional Office for Europe.

World Health Organization. (2014a). *Accelerating nutrition improvements (ANI): Mapping of stakeholders and nutrition actions in three scaling-up countries in sub-Saharan Africa: Report of a meeting*, 27–28 February 2014, Addis Ababa, Ethiopia.

Ye, Q., Zubieta, A. C., Remley, D., Angell, D., Mims, S., & Melgar-Quiñonez, H. (2009). Assessing the monthly food abundance-shortage cycle in food insecure overweight/obese women in Ohio. *Abstract. Annals of Nutrition and Metabolism, 55*(suppl 1), 602–602.

Young, S. L., Frongillo, E. A., Jamaluddine, Z., Melgar-Quiñonez, H., Pérez-Escamilla, R., Ringler, C., & Rosinger, A. Y. (2021). Perspective: The importance of water security for ensuring food security, good nutrition, and well-being. *Advances in Nutrition, 12*(4), 1058–1073.

Chapter 3
Globalization, Diet and Child Health in Three Latin American Indigenous Populations

Amanda Veile

3.1 Introduction

This chapter introduces the concepts of globalization, modernization, and the nutrition transition, and their implications for diet, development, and health of indigenous infants and children living in geographically remote areas of Latin America. Fieldwork in communities of Tsimane forager-farmers in the Bolivian Amazon, Venezuelan Pumé hunter-gatherers, and Yucatec Maya subsistence farmers provides the basis for the case studies presented here. Data were collected under the auspices of the Tsimane Health and Life History Project, the Pumé Hunter-Gatherer Subsistence and Life History Project, and the Yucatec Maya Longitudinal Life History Project, respectively.

Environmental conditions shape health, particularly in the period beginning at conception to the end of the second year of life ("the first 1000 days," http://thousanddays.org/). This is an important time for growth and immunologic and metabolic maturation (Mayneris-Perxachs & Swann, 2019; Robertson et al., 2019; Wells et al., 2020). The "first 1000 days" concept is now frequently utilized in global health efforts to identify early life factors that increase risk of childhood obesity (Hennessy et al., 2019). Here I examine several early life nutritional and epidemiologic factors that shape children's development, even in contemporary settings where childhood obesity is absent or rare. Despite being relatively geographically isolated, the Tsimane, Pumé, and Maya communities have all been exposed to some extent to the processes of globalization, modernization, and the nutrition transition.

The term "globalization" is defined in various ways. Here, it is defined as "the growing interdependence of the world's economies, cultures, and populations, brought about by cross-border trade in goods and services, technology, and flows of

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S. Datta Banik (ed.), *Human Growth and Nutrition in Latin American and Caribbean Countries*, https://doi.org/10.1007/978-3-031-27848-8_3

investment, people, and information (PIEE, 2021). One consequence of globalization is the transmission of dietary and biomedical practices across nations and continents, with novel food systems and health care practices largely flowing from wealthier to less wealthy parts of the world. Particularly in low- and middle-income countries, globalization may be coupled with rapid urbanization and widespread rural to urban migrations, which are in turn associated with increased childhood obesity rates (Corvalán et al., 2017; Danquah et al., 2020; Popkin et al., 2012).

Urbanization and widespread migration, however, does not reflect the reality of contemporary rural subsistence populations which continue to produce the majority of their food at the household level (Rapsomanikis, 2015; UNDP, 2021). Many Latin American rural indigenous communities are relatively non-industrialized, linguistically and geographically isolated, and rely heavily on traditional food procurement methods such as hunting, gathering, fishing, and small-scale farming for subsistence (UNDP, 2021). In these not uncommon but often overlooked contexts, the effects of globalization are inevitable, but often unpredictable.

The term "modernization" has been used by evolutionary anthropologists to describe the complex transition that occurs when global forces reach rural spaces, but in a non-linear and often piecemeal and sporadic fashion (Mattison & Sear, 2016; Veile et al., 2014). This process contrasts with the more abrupt nutritional and epidemiologic transitions often associated with urbanization (e.g., in the context of urban sprawl or rural to urban migration). Both are associated with "acculturation," defined here as "sustained exposure to the values, institutions, and technologies of a more dominant society" (Sam & Berry, 2010). For remote and non-industrialized communities, acculturation and modernization can have major downstream effects on subsistence and parenting practices, market integration, nutrition, epidemiology, and demography (Malina et al., 2008; Mattison & Sear, 2016; Piperata et al., 2011; Valeggia et al., 2010). As noted, these transitions are frequently prolonged, inconsistent, and piecemeal in nature. For example, market foods and highly medicalized birthing practices may become sporadically available even to isolated communities that lack basic sanitation and public health infrastructure (Veile et al., 2022a).

Market foods, however sporadic, are an integral component of the nutrition transition, with important consequences for young children's health and development. The nutrition transition is defined here as the shift from localized, "traditional" diets characterized by minimal fat and high fiber consumption to non-localized, "urbanized" diets dominated by mass-produced food and drinks of substantial salt, sugar, and fat content with minimal fiber (e.g., Moreno-Altamirano et al., 2014; Popkin et al., 2020; Rivera et al., 2002; Varela-Silva et al., 2012; Vega Mejía et al., 2018). The nutrition transition can be quite rapid in rural and urban settings, and is often a precursor of rising obesity in adults and children alike.

Despite their recent exposures to modernization and the nutrition transition, early childhood obesity remains rare or absent in the Tsimane, Pumé, and rural Maya. This is likely due to their relatively low levels of integration into the market economy, continued reliance on traditional diets, physically active childhoods, and frequent microbial exposures that can elicit immune responses that detract energy from growth (Garcia et al., 2020; Kramer et al., 2022; Martin et al., 2019; Urlacher

& Kramer, 2018; Veile et al., 2022a). Even in the absence of obesity, changes in birthing and breastfeeding practices, immune system development, and child morbidity and growth are observed. Some studies examining relationships between modernizing influences and these child outcomes are summarized and discussed here. For each population, a brief overview of the historical context, traditional diet and subsistence, nutritional transition, and infant feeding practices are summarized. These are followed by a summary of some relevant studies on the effects of modernization on children's growth and development.

3.2 Case Studies from Bolivia, Venezuela, and Mexico

3.2.1 Case Study 1: Tsimane of Bolivia

The Tsimane ethnic group lives in the wooded region of Beni in northeastern Bolivia, is one of the country's largest lowland tribes (population 16,000), and shares some genetic affiliation with the neighboring groups: the Yuracare, Trinitario, and Quechua (Bert et al., 2001; Garcia et al., 2020). The Tsimane live in and around the Maniqui River system, which experiences considerable rainfall between November and April and has an average yearly temperature of 26.8 °C. Since the establishment of Catholic and Protestant missions in the 1950s, Tsimane have become more sedentary and reliant on subsistence farming (Reyes-García et al., 2014). Until the late 1930s, the Tsimane were relatively self-sufficient and semi-nomadic foragers. Today, the Tsimane language is spoken in all communities, and Spanish fluency is greatest in the modernized communities.

During the late 1970s, a new road was built that connected the department of Beni with Bolivia's capital city, La Paz. This facilitated access to the Tsimane forest, which then was opened up to commercial logging, leading to major social and ecological changes (Jones, 1990). During that period, Tsimane men gained intermittent access to the wage labor market by fulfilling needs of the logging industry, which decimated a large portion of the forests in which the Tsimane lived (Godoy, 2001). The Beni Biosphere Reserve was established in 1982 and designated as a protected area by the United Nations Educational, Scientific, and Cultural Organization (UNESCO) in 1986 (Reyes-García et al., 2014). The Tsimane ethnic group alone have permission to live within the reserve and all commercial logging is prohibited. Despite this attempt at forest preservation, the logged regions beyond the reserve are still willingly inhabited by a number of Tsimane.

Over the past century, a number of global influences, such as the introduction of a Catholic mission, have altered the lifeways of the Tsimane people (Godoy, 2001). In the early 1970s, the New Tribes mission impacted every village downstream of the Catholic mission, electing village chiefs and erecting a series of Tsimane-teacher led bilingual schools. With the assistance of the New Tribes Mission, a central representative organization, the Gran Consejo Tsimane, was established in 1989 to represent the Tsimane as a whole. These representatives soon became involved in other indigenous movements in Bolivia. They successfully achieved legal recognition of their land rights from the Bolivian government, marking the 1990s as a pivotal period for the Tsimane. Another example of the growing Tsimane political influence was the 2010 election of the Gran Consejo Tsimane's president as mayor of the nearby large market town of San Borja (Reyes-García et al., 2014). This followed the 2006 election victory of Aymara leader Evo Morales, who was elected Bolivia's first indigenous president and served in that role for 13 years.

Tsimane Subsistence Strategies and Nutritional Transition

Fishing, hunting, gathering, and small animal husbandry provide a significant portion of the Tsimane diet, with additional reliance on seasonally variable slash-and-burn horticulture (cassava, plantains, maize, and rice) (Reyes-García et al., 2019). Tsimane men, women, and children forage for food in the forest, collect water and wood for fire, and work in horticultural gardens, among other activities (Davis & Cashdan, 2019). Hunting is primarily the responsibility of men, whereas childcare and cooking are mainly the responsibility of women. Hunting and fishing are practiced more frequently in remote communities with more plentiful natural resources (Díaz-Reviriego et al., 2016). Peccary, tapir, paca, howler, and capuchin monkeys are commonly consumed game animals, and are hunted with shotguns and rifles and with the help of dogs. Barbasco, a method of communal fishing in which plants are used to poison fish, is sometimes practiced. Hook and line, bow and arrow, and communal fishing nets are the most frequently used fishing methods.

Some Tsimane men work as seasonal wage laborers at logging camps and cattle ranches. Both men and women participate in regional market exchanges, which have risen in recent years due to the commercialization of certain forest products such as thatch palm (Vadez et al., 2008). Because of this integration into the market economy (wage labor and market participation), Tsimane diets increasingly contain foods high in fat, sugar, and salt (Bethancourt et al., 2021). Market foods include lard and vegetable oil; white flour, pasta, and soda are becoming more popular (Kraft et al., 2018; Zycherman, 2013, 2015). For the Tsimane, market integration also leads to decreased dietary diversity among households (Reyes-García et al., 2019). Increased adult body mass index and fatness are furthermore associated with increased market expenditure in the Tsimane region (Rosinger et al., 2013).

Infant Feeding Practices in the Tsimane

Tsimane infants are born in their communities, with very few hospital births, and the majority are breastfed shortly after birth (Veile et al., 2014). Tsimane infants are exclusively breastfed for approximately 4–8 months, after which they begin to consume non-breastmilk liquid and solid complementary foods (Martin et al., 2016; Veile et al., 2014). Tsimane mothers feed their infants masticated and/or boiled meat, fish, manioc, and plantain (Martin et al., 2016; Veile, 2011). In some instances, breastfeeding extends beyond three years, however, it is more commonly concluded by the age of two (Martin et al., 2016). As a population with relatively intensive, traditional breastfeeding practices, the Tsimane provide an excellent opportunity to consider dimensions of infant feeding and growth in a context of modernization and nutritional transition.

Study on Breastfeeding Patterns, Child Growth, and Health in the Tsimane
Human breastmilk is an adaptation that evolved to meet the complex and changing nutritional and immunologic demands of a growing infant (Hinde & Milligan, 2011). When compared to non-breastfed infants, breastfed infants are at lower risk of morbidity and mortality (North et al., 2022), and obesity, asthma, and allergies (Melnik, 2014). However, as infants approach six months of age, the relative benefits of breastfeeding begin to diminish. Maternal milk energy is limited and can no longer meet the caloric needs of a rapidly growing infant (Dewey, 1997; Martin, 2017). Thus, it is advised by the World Health Organization that breastfeeding be supplemented with liquid and solid weaning foods starting at the age of six months (WHO, 2011).

While this complementary feeding is crucial, it can also contribute to infant morbidity, especially where resources and sanitary infrastructure are limited, and where infant foods may be nutritionally deficient and easily contaminated (Manjang et al., 2018; Oluwafemi & Ibeh, 2011). Continued breastfeeding provides infants passive immunological support throughout the transition to independent feeding, and the WHO recommends an overall breastfeeding duration of two years or beyond (WHO, 2011). While such prolonged durations are rare in many parts of the world, one meta-analysis showed that “mixed feeding” (breastfeeding + non-breastmilk foods) was prolonged in a survey of non-industrialized, small-scale subsistence societies, with most children being fully weaned at two years of age or older (Sellen & Smay, 2001).

As part of ongoing bio-behavioral investigations, anthropological researchers have sought to characterize Tsimane breastfeeding practices, and determine their associations with modernization and with infant growth patterns. Breastfeeding patterns were assessed from 2003 to 2011, using two well-established ethnographic methods. First, researchers interviewed 215 Tsimane mothers across several Tsimane communities. Second, they conducted systematic observations of infant feeding behaviors, using validated time-allocation observational methodologies (Hames & Paolisso, 2014), on 133 Tsimane mother-infant pairs (infants aged 0-36 months) (Veile et al., 2014).

Data analyses showed that Tsimane breastfeeding patterns were intensive in global comparison. Mothers reported nearly universal breastfeeding initiation, four months on average of exclusive breastfeeding, followed by introduction of locally-derived infant complementary foods, and a mean weaning age of 19.2 (SD = 7.3) months. The observational data showed that "mixed feeding" was prolonged (ranging up to 33 months). Daytime observations of breastfeeding were more frequent than observations of other infant food consumption, until they reached ~12 months of age.

Researchers then examined intra-population variation in Tsimane breastfeeding patterns. The interviews and observational data were collected in several Tsimane communities that experience a range of modernization and market integration, based on *proximity to market towns* (close = modernized, far = less modernized) and the infant mortality rate, which ranged from 8.5% to 17.1% (low = modernized with exposure to biomedical care, high = less modernized with less access to biomedical care). The results showed that maternally-reported breastfeeding initiation was highest, exclusive breastfeeding longest, and observed breastfeeding frequency highest, in the *most* modernized Tsimane communities (Veile et al., 2014). This finding contrasts with a large number of studies showing a loss of traditional intensive breastfeeding practices in association with modernization (Barennes et al., 2012; González de Cossio et al., 2013).

Whether more traditional or modernized, Tsimane women did not (and still do not) typically work outside the home for a wage, which is a common breastfeeding barrier in less geographically isolated modernizing communities (Brauner-Otto et al., 2019; Rivera-Pasquel et al., 2015). The pattern of Tsimane intra-population variation may reflect increased exposure to medical personnel and formalized breastfeeding promotion activities, which disproportionately reach the most modernized communities (Veile et al., 2014). It may also indicate that there are unmeasured maternal constraints, such as nutritional stress, infectious morbidity, and dehydration, that could differentially affect lactating women across the spectrum of modernization (e.g., Rosinger, 2015). It might also reflect differential patterns of infant growth across the communities, that are also shaped by modernization and the nutritional transition.

The researchers next used the observational data, alongside anthropometrics, to examine the relationship between Tsimane infant feeding practices and child growth across the first three years of life. The goal was to assess whether breastfeeding was associated with improvements in growth. A positive association between breastfeeding and growth would be expected, if it protected against infant gastro-intestinal infections and immune stimulation that detracts from growth (McDade & Worthman, 1998). Alternatively, the researchers wondered if the Tsimane weaning pattern would instead conform to a more general mammalian model, in which faster-growing infants are weaned at younger ages to reduce the energetic costs of reproduction for mothers (e.g., Lee, 1996). In this scenario, breastfeeding would be negatively associated with infant growth.

From 2002-2009, a Bolivian medical team collected anthropometric data (length/height and weight) from infants and children during biannual medical visits. These were analyzed in conjunction with the breastfeeding frequency observations. A "nursing index" (similar to a population-specific Z-score) was calculated to place infants upon a "scale" of weaning, derived from mathematical models of breastfeeding versus complementary feeding observations (Veile, 2011). The nursing index was then modeled in association with children's length/height Z-scores (using CDC Standards), while accounting for community, age and sex. There were a total of 231 infant anthropometric measures available for 108 infants (aged 0-36 months), who had growth measures available from *before* the introduction of complementary foods.

Consistent with prior studies on the Tsimane (Foster et al., 2005) and indigenous South American children at large (Batis et al., 2020; Hodge & Dufour, 1991; Martin et al., 2019; Stinson, 1989), the infants were underweight and stunted relative to international and U.S. standards. Length/height Z-scores were negatively associated with the nursing index, such that taller infants nursed less frequently and were introduced complementary foods and weaned more quickly when compared to the shorter infants (Veile, 2011). Importantly, the negative association of nursing index and infant length/height, was found in all communities, across the spectrum of modernization.

Similar associations between weaning age and infant length have been documented in India (Padmadas et al., 2002) as well as Papua New Guinea (Tracer, 2009). This was also observed in several but not all communities in a recent systematic global review (Patro-Gołąb et al., 2019). This finding supports a theoretical argument that faster-growing infants may outgrow maternal energetic resources (e.g., breast milk) and are perceived by mothers as needing complementary foods sooner, whereas slower-growing infants may be perceived by mothers as needing prolonged breastfeeding investment (Ellison, 2003; Tracer, 2009). In other words, these findings suggest that infant growth drives subsequent feeding practices (rather than the other way around) because mothers respond to their children's growth patterns as they assess their readiness for complementary foods and weaning.

3.2.2 Case Study 2: The Venezuelan Pumé

The Venezuelan Pumé were known as the "Yaruro" in ethnographic literature before the 1980s. This population lives along and between three rivers, the Riecito, Cinaruco, and Capanaparo, in the Apure state near the Colombian border. Adjacent to the Pumé to the south are Andean people of Ecuador and Colombia, with whom they share hereditary links (Salzano & Callegari-Jaques, 1988). The Pumé language is spoken in all communities, and Spanish fluency is more common in the communities with high levels of market integration (Kramer & Greaves, 2017).

Apure, Venezuela, is characterized by extensive low flatlands, referred to as llanos or plains, and intercut by numerous rivers of the Orinoco River basin. In the llanos, where the Pumé and neighboring Hiwi live, there is a hyper-seasonal climate pattern, characterized by periods of drought and fire during the late and early months of the year and flooding conditions the remainder of the time (Hurtado & Hill, 1990). The llanos's meagre plant diversity and lack of large game animals means that the local ecology is defined by resource scarcity (Greaves, 1997).

Spanish explorers encountered Pumé in the southern llanos in 1589; much later, the Jesuits forcibly confined them to missions (1739). After the Jesuits were expelled from the country, the Pumé settled in Capuchin missions throughout the eighteenth and nineteenth centuries. It seems that all but indigenous Venezuelans abandoned the Apure llanos during the subsequent Venezuelan War of Independence, which lasted for approximately 100 years. Renewed interest in the region began to emerge in the 1930s before the settlement of Creole cattle ranchers grew rapidly during the 1960s. These ranches could still be found operating by 2010 and tensions – resulting from the fencing off of native foraging zones – intermittently escalated into clashes between the two groups (Kramer & Greaves, 2017).

Despite this history of conflict, many Pumé came to access to wage labor opportunities and market goods. A number of Pumé broadened their resource base to incorporate these modernizing influences; others continued to subsist as foragers with minimal market integration (Kramer & Greaves, 2017). Collectively, the resource acquisition activities of contemporary Pumé consist of fishing, hunting, and foraging for food, as well as slash-and-burn horticulture with intermittent participation in the wage and market economy (ibid).

Although some Pumé have relocated to nearby towns and cities, most have remained in the rural llanos of Apure. Their subsistence strategies and extent of market integration are largely dictated by the large rivers within their vicinity and access to agricultural-suited land. In reference to the nomadic and foraging groups who live in the central flatlands away from immediate access to the rivers, the Pumé use the name 'savanna Pumé' (Kramer & Greaves, 2007). In contrast, those non-mobile communities who establish themselves along the larger waterways, are referred to as 'river Pumé (ibid)'. This group practices a mixed strategy of foraging, horticulture, and market exchange. When Gragson conducted his research in 1997, he estimated that only 17% of the Pumé were 'Savannah Pumé' while the remaining 83% resided within close proximity of the waterways (Gragson, 1997).

From 1980 to 2010, there was a significant increase in the Pumé population. A dependable census by the OCEI (1985) placed their numbers at 3859 people in 1982. Another conducted in 1992 counted 5400 people (OCEI, 1995). Kramer and Greaves then calculated that the population increased by 3.15% between 1982 and 2001 (Kramer & Greaves, 2007). As of approximately 2010, the most recent estimates place the population at 8000 (Greaves, personal communication). It should be noted that recent data and population estimates are not available in this area due to Venezuela's political and economic instability.

Traditional Diets and Nutritional Transitions in the Pumé

The savanna Pumé number about 650, are dispersed in 24 bands over a 2800 km^2 area, and are a subpopulation of the larger Pumé linguistic group (Kramer, 2021). As central-place foragers who practice hunting, foraging, and fishing, savanna Pumé specialize in subsistence tasks based on their gender (Kramer & Greaves, 2010). Women provide mangoes and roots, while men provide fish and game taken from the wild (Kramer & Greaves, 2015). The savanna Pumé diet is characterized by wild root and mango consumption, which account for a significant portion of calories (35% and 25%, respectively). In addition, protein-based foods constitute a major part of the diet, with fish and meat representing 15% and 10% of dietary consumption, respectively. Bitter manioc is seasonally cultivated by men and women, but makes up a small portion of dietary calories (10%) (Kramer & Greaves, 2010).

There is variation in Savanna Pumé subsistence practices by season. Fishing is the primary dry season subsistence activity, with men and boys engaging in barbasco, spearfishing, and hook and line fishing. In the rainy season, fish are dispersed and replaced by small game as the main subsistence base, complemented by cultivated bitter manioc and a variety of other wild roots (Gragson, 1997). Caiman, small mammals, lizards, and migratory birds are hunted by men using bow and arrow. Even with the recent addition of hunting dogs to their subsistence hunting repertoire, wild game returns from the llanos quite meagre because game are both small and scarce (Kramer & Greaves, 2017).

The savanna Pumé diet includes a single fruit, mangoes, and long distances are traveled to obtain them. Relatively new additions to the subsistence portfolio of the savanna Pumé include wage labor and animal husbandry, though these are only occasionally employed (Kramer & Greaves, 2010). Since Greaves first reported the presence of dogs, chickens, and pigs in the 1990s, their numbers have steadily increased.

In contrast to the savanna communities, the river Pumé communities have become increasingly sedentary since the 1950s (Kramer & Greaves, 2007). Permanent villages were established along the Riecito, Cinaruco, and Capanaparo, Rivers, which serve as major routes of transportation for Venezuela. Therefore, the river Pumé people have increased contact with external groups in comparison to the savanna Pumé. Because they are easier to access, the river Pumé were the primary subject of the early ethnographic studies (Petrullo, 1939).

Compared to their savanna counterparts, river Pumé practice more agriculture. Floodplain soils yield greater return rates in comparison to the sandy soil of much of the region, and manioc and corn are the two most important crops. River Pumé also consume more protein from fishing, because fish in the major rivers are larger and more abundant than the fish in small seasonal waterways accessible by the savanna Pumé (Kramer & Greaves, 2010).

River Pumé maintain higher numbers of domestic animals for consumption and are more likely to participate in wage labor, giving them increased access to cash and market goods (Kramer & Greaves, 2007). Some highly acculturated villages engage in the market economy by producing specialized goods such as hammocks and assorted pottery. A system of exchange exists between the two Pumé groups in which the foraged materials (weaving materials, resin, fibers) of the Savannah Pumé are exchanged for goods only available on the market (pasta, clothing, various tools and cookware) and attained by the river Pumé.

Infant Feeding Practices in the Pumé

Pumé infants are born in their villages and are breastfed immediately after birth. Infants breastfeed intensively during the initial months of life, and are introduced local complementary foods at around 6 months of age (Veile et al., 2012). Soft foods such as mangos are introduced in small portions, followed by larger quantities of pre-masticated adult foods. Children eat small whole fish with bones by the time they are 2 years old, and are typically weaned by the ages of two and three. In contrast to the inseparable mother-infant dyad observed in many other subsistence populations, Pumé infants are frequently cared for and sometimes nursed by others from a very young age. Mothers more generally benefit from alloparental care of infants by family and community members, particularly in terms of time and energy savings (Kramer & Veile, 2018). In general, infant care and feeding behaviors did not change substantially from the 1990s until 2007, though one mother was seen using a bottle to provide water to her infant in the 2007 field season.

Study on Pumé and Tsimane Thymus Development and Child Growth
The Tsimane and Pumé, at the time of data collection, were relatively geographically and linguistically isolated populations, with high intra-population genetic similarity, and each living under differential conditions of modernization, market integration, and infant mortality risk (Veile et al., 2012). For example, Pumé infants inhabit a hyperseasonal environment with a relatively high burden of infectious disease. The most recent estimates of their infant mortality are 13.2% for the river Pumé, which falls within the Tsimane range during the data collection period described above (8.5–17.1%), and 34.6% for the savanna Pumé (Kramer & Greaves, 2007; Veile et al., 2014). This situation provided an excellent opportunity to study the immune system and child anthropometrics within and across relatively isolated indigenous populations, and in response to varying ecological conditions.

The thymus gland was studied in Tsimane and Pumé infants using portable ultrasound technology, and was treated as a proxy for their immunological status. The thymus is a bilobed lymphoepithelial organ, located (in humans) in the upper chest behind the sternum, and is the primary site of maturation of T-lymphocytes that orchestrate cell-mediated immune processes (Murphy et al., 2022). Thymus size and infant body size are generally correlated at birth (Aaby et al., 2002; Yekeler et al., 2004, Yilmaz Semerci et al., 2019). Its general developmental trajectory, based on healthy and well-nourished subjects, is to increase in volume postnatally and reach maximum size between four and six months, before it begins a gradual process of involution which continues throughout life (Hasselbalch et al., 1999; Yekeler et al., 2004; Shanley et al., 2009). Thymus functional (e.g., proliferative) capacity and volume are typically correlated with birthweight in infants, and are predictors of early childhood survival (Chevalier, 1994; Jeppesen et al., 2004). Although there are population differences in thymus size and developmental trajectories (Aaby et al., 2002; Park et al., 2008), cross-cultural comparisons are limited by conflicting methodologies (Varga et al., 2009).

The development of the thymus is clearly affected by the postnatal environment (Zeyrek et al., 2008), including nutritional conditions (Moore et al., 2019). Studies from resource-scarce settings further highlight the importance of developmental influences such as perinatal malnutrition, infection (Savino et al., 2022), stress hormones (Savino et al., 2002), and seasonality (Savino & Dardenne, 2000). In a hyperseasonal setting in the Gambia, being born or measured during the "hungry" season as opposed to the more favorable season, correlated with smaller thymic measurements (Aaby et al., 2002; Collinson et al., 2003). It is possible that thymus development is sensitive to suboptimal perinatal conditions because there are substantial energetic costs of thymic tissue maintenance and T-lymphocyte production in early life (Urlacher, 2023).

To offer additional empirical data on thymus size in infants from nutritionally and epidemiologically challenging settings, researchers conducted a cross-sectional study of Tsimane and Pumé infants using a portable ultrasound machine. The main goals of this research were to compare infant anthropometry and thymus size across the Tsimane and Pumé, and evaluate correlations between anthropometry and thymus size within each group. For this preliminary study, thymic volume and anthropometry (infant length/height, weight and mid-upper arm circumference (MUAC)) were measured in infants and demographic information collected from mothers by interview. One investigator (AV) was trained in thymic ultrasonography by Dr. Ricardo Sevilla at El Centro de Rehabilitación Infantil Nutricional (CRIN) in Cohabamba, Bolivia. Due to logistical and financial constraints, the sample size was small (29 Pumé infants and 57 Tsimane aged 0–2 years from 2006, 2007) but sufficient to draw some preliminary conclusions.

Despite living in vastly different nutritional and epidemiologic environments, results showed that anthropometric trajectories for the Tsimane and Pumé infants were nearly identical from birth to two years of age (Veile et al., 2012). There were no significant differences in weight, length/height, or MUAC between the two groups. Collectively, the Tsimane and Pumé infants were just slightly smaller in terms of both weight and length/height in accordance with the WHO median, and similar to the WHO mean in their mid-upper arm circumferences (WHO, 2006). This early life pattern of adequate growth, even under harsh conditions, is likely a reflection of "buffering" via breastmilk and intensive caregiving practices, and a testament to the nutritional and immunologic benefits of prolonged and intensive breastfeeding (McDade, 2003)

Tsimane infants had a mean thymus area (321 mm^2, standard deviation = 96) comparable to those previously reported for 37 malnourished school-aged individuals (6–55 months) who had experienced 9 weeks of immunonutritional rehabilitation in Bolivia (Chevalier et al., 1994). The mean thymus area in the Pumé population was significantly smaller (257 mm^2, SD 5 99), and both presented high levels of intra-population variation. When comparing across the two populations of infants, two different measures of thymic size (area and depth, or the left anterior–posterior dimension) decreased linearly and at similar rates with age. Pumé children, regardless of whether they lived on the savanna or in a river community, had smaller thymic dimensions at all ages from birth to two years of age.

Collectively, the Tsimane and Pumé infants had lower thymic depth values compared to 152 Turkish infants (Yekeler et al., 2004). Thymic depth differences were more pronounced during early infancy, and were only statistically significant at two, five, six and nine months of age (Veile et al., 2012). In the Turkish cohort, the mean thymus depth measurement increased postnatally, reached its maximum size at 6 months, decreased abruptly, and then decreased gradually, from 12 to 24 months of age (Yekeler et al., 2004). The Tsimane and Pumé infants, on the other hand, did not experience a significant growth plateau. By the second year of life, there were no statistically significant differences in mean thymic depth values when the Turkish cohort and the combined Tsimane/Pumé cohort were compared. It is important to note that this cross-population comparison did not consider body size variations between Turkish and Tsimane/Pumé infants, nor inter-observer variation in thymic ultrasonography, and thus these comparisons should be interpreted qualitatively. In particular, the difference in age-based thymic *patterning* is more important than the absolute mean value comparisons.

In an additional set of models, researchers evaluated the following predictors of thymic size in the Tsimane and Pumé infants: population, infant WAZ and MUACZ (using WHO standards), maternal age and weight, infant age and sex, season (wet/dry), and presence/absence of infant fever. Of these predictors, only infant population and age were significant predictors of thymic area and depth. However, in a sub-analysis of 56 infants aged 6-24 months (e.g., past the exclusive breastfeeding stage), MUAC Z-score was a positive and significant predictor of thymus areas. This finding persisted after accounting for infant age and population, and was significant in both Tsimane and Pumé infants in sub-analyses for each population.

The difference in mean thymus size in the Tsimane and Pumé are compelling, especially given their lack of anthropometric differences in the first two years of life. In light of this finding, it can be concluded that there is not always a straightforward phenotypic link between thymus and body size in the context of cross-population comparisons. This further suggests that the thymus is not just a "barometer of malnutrition," as it is often described in biomedical literature (Nabukeera-Barungi et al., 2021).

This finding could instead be interpreted using an energy trade-off model (e.g., Urlacher et al., 2018). If Pumé infants inhabit a more challenging environment, and have less energy available to invest in growth and immune function compared to Tsimane infants, they may invest limited energetic reserves preferentially toward growth at the expense of cell-mediated immune function (e.g., thymic tissue maintenance) (e.g., McDade, 2003). Alternatively, and perhaps more plausibility, the size of the thymus may reflect differences in the frequency of infectious morbidity across the populations (with a higher infection burden expected in the Pumé), because infection is associated with transient thymus depletion (Savino et al., 2022).

This argument makes sense in the context of the comparison with Turkish infants, who likely have minimal infection rates compared to the Tsimane and Pumé, based on their fairly low national IMR (~1.3% in 2008) (Demirel et al., 2013). In contrast, for the Tsimane and (especially) the Pumé, with their respective mortality rates of 8.5%-17.1% and 13.2%-34.6%), concurrent infant morbidity has a greater chance of impacting population mean thymus size.

It is unclear whether infection-induced thymus depletion in resource-limited environments is adaptive in that it facilitates immunologic maturation, as McDade argued (2003), or if it is a detrimental outcome brought on by adverse circumstances, as indicated by others (Nabukeera-Barungi et al., 2021). There has been limited follow-up work on the thymus in these populations. However, immunological profiles of young children (aged 0–5 years) show that Tsimane naïve T-cell proliferation is comparable to or just slightly elevated compared to children in wealthy and urbanized reference populations (Blackwell et al., 2016).

3.2.3 Case Study 3: The Yucatec Maya

The Yucatec Maya are a group of indigenous people who live throughout Mexico and Central America. Yucatec Maya is Mexico's second most widely spoken indigenous language, with more than 790,000 speakers, most of whom live on the Yucatan Peninsula (Yamasaki, 2020). According to a 2010 study, the Yucatec Maya were genetically indistinguishable from indigenous groups like the Huastecos and Choles, indicating a common heritage or recent gene flow between the groups (Martínez-Cortés et al., 2010). In addition to the Mexican states of Yucatan, Campeche, and Quintana Roo in the south, the middle and northern Yucatan Peninsula comprises the nations of Belize and Guatemala in the north. The annual precipitation ranges from 600 to 1600 mm, with a gradient increasing from the northwest to the south (de la Barreda et al., 2020; Mendoza et al., 2007).

The first evidence of human presence on the Yucatan Peninsula dates back at least 12,000–13,000 years (Chatters et al., 2014). The peninsula has been farmed by the Yucatec Maya for at least the past 3000+ years, and many traditional methods of agriculture and diet are still observable to this day (Ayora-Diaz, 2012; O'Connor, 2016; Anderson & Anderson, 2011). Although numerous excellent reviews and books have been written about the Maya civilization and the Spanish Conquest of Yucatan (e.g., Coe & Houston, 2015; Ramírez-Carrillo, 2020), this chapter will focus on a well-studied community in the humid and hilly Puuc region of northern Campeche, where there is approximately 1100 mm of annual rainfall, with 80% of it falling between May and November (Dunning et al., 2012). The community has been the site of longitudinal field research by anthropologist Karen Kramer since 1992, and is well described in her book (Kramer, 2005) and a multitude of ethnographic and scientific articles.

In the opening decades of the twentieth century, a small group of families moved to the area and founded what is now the study community. During this time, the group resided in dirt-floored huts made through traditional wattle and daub building methods and lived as swidden subsistence farmers. Within decades after the Mexican Revolution and its upheavals, the ejido land tenure system (composed of communally owned village, agriculture, and forest holdings) was established throughout rural Yucatan by the 1950s. For women of the Maya communities it has proved significant. The system ensured that they have nearly equal access to food and other resources through the shared ownership of agricultural land, and sufficient resources to support reproduction and children (Kramer, 2005). Despite an expanding population, the ejido allotment of the study community has been sufficient to support it for the past 65 years.

Yucatec Maya Traditional Diet and Nutritional Transition

During the period from ~1950–1977, each family was responsible for its own food production (Veile & Kramer, 2018). Men, women, and children were all involved in energetically intensive field and garden work. Maize provided most of the calorie intake with a smaller amount coming from squash, peanuts, beans, other fruits and vegetables, and small amounts of hunted wildlife foods. Domestic livestock such as chickens, turkeys, and pigs were reared and consumed on occasion. Plants from the forest were also collected for therapeutic purposes. *Ramon* (breadfruit) was collected for consumption during drought seasons.

There was no running water or electricity in the village, and water had to be collected by hand from a communal well. A flat or slightly hollowed oblong stone called a *metate* was used for grinding maize by hand. Hand-operated grinders, introduced circa 1940s, later became the primary method of grinding corn for women. Up until the 1960s, the roads leading to the adjacent administrative towns were not paved entirely. Villagers rarely participated in wage labor, cash cropping or market trade due to the considerable travel required between market towns, and the absence of road infrastructure and lack of automobiles.

Several progressive changes accompanied the commencement of the nutrition transition in the village. In the latter half of the 1970s, a gas-powered mill (*molino*) and a water pump were erected, which increased the efficiency of both maize production and water collection (Veile & Kramer, 2018). Over the next two decades there were relatively few changes. Villagers continued to live as subsistence farmers, mostly disconnected from wage labor and the broader market economy. The vast majority of the food was still produced at the household level.

A small number of commodities (candles, metal tools, medication, fabric, and vegetable oil) that could not be found locally were purchased using the proceeds from honey, or when minor quantities of were maize sold (Kramer, 2005). Aside from that, no cash crops were planted. A paved road into the community was constructed in the early 2000s, which allowed villagers to engage in new subsistence and wage employment opportunities. Electricity and piped water then became available to most households, and many more aspects of farming mechanized. This meant that women contributed less to energy-demanding agricultural tasks (Kramer & Veile, 2018).

The nutrition transition has affected the community, though farming remains the primary subsistence base, and most household foods are produced locally. Small stores have opened, providing goods such as cooking oil, as well as snack foods, which are consumed on special occasions, and soda, which is now consumed fairly regularly. This combination of dietary change, and decreased energy expenditure, has culminated in a significant increase in adult BMIs between 1992 and 2010 (Veile & Kramer, 2018). Additionally, from 2007 to 2016, many village children were enrolled in a program originally named *Oportunidades,* which provided anthropometric and nutritional monitoring for children aged 0–5 years (Veile & Kramer, 2017a, b). While this (now-defunct) program generally had beneficial effects on child growth outcomes across Mexico (Leroy et al., 2008; Rosado et al., 2011), its long-term effect on children in the study community remains to be seen.

In the last 20 years, wage labor remains limited due to the community's remote geographic location and perceived low monetary returns. While still low, it has more than doubled from 3% to 6% of adults over 18 (Veile & Kramer, 2018). In the early 2000s, men and (mostly unmarried) women alike began to adopt paid labor jobs (at factories, as laborers, farmhands, and domestic workers). No mothers of young children were, or currently are, employed in paid labor outside of the home. Women also began to form craft cooperatives with the help of bank and government funding, with variable monetary success.

Regardless of these developments, small-scale maize production is still practiced by most households, providing their primary source of income and subsistence. Excess honey and maize are sold to supplement the household income and to purchase essential household items. Yucatec Maya remains the predominant language spoken in the community, though Spanish fluency has increased in recent years.

Infant Feeding Practices Among the Rural Yucatec Maya

Most Maya infants were delivered in the community and breastfed immediately until ~25 years ago, when some mothers began birthing in hospitals (Veile & Kramer, 2018). Hospital delivery is now the norm, and hospital practices can cause breastfeeding initiation to be delayed (Veile & Kramer, 2015). Despite this, Yucatec Maya mothers continue to practice traditional, prolonged and frequent breastfeeding (for more than 2 years) (Veile et al., 2019). When infants reach 4–6 months old, mothers provide them complementary foods such as maize gruel, tortillas, chicken, beans, crackers, and applesauce (Veile & Kramer, 2017a, b).

Changing Birthing Practices in the Yucatec Maya

The progression from traditional Yucatec Maya midwifery to highly medicalized birthing practices in the Yucatec Maya community is now described. The findings are derived from community-wide household demographic interviews and women's reproductive histories collected at regular intervals from 1992–2019. In addition, 58 women were interviewed (2015) specifically regarding birthing and breastfeeding practices, and an elderly midwife was interviewed extensively on multiple occasions (2015–2018). Interviews were conducted by Karen Kramer, Russell Greaves, and AV, in Spanish with support from established Spanish-Maya informants and translators. Interview results were analyzed using a mix of quantitative analyses and qualitative comparisons and descriptions (Veile & Kramer, 2015, 2018).

Local midwives were responsible for overseeing all perinatal care and births in the Maya community until ~1992. Traditional midwifery practices were associated with low maternal mortality rates and facilitated the onset of breastfeeding, mother-infant bonding, and extensive broader social support for mother-infant dyads (Veile & Kramer, 2017a, b, 2018). Starting in the mid 1990's, changing medical care access, coupled with universal health insurance and new government poverty alleviation programs, resulted in the rapid medicalization of traditional birthing practices (Knaul et al., 2005; Sedesol, 2010; Smith-Oka, 2013; Serván-Mori et al., 2017).

By 2015, most births (~85%) took place in a government medical facility; cesarean deliveries accounted for approximately 30% of all the hospital births (Veile & Kramer, 2015). The community cesarean delivery rate was low compared to the

Mexican national rate (~45.5%) (Uribe-Leitz et al., 2019) but not trivial. As of 2015, Maya mothers (58/58) stated a strong preference for vaginal birth, and reported only having cesarean deliveries at the recommendation of their physicians (Veile & Kramer, 2015). All cesarean deliveries are deemed medically necessary and classified as "emergency" (unplanned intrapartum cesarean sections) or "planned" cesarean sections, which are scheduled in advance for medical reasons (Veile & Kramer, 2018). The adult women's obesity rate is rising in the community (Veile & Kramer, 2018), and is likely to indirectly account for a portion of the cesarean deliveries, because maternal obesity is associated with increased gestational complications (e.g., gestational diabetes and preeclampsia).

Studies on Cesarean Section and Child Outcomes in the Yucatec Maya

Cesarean delivery, while sometimes lifesaving, can be associated with negative maternal-infant outcomes such as 1) compromised breastfeeding success and increased formula feeding, 2) increased infant morbidity, and 3) childhood obesity (Mueller et al., 2017; Rosenberg & Trevathan, 2018; Tully & Ball, 2014). However, these associations are most often measured in relatively urbanized and wealthy populations characterized by non-intensive breastfeeding and prevalent formula feeding, sanitized households and minimal morbidity, and low physical activity and high childhood obesity rates (Carrillo-Larco et al., 2015; Kuhle et al., 2015; Veile & Kramer, 2017a, b). Biological relationships between cesarean delivery and child health outcomes are insufficiently documented across wider variety of populations and contexts (Carrillo-Larco et al., 2015). Among those neglected have been the rural Yucatec Maya and other subsistence populations who are currently experiencing modernization, the medicalization of birth, and rising cesarean delivery rates.

As a result, researchers conducted several studies to evaluate the associations of cesarean delivery with breastfeeding outcomes, child morbidity, and child growth in the Yucatec Maya. The studies draw from local clinic records, including monthly longitudinal growth, morbidity, and breastfeeding data collected by physicians and community health workers from 2007–2018, under the auspices of the *Oportunidades* child health monitoring program (n=~108 infants aged 0–5 years). Data were analyzed using repeated-measures regression modeling. This includes linear modeling of monthly longitudinal WHO Z-scores (weight and height for age and weight-for-length/BMI for age), and logistic modeling of monthly longitudinal digestive/respiratory symptoms (coded as 0/1) and presence/absence of breastfeeding and formula feeding (coded as 0/1). These outcomes were modeled as a function of birth mode, accounting for potential confounding factors.

Results showed that cesarean birth is associated with delayed breastfeeding initiation (Veile & Kramer, 2015). Despite this rocky start, cesarean-delivered infants are breastfed for longer durations (roughly 32 versus 30 months, n=88, 2290 observations) and are no more likely to be formula-fed, compared to their vaginally delivered counterparts (Veile et al., 2019). In the same study, cesarean birth was not associated with digestive or respiratory morbidity in children aged 0–5 (Veile et al., 2019). It is possible that elevated morbidity risk in cesarean delivered children is offset by the epidemiologic benefits of the Maya tradition of prolonged breastfeeding.

Though obesity remains absent in young children in this community, analyses show that cesarean birth is associated with slightly higher child weight-for-age and BMI in early childhood (Veile & Kramer, 2017a, b; Veile et al., 2022b). The effect is small but significant, and nuanced. The association between birth mode and body size increases with age and is exacerbated in high birthweight children and/or those with high maternal BMI (Veile & Kramer, 2017a). A high-birthweight 5-year-old born to a high-BMI mother, for example, would weigh 10% more if delivered by cesarean versus vaginally. Furthermore, recent work shows that the effects of cesarean delivery on childhood growth are reduced in the presence of certain household factors like traditional construction materials (e.g., earth floors) and limited sanitary infrastructure (e.g., open defecation) (Veile et al., 2022a).

The Maya experience diverges from the relatively urbanized, wealthy populations that are most often the focus of epidemiologic study (Kuhle, 2015). In contrast to many studies, cesarean delivery does not seem to compromise Maya breastfeeding success, nor does it increase formula feeding or childhood morbidity. Finally, while cesarean delivery is associated with faster growth and larger body size, the effect sizes are small, and further modulated by postnatal environmental household conditions. Taken together, these results indicate that cesarean delivery has mixed effects on child outcomes, depending on local epidemiologic conditions and the social environment in which post-cesarean development occurs (Carrillo-Larco et al., 2015; Veile & Kramer, 2017a, b).

3.3 Conclusions

These case studies, taken together, demonstrate the unpredictable nature of the nutrition transition in culturally and geographically distinct populations, the tenacity of indigenous traditions, and the numerous ways in which early life conditions influence infant-child growth and health in complex and changing environments. Despite contemporary global trends toward rapid urbanization, the Tsimane, Pumé and rural Yucatec Maya people to a large extent retain household-subsistence based economies as well as their indigenous languages and many cultural traditions. Globalization and the nutrition transition are not entirely novel, nor abrupt nor linear influences, but rather part of complex and ongoing processes dating back at least to the European conquest of the Americas. The history, biology and culture of each group are distinctive and provide unique backdrops on which contemporary processes unfold.

These and other studies of the Tsimane, Pumé and Yucatec Maya reveal substantial inter- and intra-population variation in their exposure to the nutrition transition. Tsimane and Pumé communities are rural but reflect a range of exposures to globalization and modernization, and the Yucatec Maya have become increasingly urbanized in recent years (Veile et al., 2022b). Research on these populations has shown that even minor changes in diet and activity patterns, can affect major life history functions like growth, immune function, and reproduction. These changes are best understood within the biological and cultural context of each population. For example, Tsimane breastfeeding practices are associated with exposure to modernizing influences, whereas their biobehavioral responses to infant growth pattens seems to transcend community-level differences. Pumé infants show similar thymus sizes across communities of varying modernization, and have smaller thymuses than Tsimane infants despite having identical child growth trajectories. These results indicate that non-nutritional ecological factors have major influences on their immunological development. Finally, the rural Maya show links between birth mode, breastfeeding and child growth outcomes that unfold in the recent context of the modernization of birthing practices.

Most global efforts in public health nutrition target the childhood obesity epidemic, which has reached even rural and isolated indigenous communities (Hennessy et al., 2019; Varela-Silva et al., 2012). Still, in these case studies (and many other low-income rural communities), childhood obesity remains rare. Children's growth patterns are instead characterized by short stature and relatively low body fat, which is an additional public health challenge (Martin et al., 2019). Efforts to improve early childhood growth in these contexts, come with mixed results and may even contribute to the onset of obesity. As such, biologically informed and culturally contextualized public health interventions should employ mixed-method data collection techniques to understand local perspectives, which are helpful in devising public health programs that preserve beneficial existing beliefs and practices.

References

Aaby, P., Marx, C., Trautner, S., Rudaa, D., Hasselbalch, H., Jensen, H., & Lisse, I. (2002). Thymus size at birth is associated with infant mortality: A community study from GuineaBissau. *Acta Pediatrica, 91*, 698–703.

Anderson, E. N., & Anderson, B. (2011). Development and the Yucatec Maya in Quintana Roo: Some successes and failures. *Journal of Political Ecology, 18*(1), 51–65.

Ayora-Diaz, S. I. (2012). *Foodscapes, Foodfields, and identities in the Yucatan* (1st ed.). Berghahn Books.

Barennes, H., Empis, G., Quang, T. D., Sengkhamyong, K., Phasavath, P., Harimanana, A., Sambany, E. M., & Koffi, P. N. (2012). Breast-milk substitutes: A new old-threat for breastfeeding policy in developing countries. A case study in a traditionally high breastfeeding country. *PLoS One, 7*(2), e30634.

Batis, C., Mazariegos, M., Martorell, R., Gil, A., & Rivera, J. A. (2020). Malnutrition in all its forms by wealth, education and ethnicity in Latin America: Who are more affected? *Public Health Nutrition, 23*(S1), s1–s12.

Bert, F., Corella, A., Manel, G., Perez-Perez, A., & Turbon-Borrega, D. (2001). Major mitochondrial DNA haplotype heterogeneity in highland and lowland Amerindian populations from Bolivia. *Human Biology, 73*, 1–16.

Bethancourt, H. J., Ulrich, M. A., Almeida, D. M., & Rosinger, A. Y. (2021). Household food insecurity, hair cortisol, and adiposity among Tsimane' hunter-forager-horticulturalists in Bolivia. *Obesity, 29*(6), 1046–1057.

Blackwell, A. D., Trumble, B. C., Maldonado Suarez, I., Stieglitz, J., Beheim, B., Snodgrass, J. J., Kaplan, H., & Gurven, M. (2016). Immune function in Amazonian horticulturalists. *Annals of Human Biology, 43*(4), 382–396. PMID: 27174705; PMCID: PMC4976077.

Brauner-Otto, S., Baird, S., & Ghimire, D. (2019). Maternal employment and child health in Nepal: The importance of job type and timing across the child's first five years. *Social Science & Medicine, 224*, 94–105.

Carrillo-Larco, R. M., Miranda, J. J., & Bernabé-Ortiz, A. (2015). Delivery by caesarean section and risk of childhood obesity: Analysis of a Peruvian prospective cohort. *PeerJ, 3*, e1046.

Chatters, J. C., Kennett, D. J., Asmerom, Y., Kemp, B. M., Polyak, V., Blank, A. N., Beddows, P. A., Reinhardt, E., Arroyo-Cabrales, J., Bolnick, D. A., Malhi, R. S., Culleton, B. J., Erreguerena, P. L., Rissolo, D., Morell-Hart, S., & Stafford, T. W., Jr. (2014, May 16). Late Pleistocene human skeleton and mtDNA link Paleoamericans and modern Native Americans. *Science, 344*(6185), 750–754. PMID: 24833392.

Chevalier, P. (1994). *Malnutrition Proteino-Energetique et Immunite: Tentative de restauration de l'Immunodéficience Secondaire à la Malnutrition Orstom*. Montpellier, Orstom.

Chevalier, P., Sevilla, R., Zalles, L., Sejas, E., Belmonte, M. S., & Parent, G. (1994). Study of thymus and thymocytes in bolivian preschool children during recovery from severe protein energy malnutrition. *Journal of Nutritional Immunology, 3*(1), 27–39.

Coe, M., & Houston, S. (2015). *The Maya (ancient peoples and places)*. Thames & Hudson.

Collinson, A., Moore, S., & TJ, C. & Prentice, A. (2003). Birth season and environmental influences on patterns of thymic growth in rural gambian infants. *Acta Paediatrica, 92*, 1014–1020.

Corvalán, C., Garmendia, M., Jones-Smith, J., Lutter, C., Miranda, J., Pedraza, L., & Stein, A. (2017). Nutrition status of children in Latin America. *Obesity Reviews, 18*, 7–18.

Danquah, F. I., Ansu-Mensah, M., Bawontuo, V., Yeboah, M., Udoh, R. H., Tahiru, M., & Kuupiel, D. (2020). Risk factors and morbidities associated with childhood obesity in sub-Saharan Africa: A systematic scoping review. *BMC Nutrition, 6*(1), 37.

Davis, H. E., & Cashdan, E. (2019). Spatial cognition, navigation, and mobility among children in a forager-horticulturalist population, the Tsimané of Bolivia. *Cognitive Development, 52*, 100800.

de la Barreda, B., Metcalfe, S. E., & Boyd, D. S. (2020). Precipitation regionalization, anomalies and drought occurrence in the Yucatan Peninsula, Mexico. *International Journal of Climatology, 40*(10), 4541–4555.

Demirel, G., Tezel, B., Ozbas, S., Oguz, S. S., Erdeve, O., Uras, N., & Dilmen, U. (2013). Rapid decrease of neonatal mortality in Turkey. *Maternal and Child Health Journal, 17*, 1215–1221.

Dewey, K. G. (1997). Energy and protein requirements during lactation. *Annual Review of Nutrition, 17*, 19–36.

Díaz-Reviriego, I., Fernández-Llamazares, A., Salpeteur, M., Howard, P., & Reyes-García, V. (2016). Gendered knowledge contributions to adaptive capacity and health sovereignty in Amazonia. *Ambio, 45*(3), 263–275.

Dunning, N. P., Beach, T. P., & Luzzadder-Beach, S. (2012). Kax and kol: Collapse and resilience in lowland Maya civilization. *Proceedings of the National Academy of Sciences, 109*(10), 3652–3657.

Ellison, P. T. (2003). *On fertile ground: A natural history of human reproduction*. Harvard University Press.

Foster, Z., Byron, E., Reyes-García, V., Huanca, T., Valdez, V., Apaza, L., Pérez, E., Tanner, S., Gutierrez, Y., Sandstrom, B., Yakhedts, A., Osborn, C., Godoy, R. A., & Leonard, W. R. (2005). Physical growth and nutritional status of Tsimane' Amerindian children of lowland Bolivia. *American Journal of Physical Anthropology, 126*, 343–351.

Garcia, A. R., Blackwell, A. D., Trumble, B. C., Stieglitz, J., Kaplan, H., & Gurven, M. D. (2020). Evidence for height and immune function tradeoffs among preadolescents in a high pathogen population. *Evolution, Medicine, and Public Health, 2020*(1), 86–99.

Godoy, R. (2001). *Indians, markets, and rain forests*. Columbia University Press.

González de Cossio, T., Escobar-Zaragoza, L., Gonzalez-Castell, D., Reyes-Vazquez, H., & Rivera-Dommarco, J. A. (2013). Breastfeeding in Mexico was stable, on average, but deteriorated among the poor, whereas complementary feeding improved: Results from the 1999 to 2006 national health and nutrition surveys. *Journal of Nutrition, 143*(5), 664–671.

Gragson, T. L. (1997). The use of underground plant organs and its relation to habitat selection among the Pumé Indians of Venezuela. *Economic Botany, 51*, 377–384.

Greaves, R. D. (1997). *Ethnoarchaeological investigation of subsistence mobility, resource targeting, and technological organization among Pumé Foragers of Venezuela*. PhD dissertation, Albuquerque university of New Mexico.

Hames, R., & Paolisso, M. (2014). Behavioral observation. In H. R. Bernard & C. G. Gravlee (Eds.), *Handbook of methods in cultural anthropology* (2nd ed., pp. 293–312). Rowman & Littlefield.

Hasselbalch, H., Ersbøll, A. K., Jeppesen, D. L., & Nielsen, M. B. (1999). Thymus size in infants from birth until 24 months of age evaluated by ultrasound. *Acta Radiologica, 40*, 41–44.

Hennessy, M., Heary, C., Laws, R., Van Rhoon, L., Toomey, E., Wolstenholme, H., & Byrne, M. (2019). The effectiveness of health professional-delivered interventions during the first 1000 days to prevent overweight/obesity in children: A systematic review. *Obesity Reviews, 20*(12), 1691–1707.

Hinde, K., & Milligan, L. A. (2011). Primate milk: Proximate mechanisms and ultimate perspectives. *Evolutionary Anthropology: Issues, News, and Reviews, 20*(1), 9–23.

Hodge, L., & Dufour, D. L. (1991). Cross-sectional growth of young Shipibo children in eastern Peru. *American Journal of Physical Anthropology, 84*, 35–41.

Hurtado, A. M., & Hill, K. R. (1990). Seasonality in a foraging society: Variation in diet, work effort, fertility, and sexual division of labor among the Hiwi of Venezuela. *Journal of Anthropological Research, 46*(3), 293–346.

Jeppesen, D., Hasselbalch, H., Lisse, I., & Ersboll., H. & Engelmann, M. (2004). T-lymphocyte subsets, thymic size and breastfeeding in infancy. *Pediatric Allergy and Immunology, 15*, 127–132.

Jones, J. C. (1990). A native movement and March in Eastern Bolivia: Rationale and response. *Development Anthropology Network, 8*(2), 1–8.

Knaul, F. M., & Frenk, J. (2005). Health insurance in Mexico: Achieving universal coverage through structural reform. *Health Affairs, 24*(6), 1467–1476.

Kraft, T. S., Stieglitz, J., Trumble, B. C., Martin, M., Kaplan, H., & Gurven, M. (2018). Nutrition transition in 2 lowland Bolivian subsistence populations. *The American Journal of Clinical Nutrition, 108*(6), 1183–1195.

Kramer, K. L. (2005). *Maya children: Helpers at the farm*. Harvard University Press.

Kramer, K. L. (2021). Childhood teaching and learning among savanna Pumé hunter-gatherers: Mismatch between foraging and postindustrial societies. *Human Nature, 32*(1), 87–114.

Kramer, K. L., & Greaves, R. D. (2007). Changing patterns of infant mortality and maternal fertility among Pumé foragers and horticulturalists. *American Anthropologist, 109*(4), 713–726.

Kramer, K. L., & Greaves, R. D. (2010). Synchrony between growth and reproductive patterns in human females: Early investment in growth among Pumé foragers. *American Journal of Physical Anthropology: The Official Publication of the American Association of Physical Anthropologists, 141*(2), 235–244.

Kramer, K. L., & Greaves, R. D. (2017). Why Pumé foragers retain a hunting and gathering way of life. In *Hunter-gatherers in a changing world* (pp. 109–126). Springer.

Kramer, K. L., & Veile, A. (2018). Infant allocare in traditional societies. *Physiology & Behavior, 193*, 117–126.

Kramer, K. L., Campbell, B. C., Achenbach, A., & Hackman, J. V. (2022). Sex differences in adipose development in a hunter-gatherer population. *American Journal of Human Biology, 34*(5), e23688.

Kuhle, S., Tong, O. S., & Woolcott, C. G. (2015). Association between caesarean section and childhood obesity: A systematic review and meta-analysis. *Obesity Reviews, 16*(4), 295–303.

Lee, P. C. (1996). The meanings of weaning: Growth, lactation, and life history. *Evolutionary Anthropology, 5*, 87–96.

Leroy, J. L., García-Guerra, A., García, R., Dominguez, C., Rivera, J., & Neufeld, L. M. (2008). The Oportunidades program increases the linear growth of children enrolled at young ages in urban Mexico. *The Journal of Nutrition, 138*(4), 793–798. PMID: 18356337.

Malina, R., Reyes, M., & Little, B. (2008). Epidemiologic transition in an isolated indigenous community in the Valley of Oaxaca, Mexico. *American Journal of Physical Anthropology, 137*, 69e81.

Manjang, B., Hemming, K., Bradley, C., Ensink, J., Martin, J. T., Sowe, J., et al. (2018). Promoting hygienic weaning food handling practices through a community-based programme: Intervention implementation and baseline characteristics for a cluster randomised controlled trial in rural Gambia. *BMJ Open, 8*(8), e017573.

Martin, M. (2017). Mixed-feeding in humans: Evolution and current implications. In *Breastfeeding: Anthropological approaches* (pp. 140–154). Routledge.

Martin, M. A., Garcia, G., Kaplan, H. S., & Gurven, M. D. (2016). Conflict or congruence? Maternal and infant-centric factors associated with shorter exclusive breastfeeding durations among the Tsimane. *Social Science & Medicine, 170*, 9–17.

Martin, M., Blackwell, A., Kaplan, H., & Gurven, M. (2019). Differences in Tsimane children's growth outcomes and associated determinants as estimated by WHO standards vs. within-population references. *PLoS One, 14*(4), e0214965.

Martínez-Cortés, G., Nuño-Arana, I., Rubi-Castellanos, R., Vilchis-Dorantes, G., Luna-Vázquez, A., Coral-Vazquez, R. M., et al. (2010). Origin and genetic differentiation of three Native Mexican groups (Purépechas, Triquis and Mayas): Contribution of CODIS-STRs to the history of human populations of Mesoamerica. *Annals of Human Biology, 37*(6), 801–819.

Mattison, S. M., & Sear, R. (2016). Modernizing evolutionary anthropology: Introduction to the special issue. *Human Nature, 27*(4), 335–350.

Mayneris-Perxachs, J., & Swann, J. R. (2019). Metabolic phenotyping of malnutrition during the first 1000 days of life. *European Journal of Nutrition, 58*(3), 909–930.

McDade, T. W., & Worthman, C. M. (1998). The weanling's dilemma reconsidered: A biocultural analysis of breastfeeding ecology. *Journal of Developmental and Behavioral Pediatrics, 19*, 286–299.

McDade, T. W. (2003). Life history theory and the immune system: Steps toward a human ecological immunology. *American Journal of Physical Anthropology: The Official Publication of the American Association of Physical Anthropologists, 122*(S37), 100–125.

Melnik, B. C. (2014). The potential mechanistic link between allergy and obesity development and infant formula feeding. *Allergy, Asthma & Clinical Immunology, 10*(1), 1–10.

Mendoza, B., García-Acosta, V., Velasco, V., Jáuregui, E., & DíazSandova, R. (2007). Frequency and duration of historical droughts from the 16th to the 19th centuries in the Mexican Maya lands, Yucatan Peninsula. *Climatic Change, 83*, 151–168.

Moreno-Altamirano, L., Hernández-Montoya, D., Silberman, M., Capraro, S., García-García, J. J., Soto-Estrada, G., & Sandoval-Bosh, E. (2014). The nutrition transition and the double burden of malnutrition: Changes in dietary patterns 1961-2009 in the Mexican socioeconomic context. *Archivos latinoamericanos de nutricion, 64*(4), 231–240.

Moore, S. E., Fulford, A. J., Sosseh, F., Nshe, P., Darboe, M. K., & Prentice, A. M. (2019). Thymic size is increased by infancy, but not pregnancy, nutritional supplementation in rural Gambian children: a randomized clinical trial. *BMC Medicine, 17*(1), 1–9.

Mueller, N. T., Mao, G., Bennet, W. L., Hourigan, S. K., Dominguez-Bello, M. G., Appel, L. J., & Wang, X. (2017). Does vaginal delivery mitigate or strengthen the intergenerational association of overweight and obesity? Findings from the Boston Birth Cohort. *International Journal of Obesity, 41*(4), 497–501.

Murphy, K., Weaver, C., & Berg, L. J. (2022). *Janeway's immunobiology* (10th ed.). W. W. Norton & Company.

Nabukeera-Barungi, N., Lanyero, B., Grenov, B., et al. (2021). Thymus size and its correlates among children admitted with severe acute malnutrition: A cross-sectional study in Uganda. *BMC Pediatrics, 21*, 1.

North, K., Gao, M., Allen, G., & Lee, A. C. (2022). Breastfeeding in a global context: Epidemiology, impact, and future directions. *Clinical Therapeutics, 44*(2), 228–244.

O'Connor, A. M., & Anderson, E. N. (2016). *K'oben: 3,000 years of the Maya hearth*. Rowman & Littlefield.

OCEI. (1995). *Censo Indígena de Venezuela 1992* (Tomo I). República de Venezuela, Presidencia de la República, Oficina Central de Estádisticas e Informatica.
Oluwafemi, F., & Ibeh, I. N. (2011). Microbial contamination of seven major weaning foods in Nigeria. *Journal of Health, Population, and Nutrition, 29*(4), 415.
Padmadas, S., Hutter, I., & Willekens, F. (2002). Weaning initiation patterns and subsequent linear growth progression among children aged 2-4 years in India. *International Journal of Epidemiology, 31*, 855–863.
Park, H., Hertz-Picciotto, I., Petrik, J., Palkovicova, L., Kocan, A., & Trnovec, T. (2008). Prenatal PCB exposure and thymus size at birth in neonates in Eastern Slovakia. *Environmental Health Perspectives, 116*(1), 104–109.
Patro-Gołąb, B., Zalewski, B. M., Polaczek, A., & Szajewska, H. (2019). Duration of breastfeeding and early growth: A systematic review of current evidence. *Breastfeeding Medicine, 14*(4), 218–229.
PIIE (2021). *What is globalization?* Peterson Institute for International Economics https://www.piie.com/microsites/globalization/what-is-globalization
Petrullo, V. (1939). The Yaruros of the Capanaparo River, Venezuela. *Bureau of American Ethnology Bulletin*.
Piperata, B., Spence, J., Da-Gloria, P., & Hubbe, M. (2011). The nutrition transition in Amazonia: Rapid economic change and its impact on growth and development in Ribeirinhos. *American Journal of Physical Anthropology, 146*, 1–13.
Popkin, B. M., Adair, L. S., & Ng, S. W. (2012). Global nutrition transition and the pandemic of obesity in developing countries. *Nutrition Reviews, 70*(1), 3–21.
Popkin, B. M., Corvalan, C., & Grummer-Strawn, L. M. (2020). Dynamics of the double burden of malnutrition and the changing nutrition reality. *The Lancet, 395*(10217), 65–74.
Ramírez-Carrillo, L. A. (2020). The thin broken line. History, society, andthe environment on the Yucatan peninsula. In H. Azcorra & F. Dickin-son (Eds.), *Culture, environment and health in the Yucatan peninsula: Ahuman ecology perspective* (pp. 9–36). Springer International Publishing.
Rapsomanikis, G. (2015). *The economic lives of smallholder farmers: An analysis based on household data from nine countries*. Food and Agriculture Organization of the United Nations.
Reyes-García, V., Paneque-Galvez, J., Bottazzi, P., Luz, A. C., Gueze, M., Macia, M. J., Orta-Martinez, M., & Pacheco, P. (2014). Indigenous land reconfiguration and fragmented institutions: A historical political ecology of Tsimane' lands (Bolivian Amazon). *Journal of Rural Studies, 34*, 282–291.
Reyes-García, V., Powell, B., Díaz-Reviriego, I., Fernández-Llamazares, Á., Gallois, S., & Gueze, M. (2019). Dietary transitions among three contemporary hunter-gatherers across the tropics. *Food Security, 11*(1), 109–122.
Rivera, J. A., Barquera, S., Campirano, F., Campos, I., Safdie, M., & Tovar, V. (2002). Epidemiological and nutritional transition in Mexico: Rapid increase of non-communicable chronic diseases and obesity. *Public Health Nutrition, 5*(1a), 113–122.
Rivera-Pasquel, M., Escobar-Zaragoza, L., & González de Cosío, T. (2015). Breastfeeding and maternal employment: Results from three National Nutritional Surveys in Mexico. *Maternal and Child Health Journal, 19*, 1162–1172.
Robertson, R. C., Manges, A. R., Finlay, B. B., & Prendergast, A. J. (2019). The human microbiome and child growth – First 1000 days and beyond. *Trends in Microbiology, 27*(2), 131–147.
Rosado, J. L., López, P., García, O. P., Alatorre, J., & Alvarado, C. (2011). Effectiveness of the nutritional supplement used in the Mexican Oportunidades programme on growth, anaemia, morbidity and cognitive development in children aged 12–24 months. *Public Health Nutrition, 14*(5), 931–937.
Rosenberg, K. R., & Trevathan, W. R. (2018). Evolutionary perspectives on cesarean section. *Evolution, Medicine, and Public Health, 2018*(1), 67–81.
Rosinger, A., Tanner, S., Leonard, W. R., & TAPS Bolivia Research Team. (2013). Precursors to overnutrition: the effects of household market food expenditures on measures of body composition among Tsimane' adults in lowland Bolivia. *Social Science & Medicine, 92*, 53–60.

Rosinger, A. (2015). Dehydration among lactating mothers in the Amazon: A neglected problem. *American Journal of Human Biology, 27*(4), 576–578.
Salzano, F., & Callegari-Jaques, S. M. (1988). *South American Indians: A case study in evolution*. Clarendon Press.
Sam, D. L., & Berry, J. W. (2010). Acculturation: When individuals and groups of different cultural backgrounds meet. *Perspectives on Psychological Science, 5*(4), 472–481.
Savino, W. (2002). The thymus gland is a target in malnutrition. *European Journal of Clinical Nutrition, 56*(Supp 3), 546–549.
Savino, W., & Dardenne, M. (2000). Neuroendocrine control of thymus physiology. *Endocrine Reviews, 21*(4), 412–443.
Savino, W., Durães, J., Maldonado-Galdeano, C., Perdigon, G., Cruz, D. A. M. D., & Cuervo, P. (2022). Thymus, undernutrition, and infection: Approaching cellular and molecular interactions.
Sedesol, C. E. I. (2010). Secretaria de Desarrollo Social. Consejo Nacional de Población e Instituto Nacional de Estadística Geografía Informática, Delimitación de las Zonas Metropolitanas de México, Secretaria de Desarrollo Social, Consejo Nacional de Población e Instituto Nacional de Estadística Geografía Informática.
Sellen, D. W., & Smay, D. B. (2001). Relationship between subsistence and age at weaning in "pre-industrial" societies. *Human Nature: An Interdisciplinary Biosocial Perspective, 12*(1), 47–87.
Serván-Mori, E., Contreras-Loya, D., Gomez-Dantés, O., Nigenda, G., Sosa-Rubí, S. G., & Lozano, R. (2017). Use of performance metrics for the measurement of universal coverage for maternal care in Mexico. *Health Policy and Planning, 32*(5), 625–633.
Shanley, D. P., Aw, D., Manley, N. R., & Palmer, D. B. (2009). An evolutionary perspective on the mechanisms of immunosenescence. *Trends in immunology, 30*(7), 374–381.
Smith-Oka, V. (2013). *Shaping the motherhood of indigenous Mexico*. Vanderbilt University Press.
Stinson, S. (1989). Physical growth of Ecuadorian Chachi Amerindians. *American Journal of Human Biology, 1*(6), 697–707.
Tracer, D. (2009). Breastfeeding structure as a test of parental investment theory in Papua New Guinea. *American Journal of Human Biology, 21*, 635–642.
Tully, K. P., & Ball, H. L. (2014). Maternal accounts of their breast-feeding intent and early challenges after caesarean childbirth. *Midwifery, 30*(6), 712–719.
United Nations Development Programme. (2021). *Human development report 2020: The next frontier-human development and the Anthropocene*. UN.
Uribe-Leitz, T., Barrero-Castillero, A., Cervantes-Trejo, A., Santos, J. M., de la Rosa-Rabago, A., Lipsitz, S. R., et al. (2019). Trends of caesarean delivery from 2008 to 2017, Mexico. *Bulletin of the World Health Organization, 97*(7), 502.
Urlacher, S. S., & Kramer, K. L. (2018). Evidence for energetic tradeoffs between physical activity and childhood growth across the nutritional transition. *Scientific Reports, 8*(1), 1–10.
Urlacher, S. S. (2023). The energetics of childhood: Current knowledge and insights into human variation, evolution, and health. *American Journal of Biological*. Anthropology.
Urlacher, S. S., Ellison, P. T., Sugiyama, L. S., Pontzer, H., Eick, G., Liebert, M. A., et al. (2018). Tradeoffs between immune function and childhood growth among Amazonian forager-horticulturalists. *Proceedings of the National Academy of Sciences, 115*(17), E3914–E3921.
Vadez, V., Reyes García, V., Godoy, R., Leonard, W., Huanca, T., & Byron, E. (2008). Income diversification of rural households: What role for agriculture? Household evidence from the Tsimane' Amerindians of the Bolivian Amazon. *Human Organization, 67*(4), 384–396.
Valeggia, C., Burke, K., & Fernandez-Duque, E. (2010). Nutritional status and socioeconomic change among Toba and Wichí populations of the Argentinean Chaco. *Economics and Human Biology, 8*, 100–110.
Varela-Silva, M. I., Dickinson, F., Wilson, H., Azcorra, H., Griffiths, P. L., & Bogin, B. (2012). The nutritional dual-burden in developing countries–how is it assessed and what are the health implications? *Collegium Antropologicum, 36*(1), 39–45.

Varga, I., Toth, F., Uhrinova, A., Nescakova, E., & Polar, S. (2009). Association among size of thymus, anthropometric dimensions and number of lymphocytes in peripheral blood in newborns from Slovakia. *Biomedical Papers of the Medical Faculty of the University Palacky, Olomouc, Czech Republic, 153*(3), 229–234.

Vega Mejía, N., Ponce Reyes, R., Martinez, Y., Carrasco, O., & Cerritos, R. (2018). Implications of the Western diet for agricultural production, health, and climate change. *Frontiers in Sustainable Food Systems, 2*, 88.

Veile, A. (2011). *The evolutionary ecology of human infancy* (The University of New Mexico). ProQuest Dissertations and Theses, 172.

Veile, A., Winking, J., Gurven, M., Greaves, R. D., & Kramer, K. L. (2012). Infant growth and the thymus: Data from two South American native societies. *American Journal of Human Biology, 24*(6), 768–775.

Veile, A., Martin, M., McAllister, L., & Gurven, M. (2014). Modernization is associated with intensive breastfeeding patterns in the Bolivian Amazon. *Social Science & Medicine, 100*, 148–158.

Veile, A., & Kramer, K. (2015). Birth and breastfeeding dynamics in a modernizing indigenous community. *Journal of Human Lactation, 31*(1), 145–155.

Veile, A., & Kramer, K. L. (2017a). Childhood body mass is positively associated with cesarean birth in Y ucatec M aya subsistence farmers. *American Journal of Human Biology, 29*(2), e22920.

Veile, A., & Kramer, K. L. (2017b). Shifting weanling's optimum: Breastfeeding ecology and infant health in Yucatan. In *Breastfeeding* (pp. 170–184). Routledge.

Veile, A., & Kramer, K. L. (2018). Pregnancy, birth, and babies: Motherhood and modernization in a Yucatec Village. In *Maternal death and pregnancy-related morbidity among indigenous women of Mexico and Central America* (pp. 205–223). Springer.

Veile, A., Faria, A. A., Rivera, S., Tuller, S. M., & Kramer, K. L. (2019). Birth mode, breastfeeding and childhood infectious morbidity in the Yucatec Maya. *American Journal of Human Biology, 31*(2), e23218.

Veile, A. J., Kramer, K. L., & Otárola-Castillo, E. (2022a). Household conditions modulate associations between cesarean delivery and childhood growth. *American Journal of Biological Anthropology, 179*(1), 85–103.

Veile, A., Christopher, L., Azcorra, H., Dickinson, F., Kramer, K., & Varela-Silva, I. (2022b). Differences in nutritional status between rural and urban Yucatec Maya children: The importance of early life conditions. *American Journal of Biological Anthropology, 178*(2), 205–222.

Wells, J. C., Sawaya, A. L., Wibaek, R., Mwangome, M., Poullas, M. S., Yajnik, C. S., & Demaio, A. (2020). The double burden of malnutrition: Aetiological pathways and consequences for health. *The Lancet, 395*(10217), 75–88.

WHO (World Health Organization) Multicentre Growth Reference Study Group, & de Onis, M. (2006). WHO Child Growth Standards based on length/height, weight and age. *Acta paediatrica, 95*, 76–85.

WHO (World Health Organization). (2011). *Exclusive breastfeeding for six months is best for infants everywhere*. World Health Organization; WHO Media Centre.

Yamasaki, E. (2020). Yucatec Maya language on the move: Considerations on vitality of indigenous languages in an age of globalization. In L. Siragusa & J. K. Ferguson (Eds.), *Responsibility and language practices in place*. Finnish Literature Society.

Yekeler, E., Tambag, A., Tunaci, A., Genchellac, H., Dursun, M., Gokcay, G., & Acunas, G. (2004). Analysis of the thymus in 151 healthy infants from 0 to 2 years of age. *Journal of Ultrasound Medicine, 23*, 1321–1326.

Yilmaz Semerci, S., Demirel, G., Baskan, O., & Tastekin, A. (2019). Is thymus size at birth associated with respiratory distress syndrome in preterm infants? *Journal of Neonatal-Perinatal Medicine, 12*(3), 265–269.

Zeyrek, D., Ozturk, E., Ozturk, A., & Cakmak, A. (2008). Decreased thymus size in full-term newborn infants of smoking mothers. *Medical Science Monitor: International Medical Journal of Experimental and Clinical Research, 14*(8), CR423–CR426.

Zycherman, A. (2013). *The changing value of food: Localizing modernity among the Tsimane' Indians of lowland Bolivia*. Dissertation, University of Columbia.

Zycherman, A. (2015). Shocdye' as world. *Food, Culture & Society, 18*(1), 51–69.

Chapter 4
Tuberculosis in Children: A Perspective from Life History Theory

Anaximandro Gómez-Velasco, Sudip Datta Banik, and Héctor Javier Sánchez-Pérez

4.1 Introduction

Infancy, childhood, juvenile, and adolescence are the critical periods of human growth and development. During infancy, investment in growth and development is maximal with a prolonged period of relatively slow and steady growth in childhood and juvenile stages, and an acceleration of height growth and other body dimensions throughout adolescence (Bogin, 2020; Bogin & Holly Smith, 1996; McDade et al., 2008). Thus, during these periods, energy intake is an important factor not only for adequate growth, but also for the development of other body's function, for example the immune system (McDade, 2003).

The allocation principle states that in any environment and at any time, organisms have limited time and energy to maximize their fitness. Therefore, allocation of energy to different biological functions is critical. Growth, reproduction, and maintenance are the main functions of any organism (Said-Mohamed et al., 2018). Energy available to an organism is finite, implying that any expenditure on one function leaves fewer energy to be allocated to the body's other functions and it generates trade-offs. For example, if a certain amount of energy is used for growth, it cannot be used for reproduction/or maintenance (Said-Mohamed et al., 2018). Energy is necessary for all organisms to survive and each organism has a limited amount of obtainable energy. Thus, trade-offs are fundamental in an organism to maintain and develop other biological functions simultaneously (Garcia et al., 2020; McDade et al., 2016). Organisms must take the energy through nutrition and allocate

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S. Datta Banik (ed.), *Human Growth and Nutrition in Latin American and Caribbean Countries*, https://doi.org/10.1007/978-3-031-27848-8_4

it towards their growth, reproduction and maintenance, and competition with other individuals as well as natural enemies (e.g. pathogens). On the other hand, organisms have a limited amount of obtainable and usable energy and it is determined by the environment (Garcia et al., 2020; McDade et al., 2016). However, individuals in a population might have variation in resource acquisition; individuals with better access to resources can circumvent trade-offs and this phenomenon depends on environment. Individual variation in access and quality of resources can mask trade-offs (Bolund, 2020).

Environment plays an important role in the allocation of energy across organism's functions. Organisms often experience variability in their environments which affects body's function. Consequently, organisms have to adjust life history priorities in an ongoing lifecycle that mediate trade-offs between the traits. Extrinsic mortality risk, defined as the probability of death from exogenous sources in the local environment, is an important driver of variation in life history strategies. In the ecological context, infectious diseases are considered as extrinsic mortality risk. Microbial invasion activates immune function, and this represents a body's physiological function with primary responsibility to survive. In environments with high degree of pathogens, individuals allocate energy to activate immune system function (McDade, 2003).

Infectious diseases have been studied from biomedical and epidemiological perspectives. From the biomedical approach, research has been undertaken to understand the interaction between a pathogen and its host at molecular and cellular levels seeking to enhance immunity and to provide treatment (McDade et al., 2016). The epidemiological approach has been able to provide answers of how infectious diseases are related to risk factors in order to reduce morbidity and mortality (McDade et al., 2016).

Life-history theory (LHT) approach provides a different biological framework to understand how an organism allocates energy to primary life functions: growth, reproduction and maintenance and how these traits are related in time and space within ecological and evolutive contexts (Bogin et al., 2018; McDade et al., 2016). Infectious diseases represent a high cost in energy allocation during different periods of human life but it might be more crucial during the early periods of human growth: infancy and childhood (Lochmiller & Deerenberg, 2000; McDade, 2003). Throughout these periods of human life, there is a strong selective pressure against morbidity and mortality, therefore, early investment in immune function is prioritized despite consequences for competing energetic requirements for other body's function such as growth with later repercussions in survival and reproduction (Garcia et al., 2020). During infection, the activation of the immune system is crucial for survival of an organism, but it is costly due to the resources and energy allocation to perform its functions. Infectious diseases represent a major selection pressure with respect to the development of immunity, and as an indicator of the immune system's ability to provide protection against pathogens (McDade et al., 2008).

The immune system represents a primary physiological system that plays an essential role in survival and it is considered as a component of maintenance

(McDade et al., 2016). Human immune system has two interdependent subsystems that are activated during infectious diseases: innate and acquired immunity. Each subsystem is activated at different lifecycle and it is shaped by: (i) the availability of nutritional resources, (ii) the intensity of pathogen exposure, and (iii) signals of extrinsic mortality risk (McDade et al., 2016). Both subsystems operate in a coordinated fashion with other body's systems (e.g. endocrine). There are differences between the subsystems. Innate immunity, or non-specific subsystem, provides resistance to disease without recognizing specific pathogens, and includes anatomical barriers, antimicrobial soluble proteins, natural killer cells and phagocytic cells (neutrophils, macrophages, dendritic cells). This subsystem includes inflammatory response that involves acute phase response proteins (i.e. C-reactive protein, hemoxygenase 1, haptoglobin) and the recruitment of phagocytic cells to the site of infection (Goldsby et al., 2003). On the other hand, acquired immune, or specific subsystem, is capable of recognizing and selectively eliminate specific foreign microorganisms and molecules (i.e. antigens) and has four characteristics: (i) antigenic specificity, (ii) diversity, (iii) immunologic memory, and (iv) self/non-self-recognition (Goldsby et al., 2003). Adaptive immunity responds to the challenge with a high degree of specificity as well as the remarkable property of memory.

Both immune subsystems work together to eliminate foreign invaders with implications for trade-offs in immune investments. The activation of both subsystems is highly expensive because it requires to fuel acute phase response, proliferation of lymphocytes, antigen-presenting cells, among others, and the production and release of immunoglobulins, cytokines and those cellular and molecular processes, which require energy and biochemical substrates (i.e. amino acids, lipids) (Lochmiller & Deerenberg, 2000; McDade et al., 2016). This metabolic expenditure may require long-term energy intake (i.e. in chronic infection). In an environment with adequate resources (energy intake or energy stores), the allocation of energy for both growth and maintenance would be optimized and invested for both traits. However, in resource-poor settings, the effects of poor nutrition will be traduced in strong energetic trade-offs between growth and development of immune system in the early stages of life in humans, given that both require substantial energetic investment (Garcia et al., 2020).

Trade-offs between growth and immune system might represent either short-term accommodations to temporary resource shortages, or long-term phenotypic adjustments to expected future conditions (Garcia et al., 2020). In the short-term, there are direct energy expenditure during immune system activation, phenotypic (e.g. anorexia) and physiological responses that may cause sick infants, children and juveniles to eat and adsorb less nutrients, reducing energy available for growth (McDade et al., 2008). On the contrary, long-term adjustments are expected to occur in simultaneous traits such as growth and maintenance; the high cost of immune activation and function, when energy shortages are met, energy is allocated to immune system and diverted from growth (McDade et al., 2008). In a long-term infection, investment in the adaptive immune system confers long-lasting specific immunity that would be critical for survival. But this investment carries growth-immune trade-offs since adaptive immune function is negatively associated with child height and weight (Garcia et al., 2020). This long-term phenomenon may be observed in chronic infectious diseases.

Infectious diseases are among the largest contributors of morbidity and mortality in children. Globally, infectious diseases were still responsible for more than 10.2 million deaths in 2019, representing 18% of all deaths (Paulson et al., 2021). Under-five mortality (U5MR) and neonatal mortality (NMR) rates are important indicators reflecting multiple aspects of a society's wellbeing such as access to food, nutrition, and health, among others (Paulson et al., 2021). In 2019, deaths of infants and children below 5 years of age was 5.05 million (Paulson et al., 2021). Of these deaths, 2.42 million occurred among neonates (aged <28 days) (Paulson et al., 2021). The leading causes of global U5MR in 2019 were lower respiratory infections (13.3%) and diarrheal diseases (9.9%) (Paulson et al., 2021). Among the respiratory infections, tuberculosis (TB), a major cause of disease and death in children from TB-endemic areas, was often confused with bacterial pneumonia (Thomas, 2017). In 2019, worldwide 10 million people fell ill with TB, from which 1.2 million were children (<15 years of age) (WHO, 2021). Furthermore, in 2019, TB caused 1.4 million deaths, of which 224,000 were infants, children, juveniles and adolescents (<15 years of age) (WHO, 2021). In 2021, globally 10.6 million people suffered from TB, among them 1,166,000 (11%) were children below 15 years of age (WHO, 2022). Furthermore, in 2021, TB caused 1.4 million deaths, of which 187,000 were infants, children, juveniles and adolescents (<15 years of age) (WHO, 2022). However, World Health Organization (WHO) states that there is a lack of quality data for this group due to: difficulty in diagnosing TB in infants, children, and juveniles; cases are mainly diagnosed in hospitals, cases not reported to the national programs of TB, and scarcity of nationwide survey (WHO, 2021). In a recent study, using a mathematical model taking into account TB pediatric natural history, mechanisms and risk factors for infectious exposure (HIV, malnutrition, and BCG non-vaccination), the probability of infection in a given exposure, and progression to disease among infected individuals, the authors estimated that in 2019 there were 997,500 cases in infants and children, with 481,000 cases among those aged 0–4 years and 516,500 cases in juvenile and adolescent stages (5–15 years). This study highlights that TB in children are substantially underdiagnosed and underreported (Yerramsetti et al., 2022).

Usually, *Mycobacterium tuberculosis*, the bacteria causing human TB, is acquired following exposure to a household contact with pulmonary tuberculosis (PTB). Children infected with *M. tuberculosis* may lead to an active disease, with a strong immunological response as showed by acute-phase response (APR) (Schaaf et al., 2012), activation of alveolar macrophage, recruitment of neutrophils and other cell lines in response to infection (Seddon et al., 2018), with extrapulmonary manifestations or disease containment. The infection in most infants and children remains latent, but if environmental and host conditions are adequate for *M. tuberculosis*, it can evolve to the active disease at any time of life. Infants and children infected with *M. tuberculosis* may tend to reduce appetite, manifest weight loss and experience nutrient (macro and micro) malabsorption, and altered metabolism leading to malnutrition (Jaganath & Mupere, 2012). Although *M. tuberculosis* infects mainly the lungs, the bacilli can spread to other organs. To contain the infection, host's immune system works to encapsulate the bacilli in the granuloma, which is a highly organized cell structure formed by a diversity of cells (dendritic cells, macrophages, epithelial cells, multinucleated giant cells, myeloid cells, T and B lymphocytes) (Russell, 2007). In the granuloma, there is also activation of reactive oxygen species, lipids, eicosanoids, etc. Despite robust cellular immune response to bacterial containment, *M. tuberculosis* can survive inside macrophages by arresting the normal maturation of their phagosome mediated by both cell-wall lipids and other bacterial effectors (Russell, 2007). The pathogen uses resources from host (i.e. cholesterol and lipid bodies) to maintain a chronic infection, which in turn, may be associated with systemic immune activation and wasting (Tellez-Navarrete et al., 2021). TB may lead to a chronic infection and it may decrease nutrient intake as well as internal diversion for metabolic responses to infection, increased basal metabolic rate when fever is present due to immune system activation (Salam et al., 2015). Hence, a long-term *M. tuberculosis* chronic infection may lead to impaired growth in children.

There are factors that impede effective mycobacterial containment: malnutrition, human virus immunodeficiency (HIV) co-infection, and anti-tumor necrosis factor (TNF) therapy (Tellez-Navarrete et al., 2021). Malnutrition is a significant risk factor for childhood TB and can lead to secondary immunodeficiency that increases the host's susceptibility to TB infection (Jaganath & Mupere, 2012). WHO has defined malnutrition as the imbalance between the intake of nutrients and energy and the body's requirement to ensure homeostasis, specific functions, and, in the case of children, their growth (WHO, 2022e). Fetal and infant body growth is particularly sensitive and responsive to the environmental conditions (Kuzawa, 2005). Increase of length/height of an infant, child or juvenile is often interpreted as a measure of age-specific energetic investment in growth (Bogin, 2020; Bogin & Holly Smith, 1996). The adequacy of growth in infancy, childhood, juvenile and adolescence can be assessed by calculating height-for-age z scores (HAZ), weight-for-age z scores (WAZ), weight-for-height z scores (WHZ) and body mass index (BMI) z scores using WHO children growth standards (WHO, 2022c) and growth references (de Onis et al., 2007). Growth standard is an indicator of how healthy infants and children (up to 60 months) should grow, whereas growth references indicate how the measured infants and children grow (from the 5 to 19 years age group) (Bogin, 2020).The relationship between growth, nutrition and *M. tuberculosis* infection can be examined through these standards and references (DeAtley et al., 2021; Ibrahim et al., 2017; PHR et al., 2006).

In this chapter, we use conceptual life-history theory (LHT) to analyze infancy**,** childhood, and juvenile physical growth and maintenance, immune function, and explore the interrelationships between these human traits, nutrition, and tuberculosis. We begin with analyzing the trade-offs between growth and immune system in infancy**,** childhood**,** and juvenile stages. Then, we develop and apply LHT to understand the interrelationships between growth, nutrition and tuberculosis. Finally, we explore and discuss the implications of LHT in populations of Latin American countries (LA) with high burden of tuberculosis, using the reports of population-based studies.

4.2 The Immune System in Infancy, Childhood, and Juvenile Stages

Human life can be divided into stages separated by physical, physiological and behavioral transitions: fetal, infancy, childhood, juvenile, adolescence and adulthood (Bogin, 2020; Bogin & Holly Smith, 1996; Crespi, 2011; Hochberg, 2009; McDade, 2003). Each stage is characterized by its own pattern of feeding, growth, cognitive-affective, social, brain development, and immune system development. The fetal, infancy, childhood and juvenile stages are considered as critical windows of developmental plasticity in growth and development in humans (McDade, 2003). During these stages, innate and adaptive immune systems are not fully developed yet, and infectious disease morbidity and mortality risks are high, reflecting the competing life-history of these periods. Growth is considered as a continuous biological phenomenon and varies between and within human populations, but it is more likely subjected to trade-offs and that there are coordinated developmental changes across various systems (height, weight, immune status, among others) that vary by both chronological and maturational age which can mask trade-offs (Bolund, 2020; Garcia et al., 2020).

Despite the existence of vaccination programs, which stimulate protective immune responses, infants and children may still acquire viral, bacterial, fungal and parasitic infections that have to be fought off and controlled by immune responses. For the purpose of this chapter we focus on mortality and morbidity in infancy, childhood, and juvenile stages due to TB (Dodd et al., 2014; Jenkins et al., 2017), with some brief mention of the fetal stage.

4.2.1 Fetal

During fetal growth, mammals highly depend on maternal allocation of resources. Pregnancy requires high energy requirements to maintain both mother and fetus, hence, it is energetically costly as well as a period of high metabolic plasticity that allows for the normalization of energy balances to accommodate energy demands. Maternal undernutrition contributes to fetal growth restriction, which increases the risk of neonatal deaths and, for survivors, stunting (low height-for-age) by 2 years of age (Black et al., 2013). Furthermore, prenatal undernutrition is associated with low immune function, with implications for immune development and function in the long-term that may last through adolescence and adulthood (McDade, 2003).

Thus, children whose mothers are malnourished would have a decrease in the development of their immune system with higher risk to suffer from infectious diseases (Kuzawa, 2005).

On the other hand, the fetal environment has been considered as a sterile environment in which pathogen exposure is minimum and the fetus can devote all available resources for growth and development in preparation for the transition to postnatal life (McDade, 2003). However, congenital TB infection, as well as other pathogens such as Zika virus and the severe acute respiratory syndrome coronavirus 2 (SARS-Cov-2), may be acquired via the placenta. In the case of TB, fetus may acquire *M. tuberculosis* when a mother develops hematogenous TB dissemination during pregnancy, which may be overt (as a result of advanced maternal disease) or occult following recent primary infection in the mother, sometimes signified by a pleural effusion in pregnancy (El-Arabey & Abdalla, 2021; Yeh et al., 2019; Zanluca et al., 2018). Pregnant women with active TB have been associated with poor clinical features and outcomes of the offspring such as preterm birth, low birth weight, birth asphyxia and perinatal death (Sobhy et al., 2017).

4.2.2 Infancy

The period of the infancy is defined by the stage that starts from birth until 3 years of age (Bogin, 2020; Bogin & Holly Smith, 1996). Following birth, a neonate leaves the sterile environment to be quickly exposed to a new environment (i.e pathogens, nutrition, etc.). Infancy represents the human stage when growth is directly and strongly dependent on nutrition. Breastfeeding has been recognized to decrease individual morbidity and mortality and to benefit growth, health, short and long-term well-being of children (Khan et al., 2015). Breast milk has two functions: (i) primary source of nutrition (early energy intake) and (ii) passive immune properties that help the neonate for rapid growth and to fight against infectious diseases (McDade, 2003).

During this life cycle, energetic demands are intense: growth increase and immune system is activated and upregulated. Rates of growth are rapid, particularly in the first year of life when an infant may gain 20–25 cm in length and 5 kg or more in weight (McDade, 2003). Weight is mainly devoted to the deposition as adipose tissue (Adair et al., 2013). Furthermore, it has been estimated that brain development represents an intrinsic energetic cost as high as 87% of metabolic expenditure in the first months after birth (Leonard et al., 2007).

During the first months of this period, the efficacy of immune system is hindered by the untrained innate and adaptive immune subsystems. At 8 weeks post-conception, macrophages, granulocytes, and NK cells are the cellular components of the innate immune system (O'Connell et al., 2021). For example, neonatal macrophages have reduced expression of the co-stimulatory molecules CD86 and CD40 leading to poor response to interferon gamma (IFN-γ). This impaired response leads to a diminished ability for neonatal macrophages to phagocytose pathogens and to activate T cells. Despite functional immaturity of the macrophage lineage in neonates at birth, the macrophages are one of the quickest cellular immune components to mature and approximates adult function within a few weeks. Moreover, since T and B lymphocyte repertoire are naïve, thus, there is increasing potential vulnerability to infectious diseases (O'Connell et al., 2021). Immune system among infants matures when it begins to learn about the local disease ecology, encounters pathogens, and acquires specific immune defense mechanisms that might endure beyond the period when passive immunity is no longer operative. The diversity and intensity of pathogen exposure is likely to be a key factor in defining the life history trade-offs between growth and immune system. Among infants, we might expect to see a trade-off between the investment in growth and immune function: infants who invest more energy in fighting infections will have less energy available for growth (McDade, 2003; McDade et al., 2016).

4.2.3 Childhood

Childhood has been defined as age group of 3–6.9 years up to the initiation of gonadal steroid production presaging puberty (Bogin, 2020; Bogin & Holly Smith, 1996). The transition from infancy to childhood is also defined by weaning, which takes place relatively early in humans, therefore, breastfeeding is no longer a source of nutrition or immunological resource. The child must rely on developing a functional immune system (Crespi, 2011; McDade, 2003).

In this life stage, resources are not diverted equally for both growth and immune system, and substantial trade-offs are expected to occur given the fixed amount of available energy. There is significant growth effort and increase of investment to immune function; the association of both traits may have impacts on individual's growth in environments where resources are scarce. However, this trade-off is less stringent for individuals with high or adequate resources: energy available in the body or in the environment will increase an individual's ability to afford both growth and maintenance (i.e. functional immune system) (McDade, 2003).

During this stage, adaptive immune system becomes important since a child faces new environments and encounters microorganisms and antigens, hence, educating the immune system and driving maturation and clonal expansion of T and B lymphocytes requires substantial energy expenditure. Both set of cells are important because they produce and display antigen-binding cell-surface receptors. Natural killer cell function normalizes around the age of 5 years (Guilmot et al., 2011) and changes as children progress into juvenile and adolescence stages, switching from IFGγ-producing to more cytotoxic cells (Guilmot et al., 2011; Manser & Uhrberg, 2016).

Excessive exposure to, as well as the diversity of pathogens, would require an increase in maintenance effort with a negative effect on growth. Diverse studies conducted among children of the T'simane, an indigenous Amazonian population in Bolivia, where high levels of infectious diseases have demonstrated the trade-offs between growth and immune activation. The first study that determined elevated C-reactive protein (CRP), as indicator of innate immune response, predicted smaller gains in height over a period of 3 months, at the costs to growth particularly high for 2–4 years old and for those with low energy reserves (in the form of body fat) at the time of immunostimulation (McDade et al., 2008). A second study estimated the levels of IgE in correlation with parasitic infection (helminths). The IgE profiles were characterized by a rapid increase before age five, a peak in the juvenile or adolescent period, and a decrease into adulthood (Blackwell et al., 2011). Higher total IgE levels are associated with poorer growth and shorter adult stature, suggesting a growth trade-off and higher investment to the immune response (Blackwell et al., 2010). A recent study carried out among infants and children aged 2 months to 8 years from the T'simane, estimated the trade-offs between height and immune function (Garcia et al., 2020). Using the relative balance of investment into adaptive cellular immunity (i.e. B and T cell counts) to innate cellular immunity (i.e. NK cell counts) as a proxy for long-term investment in higher immune responses, the trade-offs between age, height and immune function were determined. Total T cells and all subsets (naïve and non- naïve; CD4; CD8) and B cells significantly declined with age (Garcia et al., 2020).

4.2.4 Juvenile

This stage is considered as age group 7–9 years and concludes with readiness for sexual maturation process (Bogin, 2020; Bogin & Holly Smith, 1996). In this phase, there is a decline in the rate of growth signifying a transition to a new life stage, giving juvenility the slowest growth rate since birth (Bogin, 2020; Hochberg, 2008). At this stage, immune function continues the trends of childhood where declining T and B lymphocyte numbers proliferative responsiveness, and thymic volume approach their adult levels. The proportion of naïve lymphocytes continues to drop as clonal selection increases the proportion of memory lymphocytes following continued pathogen encounters. This maturation process helps to enhance the immune system (Garcia et al., 2020; McDade, 2003).

At the physiological level, the transition to juvenility begins with adrenarche followed by gonadarche. During adrenarche, adrenal androgens (AA) production, mainly dehydroepiandrosterone (DHEA) and its sulfate form (dehydroepiandrosteronesulphate, DHEAS) are highly produced (Hochberg, 2008). Adrenarche represents an early stage of sexual maturation, distinct from hypothalamic-pituitary-gonadal maturation and function during adolescence; the adrenal cortex secretes increased levels of the hormones DHEA and DHEAS. Studies have demonstrated that normal T cell function may be critical for the production of adrenal androgens (Chen & Parker, 2004; Wolkersdörfer et al., 1999). Furthermore, maturation of the adrenal gland during adrenarche for androgen production in the cells of the zona reticularis may be related to the expression of major histocompatibility complex (MHC) class II molecules on these cells. Perhaps the expression of these MHC class II molecules facilitates interactions between cells in the zona reticularis and immune cells such as lymphocytes, leading to alterations in androgen production (Marx et al., 1997).

On the other hand, production of oestradiol signals the maturation of reproductive organs and secondary sex characteristics during gonadarche. In addition, leptin, an adipocyte produced hormone that regulates energy expenditure and indicates the body to be prepared for sexual maturation, increases at the beginning of puberty (Kiess et al., 1999). Table 4.1 shows all stages discussed and highlights growth indicators and general immune characteristics.

Table 4.1 Life history stages in human defined by time lapse, growth indicators and general immunological characteristics

Stage and time lapse	Growth indicators	General immunological characteristics
Infancy (from birth to 3 years old)	An infant may gain 20–25 cm in length and 5 or more kg in weight. Hormonal systems that mediate growth, mainly insulin-like growth factor 2(IGF2), insulin (INS) and insulin-like growth factor 1(IGF1) in the fetal and early-infancy periods are up-regulated.	Elevated levels of CRP in high pathogen environment. Thymic cortical volume, the number of T and B lymphocytes is 3–4 times higher than in adults. Whilst babies are born with an underdeveloped immune system due to low antigen exposure *in utero*, they experience rapid antigen exposure immediately following birth. During this period, both arms of the innate and adaptive immune system mature. Monocyte and DC maturation occurs during the first year of life. Levels of NK cells average $500/mm^3$, with important variations between individuals (reported levels ranging from 20 to 1600 NK cells/mm^3), but NK cell levels then rapidly decrease by 2–3 times in the blood of newborns few days after delivery and continue to progressively decline during childhood, reaching adult levels (mean of 200 NK cells/mm^3) around 5 years of age.
Childhood (from 3 to 6.9 years old)	Rate of growth significantly decreases and proceeds at steady rate of 5–8 cm per year through stage. Growth becomes increasingly regulated by the GH-IGF1 axis (Growth Hormone-Insulin-like growth factor-I), and less controlled by IGF2 (insulin-like growth factor 2) and INS.	Thymic cortical volume, the number of T and B lymphocytes decline from their peak levels in infancy. Certain immunoglobulins increase their concentration, i.e. IgE peaks its concentration before age 5 years old in response to helminths.
Juvenile (from 7 to 9 years old)	GH-IGF-1 axis activity is enhanced in parallel with the rise in adrenal androgens; there is an increase in leptin levels, suggesting an association between body fat and transition to juvenility.	NK cell function changes in this stage, switching from IFNγ-producing to more cytotoxic NK cell lines. The expression of major histocompatibility complex (MHC) class II molecules on these cells could help to facilitate interactions between cells in the zona reticularis and immune cells such as lymphocytes leading to alterations in androgen production.

4.3 LHT Hypotheses Between Growth, Nutrition and Tuberculosis

Studying the interrelationships between growth, nutrition, immune function and infectious diseases such as TB in the early human life stages to address trade-offs is complex due to:

4.3.1 Energy and Life History Traits (Growth, Maintenance) Are Not Stable Over Time, Particularly During Early Periods of Human Development

The classical Y model for resource allocation has been employed to identify the result of investment choices of limited energy budgets between two traits. Demonstrating trade-offs in human populations have proven to be empirically challenging because comparing different individuals with respect to two life history traits would be different because resource access varies among individuals. The assumption of Y model is that resource acquisition to a function vary independently of each other (Bolund, 2020). But this is not always the case because resource allocation and acquisition depend on the resource environment. Variation between individuals in resource acquisition means that individuals with better resource access can circumvent trade-offs (Bolund, 2020).

Functional trade-offs can also involve simultaneously competing functions, for example, nutrition and immune system. Early nutrition in the form of breast milk, is an important source of energy and nutrients in infants aged 0–6 months and has immune properties that modulate inflammation while promoting innate immunity in the mucosa (WHO, 2022d). Thus, maternal nutrition and her ability to confer protection have large implications on the development of a functional innate immune system in the infant. Despite this biological benefit, breastfeeding in the contemporary world is decreasing; in low- and middle-income countries, only 37% of children younger than 6 months of age are exclusively breastfed (Victora et al., 2016). Breast milk is also a critical source of energy and nutrients during illness and reduces mortality among children who are malnourished. However, infants who are not breastfed are more susceptible to respiratory infectious diseases such as TB. It has been observed that poor nutrition affects negatively the function of immune system, both innate and cell-mediated. Malnutrition is thought to contribute to TB susceptibility and disease progression in infants and children, however, it is difficult to unravel this process *in vivo* once the child has active disease (Jaganath & Mupere, 2012).

Thus, breastfeeding has been considered to offer protection against illness, including TB during infancy and childhood. However, this may not be the case when children are in close contact with adults having TB. In a study carried out in Lima, Peru, the authors found that 22% of children, aged 6–59 months, were diagnosed with TB and 72% were exclusively breastfed for 6 months whose close TB contact was their mother. This raises the possibility that children who are breastfed by mothers with TB may be at increased risk for TB, given the close contact (Flores et al., 2021).

4.3.2 Variation in Infection Risk over Space and Time

Human populations with high TB prevalence may be more prone to be infected with *M. tuberculosis* due to a combination of risk factors such as contact probability and susceptibility, nutritional status, environmental conditions, and vaccination status. This variation alters the strength and form of selection across populations and over time (Seppälä, 2015). For example, in the Highlands region of Chiapas, Mexico, geographical information systems were used to assess the spatial and temporal distribution of tuberculosis across 19 municipalities. There was marked variation on the incidence rate of TB in the region. For example, in 1998, there were eight municipalities (44%) with twice the incidence rate in comparison with the state and Mexican national levels, but in 2012 there was only one municipality. Furthermore, clusters of two municipalities with high incidence of TB were identified: one grouped from 1998 to 2000 period, and the second one from 2006 to 2007 (Gómez-Velasco et al., 2014). This spatial and temporal TB variation illustrates the heterogeneity of risk infection within and between human populations. Due to this variation, the optimal defense strategy maximizing fitness can be context dependent.

4.3.3 Host Susceptibility

Human genotypic and phenotypic variations influence immune system against a particular pathogen. For natural selection to cause the evolution of any trait, including susceptibility to an infectious disease, there must be both genetic and phenotypic variations among individuals; therefore, immune function must vary between individuals (Seppälä, 2015). In the case of TB, both conditions appear to be satisfied. Several lines of evidence suggest that individuals within a single human population vary genetically in their susceptibility to the infection and mortality from *M. tuberculosis*. The human host response is quite variable within and between individuals as well as in populations and it depends on different biological traits: age, sex, nutritional status, immune system and vaccination status (Barry et al., 2009).

Epidemiological, clinical and genetic investigations have indicated that the host's genotype and phenotype components contribute to TB susceptibility and resistance. Clinical evidence in humans have demonstrated that *M. tuberculosis* infection is a continuous spectrum extending from sterilizing immunity, to subclinical active disease, to fulminant active disease, with conventional designations of latent infection and active disease corresponding to partially overlapping regions of biological heterogeneity (Barry et al., 2009). This TB spectrum gives a range of phenotypic variation in immune response in humans. Not all individuals exposed to *M. tuberculosis* will become infected depending on the infection pressure, many will remain free from infection. In the case of immediate bacterial clearance, or complete resistance to infection (observed in a small fraction of the population), the innate immune system will inactivate *M. tuberculosis* at the site of infection without activation of the acquired immune response. These individuals, named innate resisters, will remain negative to the TB serological tests (tuberculin skin test, TST, or Interferon Gamma Assays, IGRAS). On the other hand, most individuals infected by *M. tuberculosis* will remain asymptomatic and contain the bacterium, and enter a stage termed as latent TB infection (LTBI), inferred from the measures of acquired anti-mycobacterial immunity, such as TST and/or IGRAs. These individuals are named as non-progressors, possibly due to an exceptionally well-contained infection or absence of viable bacteria in the granuloma (Möller et al., 2018).

Furthermore, in high TB prevalence regions there also exists interindividual level variation. Among infants and children, TB is often disseminated due to early hematogenous spread of the *M. tuberculosis* after primary pulmonary infection. The most severe forms of TB are found in children (from the perspective of natural selection before reproductive age) and are generally lethal. Among infected children, the risk of developing the clinical disease is around 50% in infants and 25% in children between 2 and 5 years of age (Dodd et al., 2014). On the contrary, among adults, the infection is often limited to the lungs and reflects the reactivation of latent TB from a silent primary infection (Alcaïs et al., 2005).

At the genetic level, variations in the susceptibility to TB have been associated with polymorphisms in a number of genes, including those for the vitamin D receptor, natural resistance-associated macrophage protein 1 (NRAMP1), class I and class II major histocompatibility complex loci, interleukin-1 and its receptor antagonist, interferon and its receptor (Abel et al., 2018).

4.3.4 M. tuberculosis *Diversity*

Pathogen diversity also determines the efficiency of immune system (Seppälä, 2015). Characteristics of *M. tuberculosis* affect the form and strength of selection on immune defense traits: virulence. The long co-evolutionary history of humans and *M. tuberculosis* may have resulted in a sustained but carefully balanced host-pathogen interactions. However, TB disease depends on various host-related factors (e.g. immunological competence, age, nutritional status, vaccine status), pathogen (e.g. strain virulence), and environmental factors (e.g. intensity of exposure) (Gagneux, 2018).

Genomic studies show that the *M. tuberculosis* Complex (MTBC) is comprised of the five human-adapted lineages representing *M. tuberculosis* sensu stricto (L1–4, and L 7), two other human-adapted lineages traditionally referred to as *M.*

africanum (L5-6) and at least nine animal-adapted lineages (Brites et al., 2018). The worldwide distribution of these lineages is variable. Lineages 2 and 4 are the most widely distributed: lineage 2 (also known as East Asian lineage that includes the Beijing family of strains) predominates in East Asia, but is also present in Central Asia, Russia and South-Africa, whereas lineage 4 (also known as the Euro-American lineage) occurs frequently in populations from Asia, Europe, Africa and the Americas (Brites et al., 2018).

In general, *M. tuberculosis* genomic diversity has impacts on host immune regulation, disease severity, disease presentation and transmission (Coscolla & Gagneux, 2014). Virulence in TB can be conceptualized as a complex host-pathogen interaction comprising (i) the ability of the bacteria to survive in face of the host immune responses, (ii) their capacity to cause lung damage and infect other organs, (iii) ability to survive the aerosolization process outside of the host, (iv) capacity to successfully transmit to and infect a new host, and (vi) the unique and complex *M. tuberculosis* cell wall which stimulates and modulates host's immune system (Coscolla & Gagneux, 2014).

Genomic studies have evidenced that *M. tuberculosis* strains might be geographically adapted to the local human host population. Local adaptation refers to the phenomenon in which a pathogen that is adapted to one host species has a reduced capacity to spread among other host species (Gagneux, 2018). In the perspective of evolution, human populations with little or no known past exposure to the TB bacterium, such as the indigenous populations of the Americas and sub-Saharan Africa, have a significantly higher TB morbidity and mortality than non-indigenous populations whose ancestors had a longer (millennia) mycobacterial exposure time (Möller et al., 2018). *M. tuberculosis* is an obligate pathogen that manipulates human immune system to promote its replication and spread, as well as local adaptation to the immunological characteristics of its specific host population. Hence, numerous characteristics derived from epidemiological and genomic studies of human TB are consistent with local adaptation, but the effect of social factors should be considered as a possible confounding elements (Gagneux, 2018).

4.3.5 Diverse Clinical Variation of TB in Children Is Determined by Age and Sex

In adults, the most frequent form of TB is pulmonary tuberculosis (PTB), which develops the classical symptoms: cough, asthenia, adynamia, fever, chest pain, night sweats, chills, haemoptysis, and loss of weight (Roya-Pabon & Perez-Velez, 2016). However, the natural history of TB in infants and children varies greatly according to age and this depends on their susceptibility, which is highest during the first years of life, most likely due to undeveloped immune system (Roya-Pabon & Perez-Velez, 2016). TB clinical features in infants and children are not specific, and symptoms can mimic common childhood diseases as bacterial, viral or fungal infections, and malnutrition (Gutiérrez-González et al., 2021).

Tackling *M. tuberculosis* infection requires a complex immune response that involves both innate and adaptive immunity (Jaganath & Mupere, 2012). Among newborns, immune system has not been fully developed (Table 4.1); innate immunity and maternal antibodies are important for pathogen defense in this human stage (Jaganath & Mupere, 2012). Once *M. tuberculosis* infects a host, the bacilli reach a terminal airway and establish infection, initiating pulmonary infection, primary TB infection, however, it is capable of infecting nearly any organ resulting in a vast array of clinical features contributing to the complexity of the disease (Gutiérrez-González et al., 2021). Immediately after the exposure and primary infection from an infectious TB case, generally neither clinical nor radiologic manifestations are observed.

There are two age groups in which infants and children are either more susceptible or resistant to infection. Infants aged equal or less than 3 years and/or having weak immune system are considered as high-risk group. Among these infants, pulmonary disease progression occurs more frequently and may be associated with acute symptom onset: (I) a persistent, non-remitting cough of 2 weeks' duration; (II) weight loss (documented failure to thrive) during the preceding 3 months (III) fatigue, (IV) fever, and (V) chest pain. On the other hand, children aged or older than 3 years and with immune competence are considered low-risk children; disease progression after primary *M. tuberculosis* infection is rare and is associated with the presence of persistent, non-remitting symptoms (Marais et al., 2005). Before acquired immune responses to contain TB disease progression, *M. tuberculosis* may enter the systemic circulation and spread and infect other organs depending on dynamic pathogen-host interactions at the site of deposition (Marais & Schaaf, 2014). Disseminated TB disease may occur in the form of either miliary disease or meningitis. TB meningitis (TBM) is the most severe manifestation of childhood TB and it is most common in infants (<3 years of age) who frequently present with nonspecific symptoms before more advanced disease becomes apparent (Marais & Schaaf, 2014).

Epidemiological data point out that adult males are more affected by pulmonary TB than women, with a male/female ratio of 1.7 for the worldwide case notification (WHO, 2021), but this ratio does not follow this epidemiological pattern in children and adolescents (Neyrolles & Quintana-Murci, 2009). The risk of disease progression decreases in children and juveniles aged 5–10 years, but rises again during puberty, and this may be due to balanced inflammatory response capable of control of infection and to control disease; in this age, there seems to be a higher infection among boys (Seddon et al., 2018). However, during the juvenile stage, the risk of progression to TB increases, especially in girls. A study of over 82,000 individuals, which included infants, children, and juveniles in Puerto Rico, a trial of isoniazid prophylaxis in Alaskan Inuits, and an observational cohort in Ontario, Canada, all found that compared to males, females had higher rates of progression to TB disease in adolescence and early adulthood (Comstock et al., 1967, 1974; Grzybowski & Allen, 1964). These studies may highlight the importance of host immunological responses to *M. tuberculosis* that changes with age and sexual maturation (Seddon et al., 2018).

Infants and children infected with *M. tuberculosis* have a decline in T cell production as demonstrated in a recent study using whole blood transcriptional signature of children and adolescents with PTB and extrapulmonary TB (Hemingway et al., 2017). Recent studies indicate that sex hormones either enhance or decrease immune function activities during *M. tuberculosis* infection. For example, a robust Th1 immune response, characterized by IFN-γ production and tumor necrosis factor α (TNF-α), is vital to the control of TB, whereas a Th2 profile is detrimental (O'Garra et al., 2013). In general, testosterone is thought to downregulate the Th1 response, whereas estrogen is believed to enhance it. In reality, the effects of sex hormones on the Th1/Th2 balance are more subtle and complex (Nhamoyebonde & Leslie, 2014). Given that levels of steroid hormones vary by age, sex, and physiological state, studying these variations should be done based on resistance and susceptibility of TB (Table 4.2).

4.3.6 Nutritional Status

Nutritional status has been linked to *M. tuberculosis* infection susceptibility and disease progression as reported by the clinical and epidemiological studies. In general, it has been observed weight loss and undernutrition in patients with TB, either adults and pre-adults, and this can be caused by decreased food intake or factors due to the disease (fever, poor absorption, anorexia) (Sinha et al., 2019).

A variety of methods exist to measure the complex condition of undernutrition and its association with infectious diseases such as TB. For example, the height-for-age z-score (HAZ) indicator describes a chronic phenomenon. It measures the combined effects impact of insufficient food intake and repeated episodes of infectious disease for a prolonged period (Ibrahim et al., 2017; PHR et al., 2006). In the same way that appropriate health conditions and adequate food intake ensure proper growth; illnesses such as infectious ones- and insufficient food intake over prolonged period of time leads to chronic growth deficit (stunting or low height-for-age), which is evident by short stature-for-age. The stunting effect is more evident in children between age 3 and 5 years, because it is in this period of growth when children almost duplicate their size, and in consequence, their nutritional requirements increase. Therefore, chronic undernutrition causes a child's body to sacrifice the increase of body size (growth) for the adequate functioning of the child's organs and daily activities (maintenance). On the other hand, changes in food intake and health of a child under 5 years of age almost immediately translate into the changes in weight, because children can lose weight quickly when they are sick or starved. Thus, weight-for-height z-score (WHZ) is a very sensitive indicator and describes the immediate situation. The weight-for-age z-score (WAZ) indicator is commonly used in health programs because weight measurements are simpler to obtain than those for height. Although this indicator is less precise, it is useful because it can be

Table 4.2 Early human life stages and its immune response to *M. tuberculosis* infection

Stage and time lapse	Immunological characteristics during *M. tuberculosis* infection	General immunological characteristics
Infancy (from birth to 3 years old)	Upon initial inhalation, bacilli are phagocytosed by the alveolar macrophage, which recruits neutrophils and other innate responders as a first line of defense. However, the ability of the innate immune response to control infection may be inhibited by bacterial-mediated mechanisms, particularly inhibition of phagolysosome fusion (the key bacterial killing mechanism of these phagocytes), resulting in persistence of bacilli intracellularly. It is during this period that initial antigen trafficking to the lymph nodes by dendritic cells (DCs) is felt to occur. The acquired immune response to *M. tuberculosis* usually develops 1–3 months after initial infection (as evidenced by TST or IGRA immune sensitization), with antigen-specific lymphocytes trafficking back into the lung, facilitating activation of macrophages and granuloma formation. The neutrophils, which are short lived, undergo necrosis, contributing to a caseous center. This granulomatous response, if able to activate macrophages sufficiently to control bacterial replication, is thought to aid in containment of bacterial spread and reduce bacillary numbers, hence controlling or potentially eliminating *M. tuberculosis*. Deficiencies in the antigen-specific Th1 immune response have been well-described in infants <2 years-old.	There are elevated levels of CRP in high pathogen environment. Thymic cortical volume, the number of T and B lymphocytes is 3–4 times higher than in adults.
Childhood (from 3 to 6.9 years old)	BCG vaccination boosts mycobacterium-specific cell mediated immunity, which is associated with a reduced incidence of disseminated disease. Following early childhood, the initial granulomatous control of infection is likely to be effective. If infection is not eliminated by this stage, there is a risk of reactivation. Factors impeding effective T-cell-macrophage interaction within the granuloma increase the likelihood of disease progression. Some of these factors are well-known causes of systemic immunosuppression, such as HIV, malnutrition, and anti-tumor necrosis factor (TNF) therapy.	Thymic cortical volume, and the number of T and B lymphocytes decline from their peak levels in infancy. Certain immunoglobulins increase their concentration, i.e. IgE peaks its concentration before age 5 years old in response to helminths. NK cell function normalizes around the age of 5 years.
Juvenile (from 7 to 9 years old)	During this stage, there is a lymphocyte predominance and levels of Th1, TNF and IL2 are elevated.	There is an expression of major histocompatibility complex (MHC) class II molecules on these cells. Perhaps the expression of these MHC class II molecules facilitates interactions between cells in the zona reticularis and immune cells such as lymphocytes leading to alterations in androgen production.

easily obtained and can facilitate the monitoring of child health and nutrition over time. The presence of stunting does not exclude that of wasting (low weight-for height or wasting), or vice versa. A child under the age of 5 years who has suffered from a chronic malnutrition causing a height deficit, may also suffer from an infectious disease or an extreme lack of food that causes significant weight loss. In such cases, chronic undernutrition may be aggravated by a recent weight loss (PHR et al., 2006; Ibrahim et al., 2017). Mid-upper-arm circumference (MUAC) is a measure that strongly correlates with WHZ and it has been considered as a strong predictor of mortality (Ibrahim et al., 2017). Growth reference and standard curves for age and sex enable the grading of malnutrition into severe, moderate, or mild categories and have been used in many studies to associate with TB in infants and children.

Although measures of nutritional status are commonly standardized to global norms for children, detecting TB in infants, children and juveniles is more complicated since diagnostic tests lack sensitivity. For these reasons, studies associating undernutrition and TB in these stages are scarce. In a study carried out in Lima, Peru, pre-adults whose age were ≤17 years were enrolled to evaluate the association between weight change (WAZ) and treatment outcome, the accuracy of using weight change to predict regimen efficacy, and whether successfully treated children achieve catch-up weight gain were reported (Chiang et al., 2020). Two children's groups were conformed: group 1 included 100 children who were treated with drug-susceptible TB, including children whose treatment for drug-susceptible TB disease failed an in whom MDR-TB (multidrug resistant-tuberculosis) was subsequently diagnosed, and group 2 included 94 children with confirmed or probable MDR-TB. Weights data were obtained at baseline (≤30 days before or after the initiation of the first-line regimen for group 1 and a second-line regimen for group 2), interim during and at the end of the therapy (6th month for most group 1 participants, 12th month or later for group 2 participants). The authors observed that lower WAZ in months 3–5 and month 7 was associated with treatment failure or death in groups 1 and 2, respectively. Furthermore, children in both groups who experienced treatment failure or death had lower WAZ than successfully treated children. At the end of successful therapy, authors observed that in both groups there was no significant differences in final weight between children with severe versus non-severe TB. Another study carried out in Karachi, Pakistan, which enrolled infants, children, and adolescents (≤15 years of age), determined significant differences in the overall nutritional status in children with TB who were significantly malnourished than the controls. Mean arm upper circumference (MUAC, 15.2 ± 2.2 cm), weight-for-age (WAZ, −2.3 SD ± 1.2 among the participants ≤10 years of age), height-for-age (HAZ, −2.2 SD ± 1.6), and weight-for-height (WHZ, −1.2 SD ± 1.9 among participants <5 years old of age) in children with TB were lower compared to those values in controls (MUAC: 16.5 ± 2.3 cm; WAZ: −0.6 SD ± 4.2; HAZ: −0.4 SD ± 5.7; WHZ: −0.7 SD ± 0.9) (Iqbal et al., 2020).

Undernutrition may also be an important tool for predicting treatment success, outcomes, and mortality in children. In a study carried out in Ghana, which included 100 children <5 years of age, examined the effect of malnutrition on the pharmacokinetics of the first-line anti-tuberculosis drugs and found that nutritional status was significantly associated with rifampicin (RIF), pyrazinamide (PZA), and ethambutol (EMB) but not isoniazid concentrations. Malnutrition, especially stunting, was associated with low mean values of the required concentration of RIF, PZA and EMB for successful treatment. Authors suggest that treatment based solely on weight of children with TB and having malnutrition may lead to suboptimal drug concentration and treatment outcomes (Seneadza et al., 2021).

At the cellular and molecular levels, several studies have linked nutrition and TB infection and progression. Nutrition plays an essential role to develop the appropriate innate and Th1 immune response against this disease. Early nutrition through breastfeeding provides not only a source of energy for the newborn, but also provides immune properties (milk contains lysozyme, defensins, cytokines, among other molecules) that can be toxic to pathogens (Jaganath & Mupere, 2012). Inadequate infant nutrition may affect development of thymus, which plays an important role in T lymphocyte maturation to respond to TB infection.

Multiple vitamins were observed to have a role in immunity against *M. tuberculosis* infection or disease. Our understanding of how vitamins play a role in TB infection and disease come from the studies carried out in animal models and human cell lines. For example, *in vitro* study has determined that the metabolized form of vitamin A, all-trans-retinoic acidic (RA), is needed by infected monocytes and macrophages to mediate antimicrobial activity (Wheelwright et al., 2014). Furthermore, human macrophages (U937 cell line) stimulated with RA produced high levels of nitric oxide and this prevented intracellular survival of *M. tuberculosis* (Abd-Nikfarjam et al., 2018). Vitamin D has been recognized as a vital modulator of both innate and adaptive immune response against TB infection, enhancing the antimicrobial properties of the phagocytes, monocytes, macrophages, DCs, and neutrophils (Chandrasekaran et al., 2017).

Micronutrients are also essential to enhance immune response against various pathogens, including *M. tuberculosis*. Zinc is essential for diverse cellular processes, including immune system function; its deficiency decreases the phagocytic activity of macrophages. Patients with active TB have low levels of zinc at the time of diagnosis, but it increases after anti-tuberculosis treatment (Bahi et al., 2017). However, serum cobalt and copper concentrations were significantly higher in patients with tuberculosis compared to the controls (Choi et al., 2015).

On the contrary, recent studies have highlighted that obesity and overweight can modulate host metabolism and immune function during TB. A systematic review of cohort studies investigating the association between body mass index (BMI) and incidence of active TB found an inverse linear relationship between BMI and the risk of TB disease (Lönnroth et al., 2010). However, this study only included research carried out in adults and in high-income countries, and generalization to low-income countries, where the TB burden is presently highest, should therefore, be considered with some caution. Another study performed in Hong Kong found that obesity is associated with a lower risk of active PTB in the older population (Leung et al., 2007). A similar trend was observed in 241 new cases of TB in adults from Taiwan (Yen et al., 2017). A recent study carried in Lima, Peru established that high BMI protects adults from TB disease progression, but this does not extend to TB infection and is not observed among individuals under 12 years old (Aibana et al., 2016).

4.3.7 Co-infections

Co-infections contribute to the age-related changes of risk observed in TB. Helminths and malaria infections are both common in infants and children in countries with high TB burden. Some studies have reported an increased magnitude of intestinal parasites among TB patients. A study In India, a country with high TB burden, showed that the co-infection of this disease with intestinal parasites was 27.11% and the co-infection was more frequent in males of 1–15 years age group (KuMudini et al., 2019). In Ethiopia, another country with high TB burden, two studies conducted in Addis Ababa and Arba Minch, estimated the infection rates of intestinal parasites among PTB patients were 22% and 26.3%, respectively (Alemu et al., 2019; Alemu & Mama, 2017).

In general, the helminth–tuberculosis coinfection has impact on the aspects of immune response to TB. (i) The responses induced by the extracellular helminths and those induced by *M. tuberculosis* are often mutually antagonistic. The control of *M. tuberculosis* infection requires pro-inflammatory Th1 (IL-12, IFN-γ and TNF-α) and Th17 in host resistance to TB. The helminth infection induces strong Th2 anti-inflammatory with strong inflammatory responses by producing different cytokines (IL-4, IL-5, IL-9 and IL-13) and increased levels of eosinophils and circulating IgE antibodies, which may suppress Th1 immune response with a profound inhibitory effect on protective Th1 and Th17 responses, thus potentially modulating the cytokine environment in which TB is controlled during infection and disease progression (Babu & Nutman, 2016). (ii) The effect on diagnostic TB infection. Helminth infections appear to play an important role in modulating the immune response to purified protein derivative (PPD) and IFNγ release assays (IGRAS), therefore, indirectly affecting the tests used for diagnosing TB infection. However, helminth infections were also associated with inconclusive results in the IGRAs among children in Bangladesh (Thomas et al., 2010), and similar results were found in a study in South Africa with no significant effect of anthelmintic treatment on tuberculin skin test or IGRAs in children (Van der Zalm et al., 2016). (iii) The effect on the efficacy of the Bacillus Calmette Guerin (BCG) vaccine. The protective efficacy of BCG varies depending in which geographical location it is administered. For example, it is significant variable in low- and middle-income countries (ranging from 0% to 80%) where helminths are often co-endemic (Elias et al., 2006). In this regard, it has been documented that helminth infections significantly impair the immunogenicity of BCG vaccine. In a study conducted in Ethiopia, helminth-infected individuals showed significantly low TB antigen-specific cellular responses (as measured by reduced T cell proliferation and IFN-γ production) compared to dewormed controls (Elias et al., 2001). In the same study, poor immunogenicity of BCG vaccination in worm infected individuals compared to treated controls was observed. This observation was further demonstrated in a mouse model, infected with *Schistosoma mansoni* and later challenged with BCG vaccine. Experimental outcomes in this animal model indicated that co-infection with *S. mansoni* hinders resistance against mycobacterial infections and this was associated with impaired TB antigen-specific Th1 responses (IFN-γ and nitric oxide) and enhanced mitogen as well as worm antigen-specific Th2 type responses (Elias et al., 2006). Furthermore, it has been demonstrated that helminth-induced immune sensitization during gestation persists into childhood and skews subsequent childhood immune responses away from protective Th1 immune responses (Malhotra et al., 1999).

4.3.8 Vaccination Status and Efficacy of the Bacille Calmette-Guérin (BCG) Vaccine

Immune system can be enhanced through vaccination. To prevent TB in infants and children, the BCG vaccine is applied during neonatal and infancy stages in countries where it is part of the national childhood immunization program. The BCG vaccine has a documented protective effect against meningitis and disseminated TB in infants and children (WHO, 2022b).

Efficacy of BCG vaccine in preventing PTB has been reported in controlled trials, ranging from 0% in the trial at Chingleput in South India to 80% in the UK Medical Research Council (MRC) trial (Mangtani et al., 2014). Without BCG vaccination, approximately 30% of infected infants (<1 year old) had progress to intrathoracic TB, and 10–20% developed disseminated disease (Roya-Pabon & Perez-Velez, 2016). Among infants aged 1–2 years, the risk of progress into intrathoracic TB was 10–20% and 2–5% for disseminated disease.

In Latin America, the coverage of BCG vaccine ranges from 73–99%. This high variation in BCG vaccination coverage, between and within countries, may be due to low age-appropriate vaccines coverage rate, lack of awareness about the immunization schedule, hard to access health care facilities, reluctance in administering vaccines, hesitancy of parents regarding vaccination, insufficient infrastructure to transport and store the vaccine in hard to reach areas, and occurrence of unusual events such as natural disaster, disease outbreak as the current Covid-19 pandemic situation, especially among indigenous communities (Aranda et al., 2021). The BCG immunization coverage among 1-year-olds ranges from 20% to 99% in the Americas region (WHO, 2022a).

4.4 Growth, Undernutrition, and Tuberculosis in Latin American Countries

The recent report on global TB by WHO indicates that there is an association between the prevalence of undernutrition and the incidence of TB (WHO, 2021). Malnutrition is highly prevalent in children living in TB endemic countries. A recent study analyzing children undernutrition has determined that in low-income countries, stunting and wasting are still public health concerns, where 4.7% of children are simultaneously affected by both conditions (Victora et al., 2021). Furthermore, both conditions might already be present at birth, and that the incidence of both conditions peaks in the first 6 months of life (Victora et al., 2021).

The prevalence of undernutrition and severe undernutrition among patients in TB programs around the world is unknown because growth indicators are not being recorded as a routine procedure in many TB programs, despite recommendations by the WHO Guideline on Nutritional Care and Support for Patients with Tuberculosis as demonstrated by several retrospective studies using TB data programs from Brazil (Augusto et al., 2013; Barreto-Duarte et al., 2021; Croda et al., 2012; Fusco et al., 2017; Gaspar et al., 2016; Gava et al., 2013; Gomes de Barros et al., 2014; Sant'anna et al., 2013; Sassaki et al., 2010), Paraguay (Froberg et al., 2019), Mexico (Bello-López et al., 2019; Castañeda-Martínez et al., 2019), Ecuador (Chacón et al., 2019; Silva et al., 2019), and Colombia (Arenas-Suárez et al., 2010; Díaz et al., 2004; Villegas et al., 2014; Zabaleta et al., 2019), among other countries. Without considering nutritional status (stunting, wasting) and measuring growth parameters, there cannot be accurate estimation of the interrelationships between growth, nutrition and TB to assess LHT.

In 2019, it was estimated that there were 16,000 cases of TB in infants, children, juveniles, and adolescents under 15 years of age (5% of total estimated cases) in Latin America. However, only 10,151 cases were reported, indicating that there is still important work to be done with this vulnerable population (PAHO, 2021). In developing countries, nutritional status is relevant because significant number of TB cases are attributable to undernourishment. To our knowledge, no studies in Latin America have yet investigated the growth trade-off, undernutrition and TB infection in infants, children, juveniles and adolescents from LHT perspective. We have discussed that infancy and childhood periods of human life are critical for plasticity of growth, and undernutrition; infectious diseases are major risk factors for reduction in growth velocity. Latin American countries experience health, political, demographic, and economic transitions. Some countries have several multi-ethnic groups and each of them have their own biological, cultural, and social singularities.

The repartition of energy during growth of children and immune function is difficult to ascertain, but hypotheses have been proposed. During infancy and childhood, growth and immune system are in competition for resources, energy allocation may be shifted, especially when resources are scarce. It is plausible to assume that during TB infection in early human life stages there should be an exert of supplementary energy demands and/or trigger energy re-allocation mechanisms that could be detrimental to growth. However, this assumption is methodologically difficult to assess, as we discus in previous section, since there are few studies that have simultaneously measured the variation in physical growth, nutrition, and TB based on LHT. This relationship can be explored through population-based studies, which may provide insights into the association of growth, nutritional status, and TB in early human life stages. Table 4.3 shows data of some population-based studies carried out in some LA countries which include some growth parameters inferring the association of nutrition and TB.

Most of the studies cited above used different growth parameters to infer some association between nutrition and TB disease. However, the relationship, if any, between nutrition, using growth indicators, and TB described in these studies should be interpreted with caution. There are several reasons as follows:

(i) Although, data drawn from population-based studies combined with rigorous statistical methods may provide inference of trade-offs between these traits in children, these studies have drawbacks: not all studies measure relevant variables that are directly related to traits or are misinterpreted due to missing confounding variables; there is no homogeneity among studies (i.e. sample size, selection criteria, study design etc.) to allow comparisons in order to establish patterns. For example, the study of Chiang et al. 2020, which evaluated the association between weight change (WAZ) and treatment outcome, there was uncertainty about the accuracy of using weight change to predict regimen efficacy, and whether successfully treated children achieved catch-up weight gain or not. In general, authors found that lower WAZ was associated with treatment failure or death and successfully treated children-except group 2 participants with unknown microbiologic confirmation status-achieved catch-up weight gain. However, other growth parameters (height, MUAC, weight adjusted for height, and linear growth) were not measured in this study and therefore, a more complete evaluation of nutritional status was not undertaken.

(ii) Defining the age of acquisition of *M. tuberculosis* infection is complicated. Some studies used baseline TST positivity and/or identification of the infant, child, juvenile or adolescent as a contact of a TB case. Using these methods, it is difficult to establish when an individual was infected. Even if a source case is identified in the household and the child or adolescent screened soon thereafter, it is often unclear how long he or she had been exposed. It may also be unclear if the child or adolescent had prior exposure to another infectious TB case.

(iii) The diagnosis of TB disease in infants, children and juveniles can be challenging. A clinical diagnosis can lack specificity due to the overlap in symptoms between TB and other health problems in infants, children, and juveniles. Microbiological confirmation lacks sensitivity due to the paucibacillary nature of most forms of TB disease specially during infancy and childhood stages, as well as the challenges in obtaining respiratory specimens to diagnose TB. Other reasons for the wide variation include the different quantities and varieties of tuberculin tests used across studies, as well as inconsistent definitions of TST positivity and TB disease. Therefore, TST has limited sensitivity and specificity to diagnose TB infection in young children.

Table 4.3 Population based studies in LA showing the relationship between undernutrition and tuberculosis

Type of study	Settings	Observations
A prospective study tracking TB in infants, children, juvenile and adolescents	Towns of Surui indigenous people living in Rondonia state of Brazil	In this study, data from 37 indigenous people were analyzed; median age of children was 11.3 years (3.5–16.4). Approximately 21.1% of children were suffering from undernutrition as indicated by BMI for their age (Basta et al., 2010).
Prospective study characterizing weight among TB-affected in infants, children, juvenile and adolescents	Lima, Peru	There were two participant groups whose age was ≤17 years. The study evaluated association between weight change (weight-for-age z score, ΔWAZ) and treatment outcome, the accuracy of using weight change to predict regimen efficacy, and whether successfully treated children achieve catch-up weight gain. Results are already explained in the section 4.3.6. The authors observed that lower ΔWAZ was associated with treatment failure or death. Furthermore, children who experienced treatment failure or death had lower ΔWAZ than successfully treated children. At the end of successful therapy, authors observed that in both groups there was no significant differences in final weights between children with severe versus nonsevere TB (Chiang et al., 2020).
A descriptive cross-sectional study in infants, children, juvenile and adolescents	Indigenous communities in the Warao people of the Delta Amacuro State in Venezuela	In this study, 502 children, aged 0–15 years old, were selected under a clinical score, from which 27 children were included. Of these 27 children, four showed BMI below the standard WHO criteria (3 children and 1 adolescent). This study also demonstrated that diagnosing TB in children was difficult and that was exacerbated in rural areas (Fernández de Larrea et al., 2002).
A prospective study tracing TB in infants, children, juvenile and adolescents from May 2015 to February 2018	The study was carried out in 49 urban public sector health centers in Lima, Peru	This study investigated TB infection in children in Lima Peru, aged 0–14 years, finding 231 (49%) children being positive to TST. The median BMI (kg/m^2), IQR, was 16.8 [15.7–18.6] (Coit et al., 2019).
Retrospective study review of the medical records of infants and children with perinatal HIV infection hospitalized with a diagnosis of TB between January 1998 and June 2007	Tijuana General Hospital, Baja California, Mexico.	Thirteen (18%) children were co-infected with TB and HIV during the study period; of these, eight children were considered wasted (weight-for-age 3rd percentile) (Viani et al., 2008).

(continued)

Table 4.3 (continued)

Type of study	Settings	Observations
Prospective cohort study of household contacts (in infants, children, juvenile and adolescents) of PTB cases between September 2009 and August 2012	Lima, Peru.	The study assessed potential predictors of TB disease in individuals aged 0–14 years who did not have TB disease at baseline. The outcome of interest was the occurrence of incident TB disease during 12 months of follow-up. One-quarter (1095, 24.1%) of all children had a positive TST at baseline, with the percentage increasing with age (0–4 years: 16.6%; 5–9 years: 25.6%; 10–14 years: 32.2%). A total of 156 (3.4%) individuals were diagnosed with TB disease during follow-up, with 3.4%, 2.3%, and 4.7% among the age groups 0–4, 5–9, and 10–14 years, respectively. Adolescents aged 10–14 years, who had a positive TST result at baseline measurement, 11% of those whose weight was <62.1 kg, developed TB. On the contrary, individuals whose weight was >62.1 kg did not develop TB. This study highlights that individuals 0–14 years old develop TB when having a positive TST and whose immune system has not developed yet. Additionally, the study observed that individuals 10–14 years old who had a positive TST result at baseline, being below a certain weight threshold led to a much higher risk of TB disease than those above that threshold. This is consistent with the known increased risk of TB disease among individuals who are malnourished (Brooks et al., 2021).
Retrospective observational study including infants, children, juvenile and adolescents with pulmonary and extrapulmonary involvement, treated between January 1, 2008 and December 31, 2016	Central Hospital of Bogota Colombia	In this study, 93 individuals were diagnosed with TB whose age were 0–18 years. At clinical presentation, 26.2% of the included participants presented weight loss. Further analysis, authors determined that from 31 cases, 13.1% TB cases was associated with malnutrition according to WHO's nutritional parameters (Yunda et al., 2017).
Retrospective and descriptive study that reviewed TB cases in infants, children, juvenile and adolescents diagnosed from January 2010 to December 2013	Children's Hospital Federico Gómez, Mexico's city	From 93 individuals, age ranged from 9 months to 16 years, the most frequent clinical signs associated at the time of TB diagnosis were fever and weight loss, 50% and 40%, respectively (Vázquez-Rosales et al., 2017).

(continued)

Table 4.3 (continued)

Type of study	Settings	Observations
Case-control study carried out in infants, children, juveniles, and adolescents from 2000–2007	Shanty towns and hospitals in Lima, Peru.	In this study, 209 individuals had TB HIV-negative and 81 were co-infected with HIV, whose age were <13 years. The underweight in individuals with TB represented 4%, but those with TB and HIV represented 26%. The authors also found that HIV-positive cases associated with TB had significant lower weight-for-age. This observation indicates that individuals co-infected with TB and HIV and being underweight will be expected to delay their linear growth (Oberhelman et al., 2015).
Case-control study in infants, children, juveniles, and adolescents performed from August, 2002, to January, 2007	Two hospitals in Lima, Peru	In this study, 456 children were included whose age was 0–12 years; 218 presumptive TB cases and 238 controls. Percentage of weight-for-age was not statistically significant when compared between children with TB and controls. On the other hand, the percentage of height-for-age was statistically significant when compared between children with TB and controls (Oberhelman et al., 2010).
Retrospective study in infants, children, juveniles, and adolescents reviewing medical files collected from January 2010 to December 2015	Tertiary healthcare hospital, located in the municipality of Fortaleza, a reference in treating infectious diseases in the state of Ceará, Brazil	Eighty-eight individuals were included in the study aged 0–18 years. This study found that there was an association of PTB and being a female >10 years of age and weight loss, among other factors (Sousa et al., 2019).
Case-control study in infants, children, juveniles, and adolescents from May 2015 through February 2018	Lima, Peru	Participants included in the study were less than 15 years old. The study analyzed 89 individuals with intrathoracic/PTB, 24 cases were TB culture-confirmed and 65 with clinically diagnosed unconfirmed TB, and 199 controls. According to the WHO's growth guidelines, only three participants were found to be underweight; one in the TB culture-confirmed group and two in unconfirmed group (Flores et al., 2020).
Prospective cohort study among household contacts of PTB in all stages between September 2009 and August 2012	106 participating health centers in different regions of Lima, Peru	The study categorized contacts in the following age categories: <5, 5–11, 12–19, 20–49 and 50 years. The study enrolled 14,044 household contacts of 4500 index TB cases, from which 5441 (38.71%) were infants, children, juvenile and adolescents. The percentage of females and males having TB was similar (4.9%). Only four TB cases had lower BMI, based on WHO's age and gender-specific BMI z-score; three were female and one male (Aibana et al., 2016).

(continued)

Table 4.3 (continued)

Type of study	Settings	Observations
This work was nested within a TB diagnostic study, which included infants, children, juveniles, and adolescents	Lima, Peru	In this study, 35 participants <15 years of age were followed up to 30 months to re-evaluate their health condition with respect to TB. At the time of re-evaluation, two individuals (6%) were diagnosed with TB. The median BMI of the 35 participants was lower [16.5, IQR (15.7–18.4)] compared to the non-participants (eligible, but not enrolled) 17.5 (17.0–18.6) (Wong et al., 2021).
A prospective study investigating the performance of candidate *M. tuberculosis*-specific cytokine biomarkers for TB in infants, children, juveniles and adolescents	27 community health centers in the district of San Juan de Miraflores in Lima, Peru, between January and December 2014	A total of 203 participants were included in this study and categorized as: 53 LTBI, 98 healthy controls, 47 sick controls and five probable active TB. Four individuals in the sick control and one in the active group had loss weight in the last 2 weeks previous to the study (Sudbury et al., 2019).

From a LHT perspective, plasticity of growth allows for modulation of physical growth in response to nutrition, pathogens, and other exposure in a specific environment. However, infant and childhood diseases, particularly infections and undernutrition, are major risk factors for reduction in growth velocity. Physiological changes induced by undernutrition and/or infections can cause changes in growth velocity with long term consequences for children. The predictive adaptive response hypothesis forecasts that during the period of developmental plasticity, environmental conditions induce adaptations that allow individuals to survive and reproduce (Bateson et al., 2014; Gluckman et al., 2007). However, there are several critiques of the predictive adaptive response hypothesis. One caveat is that if environmental conditions change, then the risk of morbidity and mortality increase and individual fitness is reduced (McDade, 2003; McDade et al., 2016). In humans, the entire utility of the predictive adaptive response concept has been challenged (Bogin et al., 2007). These researchers consider the growth delays, especially stunting and low weight-for-age, as pathology, not adaptation. LHT hypotheses might not apply directly since most of traits are mediated through monetary currency, as most human populations live in societies where it is necessary to pay for food (energy intake), housing (environment), health (immunity), among other basic goods and services; therefore, humans in most societies make choices between investments such as reproduction, survival, and immunity. LHT only considers biological aspects of growth, nutrition, and pathogens, but its determinants and consequences are multifactorial and include social, economic, political, emotional and cultural factors (Bogin, 2021a, b, 2022).

In LHT, confounding factors such as variation in resource level among individuals may also affect estimates of natural selection on immune defense traits. As immune defense is condition-dependent, variation in the ability of individuals to acquire resources may obscure the trade-offs between immune defense and life-history traits. Individuals with high resources levels could be able to invest resources on traits directly promoting fitness (e.g. survival, reproduction), but also to maintain high immune function. On the contrary, individuals with low access to resources will allocate resources where is more needed, e.g. in immune system during infection. Human populations, such as in LA countries, are experiencing nutritional, social, economic, political, emotional and cultural changes that threaten infant and childhood functions of growth and maintenance. Some of the social factors associated with TB such as poor socioeconomic status, access to health services, education, and food insecurity are known to affect physical growth of children.

Since TB patients might already have lost weight and macro- and micronutrients, due to their illness, studies that measure nutritional status at the time of TB diagnosis are likely to produce spurious associations or overestimate the strength of any causal relationship between nutritional status and risk of TB. Only cohort studies (or case-control studies nested in cohorts that have established baseline nutritional status before onset of disease) can produce reliable estimates of the strength of the association. However, such studies require significant resources and few studies have been designed to estimate nutritional status and risk of TB.

4.5 Conclusions

Studying trade-offs between growth, nutrition and TB in infants, children, juveniles, and adolescents is complex in human populations because not only biological factors are important, but also social, economic, political, emotional, and cultural determinants are intervening. It is often not straightforward to measure theoretical expectations from LHT perspective because of methodological reasons. As we discussed in this work, there are many variations at different levels: host heterogeneity, *M. tuberculosis* diversity, access to the resources, among others. Although there are many studies relating malnourished children as high risk for susceptibility and developing TB disease, the mechanisms underlying this association remains unclear giving the limitations that we have discussed. In this chapter, we defined early human life development (fetal, infancy, childhood, and juvenile) and general immune response to TB infection at each stage. We also provide theoretical framework by highlighting challenges to associate growth, nutrition and TB that could help to design future studies to apply predictions from LHT into a more integrative framework. Identifying key points at which there is a strong association between those traits, hence, public health interventions to reduce the incidence of TB as well as undernutrition in these stages may be jointly implemented to attain maximum benefit. In this way, the global goals to reduce TB under the strategy "End TB" not only should consider TB diagnosis and treatment, but also focusing on nutritional management and social determinants of health.

References

Abd-Nikfarjam, B., Nassiri-Asl, M., Hajiaghayi, M., & Farivar, T. N. (2018). Role of chicoric acid and 13-cis retinoic acid in *Mycobacterium tuberculosis* infection control by human U937 macrophage. *Archivum Immunologiae et Therapiae Experimentalis, 66*(5), 399–406. https://doi.org/10.1007/s00005-018-0511-0

Abel, L., Fellay, J., Haas, D. W., Schurr, E., Srikrishna, G., Urbanowski, M., Chaturvedi, N., Srinivasan, S., Johnson, D. H., & Bishai, W. R. (2018). Genetics of human susceptibility to active and latent tuberculosis: Present knowledge and future perspectives. *The Lancet Infectious Diseases, 18*(3), e64–e75. https://doi.org/10.1016/S1473-3099(17)30623-0

Adair, L. S., Fall, C. H. D., Osmond, C., Stein, A. D., Martorell, R., Ramirez-Zea, M., Sachdev, H. S., et al. (2013). Associations of linear growth and relative weight gain during early life with adult health and human capital in countries of low and middle income: Findings from five birth cohort studies. *Lancet (London, England), 382*(9891), 525–534. https://doi.org/10.1016/S0140-6736(13)60103-8

Aibana, O., Acharya, X., Huang, C.-C., Becerra, M. C., Galea, J. T., Chiang, S. S., Contreras, C., et al. (2016). Nutritional status and tuberculosis risk in adult and pediatric household contacts. *PLoS One, 11*(11), e0166333. https://doi.org/10.1371/journal.pone.0166333

Alcaïs, A., Fieschi, C., Abel, L., & Casanova, J.-L. (2005). Tuberculosis in children and adults: Two distinct genetic diseases. *The Journal of Experimental Medicine, 202*(12), 1617–1621. https://doi.org/10.1084/jem.20052302

Alemu, G., & Mama, M. (2017). Intestinal helminth co-infection and associated factors among tuberculosis patients in Arba Minch, Ethiopia. *BMC Infectious Diseases, 17*(1), 68. https://doi.org/10.1186/s12879-017-2195-1

Alemu, A., Kebede, A., Dagne, B., Amare, M., Diriba, G., Yenew, B., Tesfaye, E., et al. (2019). Intestinal parasites co-infection and associated factors among active pulmonary tuberculosis patients in selected health centers, Addis Ababa, Ethiopia: Unmatched case control study. *BMC Infectious Diseases, 19*(1), 407. https://doi.org/10.1186/s12879-019-4009-0

Aranda, Z., Arana-Cedeño, M., Meléndez-Navarro, D. M., Meneses-Navarro, S., & Sánchez-Pérez, H. J. (2021). A call for COVID-19 immunization campaigns that address the specific circumstances of indigenous peoples of Latin America and the Caribbean. *The Lancet Regional Health – Americas, 3*(November). https://doi.org/10.1016/j.lana.2021.100074

Arenas-Suárez, N. E., García-Gutiérrez, A. M., Coronado-Ríos, S. M., Beltrán-Bocanegra, C. A., Acosta-Botero, S. M., Gómez-Marín, J. E., & Quintero-Álvarez, L. (2010). Prevalencia de tuberculosis infantil en Armenia, Colombia. *Revista de Salud Pública, 12*(6), 1000–1009.

Augusto, C. J., da Silva, W., Carvalho, A. D., Gonçalves, M., & das Graças Braga Ceccato, and Silvana Spindola de Miranda. (2013). Characteristics of tuberculosis in the state of Minas Gerais, Brazil: 2002–2009. *Jornal Brasileiro De Pneumologia: Publicacao Oficial Da Sociedade Brasileira De Pneumologia E Tisilogia, 39*(3), 357–364. https://doi.org/10.1590/S1806-37132013000300013

Babu, S., & Nutman, T. B. (2016). Helminth-tuberculosis co-infection: An immunologic perspective. *Trends in Immunology, 37*(9), 597–607. https://doi.org/10.1016/j.it.2016.07.005

Bahi, G. A., Boyvin, L., Méité, S., M'Boh, G. M., Yeo, K., N'Guessan, K. R., Bidié, A. D. P., & Djaman, A. J. (2017). Assessments of serum copper and zinc concentration, and the cu/Zn ratio determination in patients with multidrug resistant pulmonary tuberculosis (MDR-TB) in Côte d'Ivoire. *BMC Infectious Diseases, 17*(1), 257. https://doi.org/10.1186/s12879-017-2343-7

Barreto-Duarte, B., Araújo-Pereira, M., Nogueira, B. M. F., Sobral, L., Rodrigues, M. M. S., Queiroz, A. T. L., Rocha, M. S., et al. (2021). Tuberculosis burden and determinants of treatment outcomes according to age in Brazil: A nationwide study of 896,314 cases reported between 2010 and 2019. *Frontiers in Medicine, 8*, 706689. https://doi.org/10.3389/fmed.2021.706689

Barry, C. E., 3rd, Boshoff, H. I., Dartois, V., Dick, T., Ehrt, S., Flynn, J. A., Schnappinger, D., Wilkinson, R. J., & Young, D. (2009). The spectrum of latent tuberculosis: Rethinking the biology and intervention strategies. *Nature Reviews. Microbiology, 7*(12), 845–855. https://doi.org/10.1038/nrmicro2236

Basta, P. C., Rios, D. P. G., Alves, L. C. C., Sant' Anna, C. C., & Junior, C. E. A. C. (2010). Clinical and radiological study of Suruí indigenous children and adolescents, Amazon Region, Brazil. *Revista da Sociedade Brasileira de Medicina Tropical, 43*(6), 719–722. https://doi.org/10.1590/s0037-86822010000600024

Bateson, P., Gluckman, P., & Hanson, M. (2014). The biology of developmental plasticity and the predictive adaptive response hypothesis. *The Journal of Physiology, 592*(11), 2357–2368. https://doi.org/10.1113/jphysiol.2014.271460

Bello-López, J. M., León-García, G., Araceli Rojas-Bernabé, V., Fernández-Sánchez, O. G.-H., Rámirez, J. M., & Ibáñez-Cervantes, G. (2019). Morbidity trends and risk of tuberculosis: Mexico 2007–2017. *Canadian Respiratory Journal, 2019*, 8295261. https://doi.org/10.1155/2019/8295261

Black, R. E., Victora, C. G., Walker, S. P., Bhutta, Z. A., Christian, P., de Onis, M., Ezzati, M., et al. (2013). Maternal and child undernutrition and overweight in low-income and middle-income countries. *Lancet (London, England), 382*(9890), 427–451. https://doi.org/10.1016/S0140-6736(13)60937-X

Blackwell, A. D., Snodgrass, J. J., Madimenos, F. C., & Sugiyama, L. S. (2010). Life history, immune function, and intestinal helminths: Trade-offs among immunoglobulin E, C-reactive protein, and growth in an Amazonian population. *American Journal of Human Biology: The Official Journal of the Human Biology Council, 22*(6), 836–848. https://doi.org/10.1002/ajhb.21092

Blackwell, A. D., Gurven, M. D., Sugiyama, L. S., Madimenos, F. C., Liebert, M. A., Martin, M. A., Kaplan, H. S., & Josh Snodgrass, J. (2011). Evidence for a peak shift in a humoral response to helminths: Age profiles of IgE in the Shuar of Ecuador, the Tsimane of Bolivia, and the U.S. NHANES. *PLoS Neglected Tropical Diseases, 5*(6), e1218. https://doi.org/10.1371/journal.pntd.0001218

Bogin, B. (2020). *Patterns of human growth* (3rd ed.). Cambridge University Press.

Bogin, B. (2021a). Fairer taxation to curb inequality and boost health. *Nature, 594*(7864), 495. https://doi.org/10.1038/d41586-021-01698-1

Bogin, B. (2021b). Social-Economic-Political-Emotional (SEPE) factors regulate human growth. *Human Biology and Public Health*, 1. https://doi.org/10.52905/hbph.v1.10

Bogin, B. (2022). Fear, violence, inequality, and stunting in Guatemala. *American Journal of Human Biology: The Official Journal of the Human Biology Council, 34*(2), e23627. https://doi.org/10.1002/ajhb.23627

Bogin, B., & Holly Smith, B. (1996). Evolution of the human life cycle. *American Journal of Human Biology: The Official Journal of the Human Biology Council, 8*(6), 703–716. https://doi.org/10.1002/(SICI)1520-6300(1996)8:6<703::AID-AJHB2>3.0.CO;2-U

Bogin, B., Silva, M. I. V., & Rios, L. (2007). Life history trade-offs in human growth: Adaptation or pathology? *American Journal of Human Biology: The Official Journal of the Human Biology Council, 19*(5), 631–642. https://doi.org/10.1002/ajhb.20666

Bogin, B., Varea, C., Hermanussen, M., & Scheffler, C. (2018). Human life course biology: A centennial perspective of scholarship on the human pattern of physical growth and its place in human biocultural evolution. *American Journal of Physical Anthropology, 165*(4), 834–854. https://doi.org/10.1002/ajpa.23357

Bolund, E. (2020). The challenge of measuring trade-offs in human life history research. *Evolution and Human Behavior, Current Debates in Human Life History Research, 41*(6), 502–512. https://doi.org/10.1016/j.evolhumbehav.2020.09.003

Brites, D., Loiseau, C., Menardo, F., Borrell, S., Boniotti, M. B., Warren, R., Dippenaar, A., et al. (2018). A new phylogenetic framework for the animal-adapted mycobacterium tuberculosis complex. *Frontiers in Microbiology, 9*. https://doi.org/10.3389/fmicb.2018.02820

Brooks, M. B., Lecca, L., Contreras, C., Calderon, R., Yataco, R., Galea, J., Huang, C.-C., Murray, M. B., & Becerra, M. C. (2021). Prediction tool to identify children at highest risk of tuberculosis disease progression among those exposed at home. *Open Forum Infectious Diseases, 8*(11), ofab487. https://doi.org/10.1093/ofid/ofab487

Castañeda-Martínez, F. C., Valdespino-Padilla, M. G., Cazares-Montero, S., & Martínez-Lemus, M. A. (2019). Characterization of tuberculosis in the Michoacan Local Office, period 2015–2018. *Revista Médica del Instituto Mexicano del Seguro Social, 57*(4), 232–240.

Chacón, A., Alarcón, E., & López, L. (2019). Factores Asociados al Cumplimiento de La Terapia Preventiva Con Isoniacida En Niños En Quito, Ecuador (2014-2016 y 2018). *Revista Panamericana de Salud Pública, 43*, e97. https://doi.org/10.26633/RPSP.2019.97

Chandrasekaran, P., Saravanan, N., Bethunaickan, R., & Tripathy, S. (2017). Malnutrition: Modulator of immune responses in tuberculosis. *Frontiers in Immunology, 8*, 1316. https://doi.org/10.3389/fimmu.2017.01316

Chen, C. C. G., & Parker, C. R. (2004). Adrenal androgens and the immune system. *Seminars in Reproductive Medicine, 22*(4), 369–377. https://doi.org/10.1055/s-2004-861553

Chiang, S. S., Park, S., White, E. I., Friedman, J. F., Cruz, A. T., Del Castillo, H., Lecca, L., Becerra, M. C., & Seddon, J. A. (2020). Using changes in weight-for-age z score to predict effectiveness of childhood tuberculosis therapy. *Journal of the Pediatric Infectious Diseases Society, 9*(2), 150–158. https://doi.org/10.1093/jpids/piy138

Choi, R., Kim, H.-T., Lim, Y., Min-Ji Kim, O., Kwon, J., Jeon, K., Park, H. Y., Jeong, B.-H., Koh, W.-J., & Lee, S.-Y. (2015). Serum concentrations of trace elements in patients with tuberculosis and its association with treatment outcome. *Nutrients, 7*(7), 5969–5981. https://doi.org/10.3390/nu7075263

Coit, J., Mendoza, M., Pinedo, C., Marin, H., Chiang, S. S., Lecca, L., & Franke, M. (2019). Performance of a household tuberculosis exposure survey among children in a Latin American setting. *The International Journal of Tuberculosis and Lung Disease: The Official Journal of the International Union Against Tuberculosis and Lung Disease, 23*(11), 1223–1227. https://doi.org/10.5588/ijtld.18.0841

Comstock, G. W., Ferebee, S. H., & Hammes, L. M. (1967). A controlled trial of community-wide isoniazid prophylaxis in Alaska. *The American Review of Respiratory Disease, 95*(6), 935–943. https://doi.org/10.1164/arrd.1967.95.6.935

Comstock, G. W., Livesay, V. T., & Woolpert, S. F. (1974). The prognosis of a positive tuberculin reaction in childhood and adolescence. *American Journal of Epidemiology, 99*(2), 131–138. https://doi.org/10.1093/oxfordjournals.aje.a121593

Coscolla, M., & Gagneux, S. (2014). Consequences of genomic diversity in *Mycobacterium tuberculosis*. *Seminars in Immunology, 26*(6), 431–444. https://doi.org/10.1016/j.smim.2014.09.012

Crespi, B. (2011). The evolutionary biology of child health. *Proceedings of the Biological Sciences, 278*(1711), 1441–1449. https://doi.org/10.1098/rspb.2010.2627

Croda, M. G., Trajber, Z., da Costa Lima, R., & Croda, J. (2012). Tuberculosis control in a highly endemic indigenous community in Brazil. *Transactions of the Royal Society of Tropical Medicine and Hygiene, 106*(4), 223–229. https://doi.org/10.1016/j.trstmh.2012.01.005

de Larrea, F., Carlos, C. F., López, D., del Nogal, B., Rodríguez, N., Convit, J., Araujo, Z., & de Waard, J. H. (2002). Tuberculosis in subjects under 15 years of age in the population of Warao in Venezuela. *Investigación Clínica, 43*(1), 35–48.

DeAtley, T., Workman, L., Theron, G., Bélard, S., Prins, M., Bateman, L., Grobusch, M. P., et al. (2021). The child ecosystem and childhood pulmonary tuberculosis: A South African perspective. *Pediatric Pulmonology, 56*(7), 2212–2222. https://doi.org/10.1002/ppul.25369

der Zalm, V., Marieke, M., van Soelen, N., Mandalakas, A. M., Jacobsen, M., Detjen, A. K., Marx, F. M., Grewal, H. M. S., Cotton, M. F., Walzl, G., & Hesseling, A. C. (2016). The effect of deworming on tests of tuberculosis infection in children with recent tuberculosis exposure: A randomized controlled trial. *The Pediatric Infectious Disease Journal, 35*(6), 622–627. https://doi.org/10.1097/INF.0000000000001115

Díaz, M. L., Muñoz, S., & García, L. B. (2004). Tuberculosis en el Hospital Universitario San José, Popayán, 1998–2000. *Biomédica, 24*, 92–101.
Dodd, P. J., Gardiner, E., Coghlan, R., & Seddon, J. A. (2014). Burden of childhood tuberculosis in 22 high-burden countries: A mathematical modelling study. *The Lancet Global Health, 2*(8), e453–e459. https://doi.org/10.1016/S2214-109X(14)70245-1
El-Arabey, A. A., & Abdalla, M. (2021). Transplacental transmission of SARS-CoV-2 infection via NRP1. *Travel Medicine and Infectious Disease, 40*, 101987. https://doi.org/10.1016/j.tmaid.2021.101987
Elias, D., Wolday, D., Akuffo, H., Petros, B., Bronner, U., & Britton, S. (2001). Effect of deworming on human T cell responses to mycobacterial antigens in helminth-exposed individuals before and after Bacille Calmette-Guérin (BCG) vaccination. *Clinical and Experimental Immunology, 123*(2), 219–225. https://doi.org/10.1046/j.1365-2249.2001.01446.x
Elias, D., Akuffo, H., & Britton, S. (2006). Helminthes could influence the outcome of vaccines against TB in the tropics. *Parasite Immunology, 28*(10), 507–513. https://doi.org/10.1111/j.1365-3024.2006.00854.x
Flores, J. A., Calderón, R., Mesman, A. W., Soto, M., Coit, J., Aliaga, J., Mendoza, M., et al. (2020). Detection of *Mycobacterium tuberculosis* DNA in buccal swab samples from children in Lima, Peru. *The Pediatric Infectious Disease Journal, 39*(11), e376–e380. https://doi.org/10.1097/INF.0000000000002828
Flores, J. A., Coit, J., Mendoza, M., Leon, S. R., Konda, K., Lecca, L., & Franke, M. F. (2021). Is exclusive breastfeeding for six-months protective against pediatric tuberculosis? *Global Health Action, 14*(1), 1861922. https://doi.org/10.1080/16549716.2020.1861922
Froberg, J., Sequera, V. G., Tostmann, A., Aguirre, S., & Magis-Escurra, C. (2019). Assessment of tuberculosis incidence and treatment success rates of the indigenous maká community in Paraguay. *BioRxiv, 1*(1), 1–21. https://doi.org/10.1101/620161
Fusco, A. P., Biffi, R. A., Arcêncio, M. Y., Palha, P. F., Reis, A. A. D., de Araújo Alecrim, T. F., & Protti, S. T. (2017). Spatial distribution of tuberculosis in a municipality in the interior of São Paulo, 2008–2013. *Revista Latino-Americana de Enfermagem, 25*(June), e2888. https://doi.org/10.1590/1518-8345.1064.2888
Gagneux, S. (2018). Ecology and evolution of *Mycobacterium tuberculosis*. *Nature Reviews. Microbiology, 16*(4), 202–213. https://doi.org/10.1038/nrmicro.2018.8
Garcia, A. R., Blackwell, A. D., Trumble, B. C., Stieglitz, J., Kaplan, H., & Gurven, M. D. (2020). Evidence for height and immune function trade-offs among preadolescents in a high pathogen population. *Evolution, Medicine, and Public Health, 2020*(1), 86–99. https://doi.org/10.1093/emph/eoaa017
Gaspar, R. S., Nunes, N., Nunes, M., & Rodrigues, V. P. (2016). Temporal analysis of reported cases of tuberculosis and of tuberculosis-HIV co-infection in Brazil between 2002 and 2012. *Jornal Brasileiro De Pneumologia: Publicacao Oficial Da Sociedade Brasileira De Pneumologia E Tisilogia, 42*(6), 416–422. https://doi.org/10.1590/S1806-37562016000000054
Gava, C., Malacarne, J., Rios, D. P. G., Sant'Anna, C. C., Camacho, L. A. B., & Basta, P. C. (2013). Tuberculosis in indigenous children in the Brazilian Amazon. *Revista De Saude Publica, 47*(1), 77–85. https://doi.org/10.1590/s0034-89102013000100011
Gluckman, P. D., Hanson, M. A., & Beedle, A. S. (2007). Early life events and their consequences for later disease: A life history and evolutionary perspective. *American Journal of Human Biology: The Official Journal of the Human Biology Council, 19*(1), 1–19. https://doi.org/10.1002/ajhb.20590
Goldsby, R. A., Kindt, T. J., Osborne, B. A., & Kuby, J. (2003). *Immunology* (5th ed.). W. H. Freeman and company.
Gomes de Barros, P., Lima Pinto, M., Carla, T., da Silva, E., Silva, L., Ribeiro Monteiro, T. M., & de Figueiredo. (2014). Epidemiological profile of extra-pulmonary tuberculosis cases in a municipality of Paraiba state, 2001–2010. *Cadernos Saúde Coletiva, 22*(4), 343–350. https://doi.org/10.1590/1414-462X201400040007

Gómez-Velasco, A., Bencomo-Alerm, A., Valencia, E., Batista, R., Sánchez-Pérez, H. J., & Muñoz-Hernández, J. A. (2014). Spatial and temporal analysis of tuberculosis in the highlands of Chiapas, Mexico. *World Conference on Lung Health of the International Union Against Tuberculosis and Lung Disease (The Union), 18*(11), S383.

Grzybowski, S., & Allen, E. A. (1964). The Challege of tuberculosis in decline. A study based on the epidemiology of tuberculosis in Ontario, Canda. *The American Review of Respiratory Disease, 90*, 707–720. https://doi.org/10.1164/arrd.1964.90.5.707

Guilmot, A., Hermann, E., Braud, V. M., Carlier, Y., & Truyens, C. (2011). Natural killer cell responses to infections in early life. *Journal of Innate Immunity, 3*(3), 280–288. https://doi.org/10.1159/000323934

Gutiérrez-González, L. H., Juárez, E., Carranza, C., Carreto-Binaghi, L. E., Alejandre, A., Cabello-Gutiérrrez, C., & Gonzalez, Y. (2021). Immunological aspects of diagnosis and management of childhood tuberculosis. *Infection and Drug Resistance, 14*, 929–946. https://doi.org/10.2147/IDR.S295798

Hemingway, C., Berk, M., Anderson, S. T., Wright, V. J., Hamilton, S., Eleftherohorinou, H., Kaforou, M., et al. (2017). Childhood tuberculosis is associated with decreased abundance of T cell gene transcripts and impaired T cell function. *PLoS One, 12*(11), e0185973. https://doi.org/10.1371/journal.pone.0185973

Hochberg, Z. (2008). Juvenility in the context of life history theory. *Archives of Disease in Childhood, 93*(6), 534–539. https://doi.org/10.1136/adc.2008.137570

Hochberg, Z. (2009). Evo–Devo of child growth II: Human life history and transition between its phases. *European Journal of Endocrinology, 160*(2), 135–141. https://doi.org/10.1530/EJE-08-0445

Ibrahim, M. K., Zambruni, M., Melby, C. L., & Melby, P. C. (2017, August). Impact of childhood malnutrition on host defense and infection. *Clinical Microbiology Reviews*. https://doi.org/10.1128/CMR.00119-16

Iqbal, N. T., Ahmed, K., Qamar, F. N., Shaheen, F., Mehnaz, A., Arif, F., Saeed, A. A., et al. (2020). Antibody-secreting cells to diagnose mycobacterium tuberculosis infection in children in Pakistan. *MSphere, 5*(1), e00632–e00619. https://doi.org/10.1128/mSphere.00632-19

Jaganath, D., & Mupere, E. (2012). Childhood tuberculosis and malnutrition. *The Journal of Infectious Diseases*, jis608. https://doi.org/10.1093/infdis/jis608

Jenkins, H. E., Yuen, C. M., Rodriguez, C. A., Nathavitharana, R. R., McLaughlin, M. M., Donald, P., Marais, B. J., & Becerra, M. C. (2017). Mortality in children diagnosed with tuberculosis: A systematic review and meta-analysis. *The Lancet Infectious Diseases, 17*(3), 285–295. https://doi.org/10.1016/S1473-3099(16)30474-1

Khan, J., Vesel, L., Bahl, R., & Martines, J. C. (2015). Timing of breastfeeding initiation and exclusivity of breastfeeding during the first month of life: Effects on neonatal mortality and morbidity—A systematic review and meta-analysis. *Maternal and Child Health Journal, 19*(3), 468–479. https://doi.org/10.1007/s10995-014-1526-8

Kiess, W., Reich, A., Meyer, K., Glasow, A., Deutscher, J., Klammt, J., Yang, Y., Müller, G., & Kratzsch, J. (1999). A role for leptin in sexual maturation and puberty? *Hormone Research, 51*(Suppl 3), 55–63. https://doi.org/10.1159/000053163

KuMudini, P., Mrita, J., PratiMa, S., Ipsa, M. P., Priya, R. L., & Jagadananda, J. (2019). Prevalence of intestinal parasitic infections among pulmonary tuberculosis patients in a tertiary care hospital, Bhubaneswar, Odisha, India. *Journal of Clinical and Diagnostic Research, 13*(8), 12–15.

Kuzawa, C. W. (2005). Fetal origins of developmental plasticity: Are fetal cues reliable predictors of future nutritional environments? *American Journal of Human Biology: The Official Journal of the Human Biology Council, 17*(1), 5–21. https://doi.org/10.1002/ajhb.20091

Leonard, W. R., Josh Snodgrass, J., & Robertson, M. L. (2007). Effects of brain evolution on human nutrition and metabolism. *Annual Review of Nutrition, 27*, 311–327. https://doi.org/10.1146/annurev.nutr.27.061406.093659

Leung, C. C., Lam, T. H., Chan, W. M., Yew, W. W., Ho, K. S., Leung, G., Law, W. S., Tam, C. M., Chan, C. K., & Chang, K. C. (2007). Lower risk of tuberculosis in obesity. *Archives of Internal Medicine, 167*(12), 1297–1304. https://doi.org/10.1001/archinte.167.12.1297

Lochmiller, R. L., & Deerenberg, C. (2000). Trade-offs in evolutionary immunology: Just what is the cost of immunity? *Oikos, 88*(1), 87–98. https://doi.org/10.1034/j.1600-0706.2000.880110.x

Lönnroth, K., Williams, B. G., Cegielski, P., & Dye, C. (2010). A consistent log-linear relationship between tuberculosis incidence and body mass index. *International Journal of Epidemiology, 39*(1), 149–155. https://doi.org/10.1093/ije/dyp308

Malhotra, I., Mungai, P., Wamachi, A., Kioko, J., Ouma, J. H., Kazura, J. W., & King, C. L. (1999). Helminth- and bacillus Calmette-Guérin-induced immunity in children sensitized in utero to Filariasis and schistosomiasis. *Journal of Immunology (Baltimore, Md. : 1950), 162*(11), 6843–6848.

Mangtani, P., Abubakar, I., Ariti, C., Beynon, R., Pimpin, L., Fine, P. E. M., Rodrigues, L. C., et al. (2014). Protection by BCG vaccine against tuberculosis: A systematic review of randomized controlled trials. *Clinical Infectious Diseases, 58*(4), 470–480. https://doi.org/10.1093/cid/cit790

Manser, A. R., & Uhrberg, M. (2016). Age-related changes in natural killer cell repertoires: Impact on NK cell function and immune surveillance. *Cancer Immunology, Immunotherapy: CII, 65*(4), 417–426. https://doi.org/10.1007/s00262-015-1750-0

Marais, B. J., & Schaaf, S. (2014). Tuberculosis in children. *Cold Spring Harbor Perspectives in Medicine, 4*(9), a017855. https://doi.org/10.1101/cshperspect.a017855

Marais, B. J., Gie, R. P., Obihara, C. C., Hesseling, A. C., Schaaf, H. S., & Beyers, N. (2005). Well defined symptoms are of value in the diagnosis of childhood pulmonary tuberculosis. *Archives of Disease in Childhood, 90*(11), 1162–1165. https://doi.org/10.1136/adc.2004.070797

Marx, C., Bornstein, S. R., Wolkersdörfer, G. W., Peter, M., Sippell, W. G., & Scherbaum, W. A. (1997). Relevance of major histocompatibility complex class II expression as a hallmark for the cellular differentiation in the human adrenal cortex. *The Journal of Clinical Endocrinology and Metabolism, 82*(9), 3136–3140. https://doi.org/10.1210/jcem.82.9.4194

McDade, T. W. (2003). Life history theory and the immune system: Steps toward a human ecological immunology. *American Journal of Physical Anthropology Suppl, 37*, 100–125. https://doi.org/10.1002/ajpa.10398

McDade, T. W., Reyes-García, V., Tanner, S., Huanca, T., & Leonard, W. R. (2008). Maintenance versus growth: Investigating the costs of immune activation among children in lowland Bolivia. *American Journal of Physical Anthropology, 136*(4), 478–484. https://doi.org/10.1002/ajpa.20831

McDade, T. W., Georgiev, A. V., & Kuzawa, C. W. (2016). Trade-offs between acquired and innate immune defenses in humans. *Evolution, Medicine, and Public Health, 2016*(1), 1–16. https://doi.org/10.1093/emph/eov033

Möller, M., Kinnear, C. J., Orlova, M., Kroon, E. E., van Helden, P. D., Schurr, E., & Hoal, E. G. (2018). Genetic resistance to *Mycobacterium tuberculosis* infection and disease. *Frontiers in Immunology, 9*, 2219. https://doi.org/10.3389/fimmu.2018.02219

Neyrolles, O., & Quintana-Murci, L. (2009). Sexual inequality in tuberculosis. *PLoS Medicine, 6*(12), e1000199. https://doi.org/10.1371/journal.pmed.1000199

Nhamoyebonde, S., & Leslie, A. (2014). Biological differences between the sexes and susceptibility to tuberculosis. *The Journal of Infectious Diseases, 209 Suppl 3*(July), S100–S106. https://doi.org/10.1093/infdis/jiu147

O'Connell, A. E., Rivers, A. E., & Slayton, W. B. (2021). The development of the human immune system. In E. J. Werner, M. C. Sola-Visner, P. A. de Alarcón, & R. D. Christensen (Eds.), *Neonatal hematology: Pathogenesis, diagnosis, and management of hematologic problems* (3rd ed., pp. 25–42). Cambridge University Press. https://doi.org/10.1017/9781108773584.005

O'Garra, A., Redford, P. S., McNab, F. W., Bloom, C. I., Wilkinson, R. J., & Berry, M. P. R. (2013). The immune response in tuberculosis. *Annual Review of Immunology, 31*, 475–527. https://doi.org/10.1146/annurev-immunol-032712-095939

Oberhelman, R. A., Soto-Castellares, G., Gilman, R. H., Caviedes, L., Castillo, M. E., Kolevic, L., Del Pino, T., et al. (2010). Diagnostic approaches for paediatric tuberculosis by use of different specimen types, culture methods, and PCR: A prospective case-control study. *The Lancet Infectious Diseases, 10*(9), 612–620. https://doi.org/10.1016/S1473-3099(10)70141-9

Oberhelman, R. A., Soto-Castellares, G., Gilman, R. H., Castillo, M. E., Kolevic, L., Delpino, T., Saito, M., et al. (2015). A controlled study of tuberculosis diagnosis in HIV-infected and uninfected children in Peru. *PLoS One, 10*(4), e0120915. https://doi.org/10.1371/journal.pone.0120915

Onis, Mercedes de, Onyango, A. W., Borghi, E., Siyam, A., Nishida, C., & Siekmann, J. (2007). Development of a WHO growth reference for school-aged children and adolescents. *Bulletin of the World Health Organization, 85*(9), 660–667. https://doi.org/10.2471/blt.07.043497

PAHO. (2021). *Tuberculosis En Las Américas. Informe Regional 2020*. PAHO. https://iris.paho.org/bitstream/handle/10665.2/55047/9789275324479_spa.pdf?sequence=4&isAllowed=y

Paulson, K. R., Kamath, A. M., Alam, T., Bienhoff, K., Abady, G. G., Abbas, J., Abbasi-Kangevari, M., et al. (2021). Global, regional, and national progress towards sustainable development goal 3.2 for neonatal and child health: All-cause and cause-specific mortality findings from the global burden of disease study 2019. *Lancet, 398*(10303), 870–905. https://doi.org/10.1016/S0140-6736(21)01207-1

PHR, ECOSUR, and CCESC. (2006). *Excluded People, Eroded Communities. Realizing the Ight to Health in Chiapas, Mexico*. Physicians for Human Rights, El Colegio de la Frontera Sur, y Centro de Capacitación en Ecología y Salud para campesinos-defensoría del derecho a la salud. https://phr.org/wp-content/uploads/2006/06/excluded-people-eroded.pdf

Roya-Pabon, C. L., & Perez-Velez, C. M. (2016). Tuberculosis exposure, infection and disease in children: A systematic diagnostic approach. *Pneumonia (Nathan Qld), 8*, 23. https://doi.org/10.1186/s41479-016-0023-9

Russell, D. G. (2007). Who puts the tubercle in tuberculosis? *Nature Reviews. Microbiology, 5*(1), 39–47. https://doi.org/10.1038/nrmicro1538

Said-Mohamed, R., Pettifor, J. M., & Norris, S. A. (2018). Life history theory hypotheses on child growth: Potential implications for short and long-term child growth, development and health. *American Journal of Physical Anthropology, 165*(1), 4–19. https://doi.org/10.1002/ajpa.23340

Salam, R. A., Das, J. K., & Bhutta, Z. A. (2015). Current issues and priorities in childhood nutrition, growth, and infections. *The Journal of Nutrition, 145*(5), 1116S–1122S. https://doi.org/10.3945/jn.114.194720

Sant'anna, C. C., Schmidt, C. M., Pombo March, M. d. F. B., Pereira, S. M., & Barreto, M. L. (2013). Tuberculosis among adolescents in two Brazilian State capitals. *Cadernos de Saúde Pública, 29*(1), 111–116. https://doi.org/10.1590/s0102-311x2013000100013

Sassaki, C. M., Scatena, L. M., Gonzales, R. I. C., Ruffino-Netto, A., Hino, P., & Villa, T. C. S. (2010). Predictors of favorable results in pulmonary tuberculosis treatment (Recife, Pernambuco, Brazil, 2001–2004). *Revista da Escola de Enfermagem da U.S.P., 44*(2), 504–510.

Schaaf, H. S., Cilliers, K., Willemse, M., Labadarios, D., Kidd, M., & Donald, P. R. (2012). Nutritional status and its response to treatment of children, with and without HIV infection, hospitalized for the management of tuberculosis. *Paediatrics and International Child Health, 32*(2), 74–81. https://doi.org/10.1179/2046905512Y.0000000008

Seddon, J. A., Chiang, S. S., Esmail, H., & Coussens, A. K. (2018). The wonder years: What can primary school children teach us about immunity to *Mycobacterium tuberculosis*? *Frontiers in Immunology, 9*, 2946. https://doi.org/10.3389/fimmu.2018.02946

Seneadza, H., Ayegua, N., Antwi, S., Yang, H., Enimil, A., Dompreh, A., Wiesner, L., Peloquin, C. A., Lartey, M., Lauzardo, M., & Kwara, A. (2021). Effect of malnutrition on the pharmacokinetics of anti-tuberculosis drugs in Ghanaian children. *The International Journal of Tuberculosis and Lung Disease : The Official Journal of the International Union against Tuberculosis and Lung Disease, 25*(1), 36–42. https://doi.org/10.5588/ijtld.20.0301

Seppälä, O. (2015). Natural selection on quantitative immune defence traits: A comparison between theory and data. *Journal of Evolutionary Biology, 28*(1), 1–9. https://doi.org/10.1111/jeb.12528

Silva, G., Pérez, F., & Marín, D. (2019). Tuberculosis En Niños y Adolescentes En Ecuador: Análisis de La Notificación, Las Características de La Enfermedad y El Resultado Del Tratamiento. *Revista Panamericana de Salud Pública, 43*, e104. https://doi.org/10.26633/RPSP.2019.104

Sinha, P., Davis, J., Saag, L., Wanke, C., Salgame, P., Jackson Mesick, C., Horsburgh, R., & Hochberg, N. S. (2019). Undernutrition and tuberculosis: Public health implications. *The Journal of Infectious Diseases, 219*(9), 1356–1363. https://doi.org/10.1093/infdis/jiy675

Sobhy, S., Zoe Babiker, J., Zamora, K. S., & Khan, and H. Kunst. (2017). Maternal and perinatal mortality and morbidity associated with tuberculosis during pregnancy and the postpartum period: A systematic review and meta-analysis. *BJOG : An International Journal of Obstetrics and Gynaecology, 124*(5), 727–733. https://doi.org/10.1111/1471-0528.14408

Sousa, G. J. B., de Oliveira Silva, J. C., de Queiroz, T. V., Bravo, L. G., Brito, G. C. B., de Souza Pereira, A., Pereira, M. L. D., & Santos, L. K. X. D. (2019). Clinical and epidemiological features of tuberculosis in children and adolescents. *Revista Brasileira de Enfermagem, 72*(5), 1271–1278. https://doi.org/10.1590/0034-7167-2018-0172

Sudbury, E. L., Otero, L., Tebruegge, M., Messina, N. L., Seas, C., Montes, M., Rìos, J., et al. (2019). *Mycobacterium tuberculosis*-specific cytokine biomarkers for the diagnosis of childhood TB in a TB-endemic setting. *Journal of Clinical Tuberculosis and Other Mycobacterial Diseases, 16*, 100102. https://doi.org/10.1016/j.jctube.2019.100102

Tellez-Navarrete, N. A., Ramon-Luing, L. A., Muñoz-Torrico, M., Osuna-Padilla, I. A., & Chavez-Galan, L. (2021). Malnutrition and tuberculosis: The gap between basic research and clinical trials. *Journal of Infection in Developing Countries, 15*(3), 310–319. https://doi.org/10.3855/jidc.12821

Thomas, T. A. (2017). Tuberculosis in children. *Pediatric Clinics of North America, 64*(4), 893–909. https://doi.org/10.1016/j.pcl.2017.03.010

Thomas, T. A., Mondal, D., Noor, Z., Liu, L., Alam, M., Haque, R., Banu, S., Sun, H., & Peterson, K. M. (2010). Malnutrition and helminth infection affect performance of an interferon gamma-release assay. *Pediatrics, 126*(6), e1522–e1529. https://doi.org/10.1542/peds.2010-0885

Vázquez-Rosales, J. G., Gallegos, C. A., Novales, M. G. M., Del Carmen, Y., Pacheco, F., Zamora, M. G. L., Rosas, D. O. P., & Santos, F. S. (2017). A case-series analysis of tuberculosis in pediatric patients treated in a tertiary level hospital. *Boletin Medico Del Hospital Infantil De Mexico, 74*(1), 27–33. https://doi.org/10.1016/j.bmhimx.2016.10.008

Viani, R. M., Lopez, G., Chacón-Cruz, E., Hubbard, P., & Spector, S. A. (2008). Poor outcome is associated with delayed tuberculosis diagnosis in HIV-infected children in Baja California, Mexico. *The International Journal of Tuberculosis and Lung Disease: The Official Journal of the International Union Against Tuberculosis and Lung Disease, 12*(4), 411–416.

Victora, C. G., Bahl, R., Barros, A. J. D., França, G. V. A., Horton, S., Krasevec, J., Murch, S., Sankar, M. J., Walker, N., & Rollins, N. C. (2016). Breastfeeding in the 21st century: Epidemiology, mechanisms, and lifelong effect. *Lancet, 387*(10017), 475–490. https://doi.org/10.1016/S0140-6736(15)01024-7

Victora, C. G., Christian, P., Vidaletti, L. P., Gatica-Domínguez, G., Menon, P., & Black, R. E. (2021). Revisiting maternal and child undernutrition in low-income and middle-income countries: Variable progress towards an unfinished agenda. *Lancet (London, England), 397*(10282), 1388–1399. https://doi.org/10.1016/S0140-6736(21)00394-9

Villegas, S. L., Ferro, B. E., Rojas, C. M., & Perez-Velez, C. M. (2014). Assessment of children exposed to adult pulmonary tuberculosis in Cali, Colombia. *Paediatrics and International Child Health, 34*(3), 170–177. https://doi.org/10.1179/2046905514Y.0000000128

Wheelwright, M., Kim, E. W., Inkeles, M. S., De Leon, A., Pellegrini, M., Krutzik, S. R., & Liu, P. T. (2014). All-trans retinoic acid-triggered antimicrobial activity against *Mycobacterium tuberculosis* is dependent on NPC2. *Journal of Immunology (Baltimore, Md.: 1950), 192*(5), 2280–2290. https://doi.org/10.4049/jimmunol.1301686

WHO. (2021). *Global tuberculosis report 2021*. WHO. https://www.who.int/publications/i/item/9789240037021

WHO. (2022) *Global tuberculosis report 2022*. WHO. https://reliefweb.int/report/world/global-tuberculosis-report-2022?gclid=CjwKCAjw67ajBhAVEiwA2g_jEIriBcS49VYBZuKQbDm-JMeesizTwx5DXyb5ZGDgTd-VwsTHuB0s9xoC3LUQAvD_BwE

WHO. (2022a). *Bacille Calmette-Guérin (BCG) immunization coverage among 1 years old*. 2022. https://www.who.int/data/maternal-newborn-child-adolescent-ageing/indicator-explorer-new/mca/baccille-calmette-gu%C3%A9rin-(bcg)-immunization-coverage-among-1-year-olds-(−)

WHO. (2022b). *BCG*. 2022. https://www.who.int/teams/health-product-policy-and-standards/standards-and-specifications/vaccines-quality/bcg

WHO. (2022c). *Child growth standards*. 2022. https://www.who.int/tools/child-growth-standards

WHO. (2022d). *Infant and young child feeding*. 2022. https://www.who.int/news-room/fact-sheets/detail/infant-and-young-child-feeding

WHO. (2022e). *Malnutrition*. 2022. https://www.who.int/westernpacific/health-topics/malnutrition

Wolkersdörfer, G. W., Lohmann, T., Marx, C., Schröder, S., Pfeiffer, R., Stahl, H. D., Scherbaum, W. A., Chrousos, G. P., & Bornstein, S. R. (1999). Lymphocytes stimulate dehydroepiandrosterone production through direct cellular contact with adrenal zona reticularis cells: A novel mechanism of immune-endocrine interaction. *The Journal of Clinical Endocrinology and Metabolism, 84*(11), 4220–4227. https://doi.org/10.1210/jcem.84.11.6110

Wong, M., Coit, J. M., Mendoza, M., Chiang, S. S., Marin, H., Galea, J. T., Lecca, L., & Franke, M. F. (2021). Incident tuberculosis diagnoses in children at high risk for disease. *Open Forum Infectious Diseases, 8*(3), ofab075. https://doi.org/10.1093/ofid/ofab075

Yeh, J.-J., Lin, S.-C., & Lin, W.-C. (2019). Congenital tuberculosis in a neonate: A case report and literature review. *Frontiers in Pediatrics, 7*, 255. https://doi.org/10.3389/fped.2019.00255

Yen, Y.-F., Hu, H.-Y., Lee, Y.-L., Ku, P.-W., Lin, I.-F., Chu, D., & Lai, Y.-J. (2017). Obesity/overweight reduces the risk of active tuberculosis: A nationwide population-based cohort study in Taiwan. *International Journal of Obesity (2005), 41*(6), 971–975. https://doi.org/10.1038/ijo.2017.64

Yerramsetti, S., Cohen, T., Atun, R., & Menzies, N. A. (2022). Global estimates of paediatric tuberculosis incidence in 2013–19: A mathematical modelling analysis. *The Lancet Global Health, 10*(2), e207–e215. https://doi.org/10.1016/S2214-109X(21)00462-9

Yunda, L. F., Imbachí, E. V., Sepúlveda, F., Herrera, K. C. M., & Moreno, G. C. (2017). Pulmonary tuberculosis in a pediatric reference hospital in Bogotá, Colombia. *International Journal of Mycobacteriology, 6*(3), 258–263. https://doi.org/10.4103/ijmy.ijmy_68_17

Zabaleta, A. P., Llerena, C., & Valbuena, A. (2019). Resistant tuberculosis in children under 15 years of age, Colombia 2010–2015. *Biomedica: Revista Del Instituto Nacional De Salud, 39*(2), 330–338. https://doi.org/10.7705/biomedica.v39i3.4258

Zanluca, C., de Noronha, L., & Santos, C. N. D. D. (2018). Maternal-fetal transmission of the Zika virus: An intriguing interplay. *Tissue Barriers, 6*(1), e1402143. https://doi.org/10.1080/21688370.2017.1402143

Chapter 5
Non-nutritional Components in the Diet

Lawrence M. Schell

5.1 Introduction

Studies of diet, nutrition and growth focus on the nutritional value of foods. However, many foods carry with them unwanted additives. Today chemical exposure is widespread and even people in remote communities carry burdens of pesticides or herbicides or industrial chemicals, or all three (Abass et al., 2018). Exposure to chemicals comes from several sources. Aside from occupational exposures which have tended to be acute, a main pathway of chronic exposure to chemicals is through ingestion including lactation. Other avenues are via respiration, dermal contact and transplacental exposure. Children are exposed via all four pathways. Although we associate food with nutrition, food also may carry small amounts of toxic chemicals as unintended additions. Dietary exposure is most often chronic, with the exception of accidental food poisonings with chemicals. These chronic exposures are very difficult to detect outside of the laboratory. Thus, people are exposed unknowingly to a variety of chemicals.

The fetus and children are especially at risk because of their size, maturational status, and behavior. Per unit of body weight, children ingest more food and breathe more air. The liver which is the chief organ that metabolizes chemicals in circulation is immature during gestation. An immature liver allows chemicals to circulate in the fetal blood supply for longer periods than in adults. Young children may be slower to metabolize xenobiotics as well. Children also engage in behaviors that bring more chemicals into the body. For example, the hand to mouth behavior that is characteristic of early toddlers introduces dirt and dust in the environment into the body

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S. Datta Banik (ed.), *Human Growth and Nutrition in Latin American and Caribbean Countries*, https://doi.org/10.1007/978-3-031-27848-8_5

thereby contributing to the body burden of lead. Exposure to chemicals by food as well as air, across the placenta and even through skin contact by the developing human poses a risk to the individual's health and growth. Exposure is widespread and very few children in the world are not carrying a burden of one or more chemicals that did not exist a century ago.

In this chapter certain terms are used that require explanations. Xenobiotics are any biological material that is foreign to the organism. The term, chemicals, covers a wide range of materials but in this chapter points to pesticides, herbicides, chemicals made for food preservation, and chemicals invented to aid industrial production (e.g., polychlorinated biphenyls) as well as chemicals made accidentally (e.g., dioxin). These chemicals can be classified in several ways. Many are organochlorines, a grouping into which many pesticides such as DDT and herbicides fall. Organochlorines tend to be highly persistent and resistant to breakdown in the body and the environment. These are also termed persistent organic pollutants (POPs). These organic compounds (e.g., many pesticides and herbicides) are highly persistent in the environment and persist in the body as they are metabolized slowly. Some of the POPs have activity that resembles hormones in the endocrine system and are termed endocrine disruptors. As the hormones of the endocrine system are involved in the regulation of growth, maturation, reproduction, mentation, stress, and fight/flight reactions, etc., any disturbance of the endocrine system can have widespread effects. Furthermore, there are many pathways for their action. According to the USEPA (US Environmental Protection Agency) endocrine disruptors can "interfere with the synthesis, secretion, transport, binding, action, or elimination of natural hormones in the body that are responsible for the maintenance of homeostasis (normal cell metabolism), reproduction, development, and/or behavior."

From the point of view of researchers and policy makers of nutrition and child growth and health, the organochlorines are of greatest concern. There are some exceptions, however. Heavy metals such as lead and arsenic have been shown to affect growth, sexual maturation, and neurobehavioral development. Other metals may have similar effects. Some pesticides have metals in their formulation and metals can be contaminants of pesticides (Defarge et al., 2018).

Knowing the extent of exposure and the impact of these chemicals on the fetus and on children is necessary because many chemicals are extremely valuable in assisting manufacturing and agriculture. Yields could be far lower without certain herbicides and pesticides. The possibility of increasing yields and increasing manufacturing productivity leads to the development of new chemicals every year. Currently, 2000 new chemicals are developed in the United States each year. There are now 80,000 chemicals registered for use, but of these only 20,000 have been examined for safety. Sixty-thousand chemicals are in use without safety testing in the US. The US may not be a model, but it is wealthy and has government agencies that are tasked with testing, yet most chemicals are not tested before entering the market and being put to use. Countries with fewer resources may be able to mount even less scrutiny.

There is substantial evidence today of widespread use of pesticides in the production of fruits and vegetables frequently consumed. For example, in 2008, 4850 million pounds (2,195,387,071 kg) of pesticides were used and the usage increased steadily through 2009, 2010, 2011 and 2012 when 5821 million pounds were used globally (USEPA, 2016). However, few countries maintain comprehensive programs to test produce for the large number of pesticide residues.

To gauge the occurrence of pesticides and their amounts on produce grown outside the US, some information is available from the Food and Drug Administration (FDA), Pesticide Monitoring Program that tests samples imported into the US. Analyses of imported produce consistently find fruits and vegetables bearing one or more pesticide levels above the safe limit standard. In 2008, the US FDA analyzed 3656 fruit and vegetable samples. Violative pesticide residues were found in 4.4% of imported vegetables and 4.8% of imported fruits (Neff et al., 2012). However, the FDA samples a fraction of produce that is imported; during fiscal years 2000–2007 the FDA inspected only about 0.77% of imported produce shipments and conducted laboratory analyses on only 0.22% of shipments (Neff et al., 2012). Neff et al. (2012) modeled pesticide excess for selected imported produce (fruits and vegetables) as the difference between the pesticide level allowed in the exporting country for each fruit or vegetable and that allowed in the importing country (the US), multiplied by the tons of import. By this method of calculation, of the 20 top commodities with excess pesticide residues, 15 were from countries south of the US border (Neff et al., 2012, Table 4). The organ systems known to be targeted by the pesticides are (in order of the number of pesticides having an effect) body weight, liver, blood, endocrine, kidney, CNS, reproductive, and developmental, spleen, gastrointestinal, ocular, respiratory, vascular and carcinogen.

Although pesticide testing of produce is too infrequent to provide a very comprehensive picture of pesticide use and exposure, another source of information on the use of pesticides is provided by data on tons of pesticides used by country. Although this is not a measurement of pesticides on produce it is an indicator of pesticide use. Countries with the most hectares under cultivation could be expected to use the most pesticides. Therefore, assessment is based on tons per hectare of

Table 5.1 The ten countries with the most pesticides used per hectare of cropland

Country	Kg of pesticide per hectare of cropland	Pesticide use in tons-rank	Tons of pesticide used
Maldives	52.6	109	363
Trinidad and Tobago	24.9	86	1,171
Costa Rica	22.5	34	12,811
Bahamas	21.1	114	254
Barbados	21.1	118	168
Saint Lucia	19.6	116	196
Hong Kong	16.6	129	68
Ecuador	13.9	19	34,253
Taiwan	13.3	35	10,549
China	13.1	1	1,763,000

https://www.worldometers.info/food-agriculture/pesticides-by-country/

cultivated land and not total pesticides used. Table 5.1 shows the ten countries that use the most pesticides per hectare and the rank by total tons of pesticides used.

While there is good documentation of pesticide use by different countries, documenting human exposure to pesticides and other polluting toxicants is demonstrated by measurement of toxicants in adipose tissue and or in body fluids such as blood, urine and breast milk. A major hindrance is the cost of laboratory testing and the number of different chemicals that could reasonably deserve monitoring. In addition, some of the analyses may not be possible in many laboratories. Still, there is ample evidence of exposure and body burdens. The situation in Mexico is taken as an example in this report.

For persons who are not exposed through the application of pesticides on crops, the diet is a major source of exposure. Diaz-Vallejo and colleagues made an exhaustive analysis of pesticides residues on produce collected at points of sale between 2013 and 2018 (Diaz-Vallejo et al., 2021). Of 230 samples tested, 57.4% contained one or more pesticide residues. Residue concentrations exceeded Maximum Residue Limits (MRLs) in 14.8% of the samples. Prohibited pesticides were detected in 14.3% of samples tested. Nearly half of the samples tested bore multiple pesticide residues. While the focus on fruits and vegetables is logical as they receive pesticide treatments, pesticides can enter through other avenues of the food chain in high fat foods also, such as in butter and milk (Waliszewski et al., 1997).

Studies of women in Veracruz found detectable levels of lindane and DDT in adipose tissues samples (Herrero-Mercado et al., 2010a, b). Adipose tissue samples of adults in Veracruz showed significantly higher levels of DDT and HCH (hexachlorohexane) than comparable sample from Puebla (Waliszewski et al., 2010). Adipose tissue from all mothers (100%) sampled from Tabasco, Mexico had detectable levels of DDE and nearly all had detectable levels of DDT (Waliszewski et al. 2012, 16). Mothers had significantly higher levels than men. Owing to its relatively high fat content, human breast milk can contain lipophilic chemicals such as organochlorine pesticides. Breast milk from Mexico City, Cuernavaca and rural Morelos was tested for organochlorine pesticides with the highest levels found in the sample from rural Morelos (Elvia et al., 2000). Breast milk from Chelem, Yucatan, was found to contain relatively high levels of DDE, gamma-chlordane, beta-hexacyclohexane (beta-HCH) and PCB congeners (IUPAC# 170, 28, and 44) (Rodas-Ortiz et al., 2008). Milk of Mayan mothers also had high concentrations of organochlorine pesticides (heptachlor epoxide, endrin, dieldrin, endosulfan II, heptachlor, and endrin aldehyde) reflecting the easy migration of agricultural pesticides through karstic soil to water sources (Polanco Rodriguez et al., 2017). Guerrero mothers' breast milk had measurable concentrations of DDE, DDT, and HCB but the levels were lower in comparison to other states in Mexico (Chávez-Almazán et al., 2014). In general, measured levels increase with the age reflecting the accumulation of persistent organic compounds in tissues and the dynamic balance between levels in adipose depots and breast milk fat (Waliszewski et al., 2011, 2012, 2014).

While the main storage depot of organochlorine pesticides is adipose tissue, a comparison of levels among adipose tissue, serum, and umbilical cord blood among mother infant pairs in Veracruz, Mexico demonstrated significant differences in concentrations with the highest concentrations found in the umbilical cord blood followed by maternal serum with the lowest concentration in maternal adipose tissue (Herrero-Mercado et al., 2011). Transfer of organochlorine pesticides before birth was shown in a study of umbilical cord blood from births in Veracruz; DDE was found in 100% of the samples (Herrero-Mercado et al., 2010a, b). Studies of children's levels are not common. One study of 6–12 year old children living in the Yaqui and Mayo valleys of Sonora found DDE (p-p'-DDE) in 100% of the samples, but far lower percentages of other pesticides (lindane, DDT, aldrin, and endosulfan) were found while methoxychlor and endrin were not found in any sample; lead and arsenic were found in all samples which likely reflects the past use of pesticides containing lead and arsenic (Meza-Montenegro et al., 2013). A study of 160 children, 1–14 years of age, whose families worked in tobacco agriculture were found to have evidence of pesticide exposure (Gamlin et al., 2007). Another study of children 5–15 years of age in two agricultural communities, Ahuacapan and Agua Caliente in the state of Jalisco, found 100% of the study subjects were burdened with at least two of the compounds while six of the compounds (malathion, metoxuron, glyphosate, dimethoate, enilconazole, and acetochlor) were detected in more than 70% of the children (Sierra-Diaz et al., 2019).

Exposure matters because many of these chemicals are considered endocrine disruptors with health effects. These were first discovered among workers that used them at high levels routinely in their occupations. For many years guidelines for exposure were based on the average sized male worker, and safety guidelines for pregnant women and subadults have only recently been developed and only for some chemicals. The US Agency for Toxic Substances and Disease Registry maintains a library of health effects and other information for the POPs and other chemicals (ATSDR, 2021) last updated in September of 2021. The health outcomes getting greatest attention are cancers, reproductive disorders and neurological/cognitive development. There is some information on growth and maturation.

5.2 Pesticides, Health, Growth and Maturation

Evaluating health effects, including growth and maturation, is difficult for many reasons, chief among these is the cost of testing. Testing human sera for polychlorinated biphenyls, for example, can cost over 500 USD per person depending on the number of congeners to be measured. In addition, not every laboratory can perform the analyses with appropriate quality control standards leaving researchers in some areas without necessary support.

Studies of Mexican populations have found disturbing associations of pesticides with various health outcomes. An index of placental maturation was correlated with pesticide exposure among mothers in Chihuahua, Mexico suggesting that maternal transfer of nutrients to the fetus could be impaired (Acosta-Maldonado et al., 2009). IUGR has been linked to a history of maternal pesticides exposure by mothers in

Chihuahua, Mexico (Levario-Carrillo et al., 2004). there was an increased risk but a not significant one between pesticide exposure evident in serum (levels of p,p′ DDE and beta-HCB) and preterm birth (Torres-Arreola et al., 2003). However, Lacasaña and colleagues found that there was a greater than 4-fold increase in the risk of anencephaly in children of mothers who worked in agriculture and the risk to children of fathers who applied pesticides was also significantly elevated though not as greatly (Lacasaña et al., 2006). Workers in an anti-malaria campaign who experienced substantial exposures to DDT fathered children with higher rates of birth defects (Salazar-Garcia et al., 2004). A study of birth defects in Nayarit, Mexico found highly significant relationships between the extent of mother's exposure to pesticides and the risk of malformations in her child (Medina-Carrilo et al., 2002). Exposed mothers were 3.5 times more likely to have a malformed child. If she lived near where pesticides were applied the risk was 3.7-fold, and if she had been exposed to pesticides in her occupation the risk was more than 6-fold.

There have been several reviews of growth and maturation effects from some of these EDCs and other chemicals (West et al., 2021; Uldbjerg et al., 2022; Pascale & Laborde, 2020; Harley et al., 2016; Kadawathagedara et al., 2018). As a group, the individual studies reviewed in these papers have produced varying results, some showing depressed growth and others not, some showing increases in BMI and others not. If any conclusion is secure, it is that different chemicals can act on the human body in different ways and all chemicals do not have the same effect despite being included under the umbrella of chemicals. While the specific chemical exposure is one major factor, there are additional sources of variation: differences in the dose or level of exposure; differences in sample sizes; differences in when exposure occurred or was measured; and whether other exposures were included in the analysis; and other contributors to variations in results (West et al., 2021).

Although repeated studies of the same toxicants at similar levels are rare, the relationships of DDT and DDE with measures of growth and maturation have been investigated in numerous studies. Several, though not all studies of DDE measured in cord blood, show a negative relationship with birth weight (Jusko et al., 2006; Lamb et al., 2006; Mendez et al., 2011). Studies of birth length do not find associations with DDE (Lopez-Espinosa et al., 2011; Sagiv et al., 2007). While measuring weight at birth is straightforward, measuring length at birth is difficult, and when performed by untrained personnel, may contain a large error component. Greater weight and BMI in postnatal life have been associated with DDE (Dhooge et al., 2010, 2011; Karmaus et al., 2009). Lesser height in older children and adolescents has been associated with DDT or DDE (Ribas-Fito et al., 2006; Karmaus et al., 2002; Gladen et al., 2000), yet in Russian boys, there was no association of DDE with height (Burns et al., 2012). Several studies have not found associations with height (Gladen et al., 2004; Dhooge et al., 2010). Clearly some of the sources of variation in studies of exposures and growth, referred to earlier in this chapter, are operating.

Studies of DDT are inconsistent in showing delays, acceleration and no association in the age at menarche in relation to DDT measured in postnatal life or during prenatal development (West et al., 2021). There are conflicting results from studies of pesticides and herbicides and human growth and maturation. However, there is now sufficient evidence of negative effects of purported endocrine disrupting pesticides and herbicides to be concerned about effects on growth, maturation and even reproduction.

5.3 Conclusion

There is ample evidence that fruits and vegetables as well as other foods such as butter and milk may contain pesticide residues in addition to the nutrients that are the focus of studies of growth and diet. Adulteration of foods has a long history beginning before government regulations were imposed to improve the health of the population. Today, prenatal and postnatal growth, development and the health of children generally are still in need of protection. The fetus and the child are more susceptible than adults who are larger, have more mature detoxifying mechanisms, and are no longer developing. The many studies of pesticides, herbicides and other chemicals in our foods are consistent in at least one respect: they have not found any benefits to their place in our diets while there is evidence of detrimental effects.

References

Abass, K., Emelyanova, A., & Rautio, A. (2018). Temporal trends of contaminants in Arctic human populations. *Environmental Science and Pollution Research International*, *25*(29), 28834–28850. https://doi.org/10.1007/s11356-018-2936-8. Epub 2018 Aug 25. Erratum in: *Environmental Science and Pollution Research International*. 2019: PMID: 30145756; PMCID.

Acosta-Maldonado, B., Sánchez-Ramírez, B., Reza-López, S., & Levario-Carrillo, M. (2009). Effects of exposure to pesticides during pregnancy on placental maturity and weight of newborns: A cross-sectional pilot study in women from the Chihuahua State, Mexico. *Human & Experimental Toxicology, 28*(8), 451–459. https://doi.org/10.1177/0960327109107045

ATSDR. (2021). *ToxFAQs*. Agency for Toxic Substances and Disease Registry, Centers for Disease Control and Prevention. From https://wwwn.cdc.gov/TSP/ToxFAQs/ToxFAQsLanding.aspx

Burns, J. S., Williams, P. L., Sergeyev, O., Korrick, S. A., Lee, M. M., Revich, B., Altshul, L., Del Prato, J. T., Humblet, O., Patterson, D. G., Turner, W. E., Starovoytov, M., & Hauser, R. (2012). Serum concentrations of organochlorine pesticides and growth among Russian boys. *Environmental Health Perspectives, 120*(2), 303–308. https://doi.org/10.1289/ehp.1103743

Chávez-Almazán, L. A., Diaz-Ortiz, J., Alarcón-Romero, M., Dávila-Vazquez, G., Saldarriaga-Noreña, H., & Waliszewski, S. M. (2014). Organochlorine pesticide levels in breast milk in Guerrero, Mexico. *Bulletin of Environmental Contamination and Toxicology, 93*(3), 294–298. https://doi.org/10.1007/s00128-014-1308-4

Defarge, N., Spiroux de Vendômois, J., & Séralini, G. E. (2018). Toxicity of formulants and heavy metals in glyphosate-based herbicides and other pesticides. *Toxicology Reports, 5*, 156–163. https://doi.org/10.1016/j.toxrep.2017.12.025

Dhooge, W., Den Hond, E., Koppen, G., Bruckers, L., Nelen, V., Van De Mieroop, E., Bilau, M., Croes, K., Baeyens, W., Schoeters, G., & Van Larebeke, N. (2010). Internal exposure to pollutants and body size in Flemish adolescents and adults: Associations and dose-response relationships. *Environment International, 36*(4), 330–337. https://doi.org/10.1016/j.envint.2010.01.005

Dhooge, W., den Hond, E., Koppen, G., Bruckers, L., Nelen, V., van de Mieroop, E., Bilau, M., Croes, K., Baeyens, W., Schoeters, G., & van Larebeke, N. (2011). Internal exposure to pollutants and sex hormone levels in Flemish male adolescents in a cross-sectional study: associations and dose-response relationships. *Journal of Exposure Science & Environmental Epidemiology, 21*(1), 106–113. https://doi.org/10.1038/jes.2009.63. PMID: 20010975

Díaz-Vallejo, J, Barraza-Villarreal, A, Yáñez-Estrada, L, & Hernández-Cadena, L. (2021). [Pesticide residues in food: Health risk and regulation in Veracruz, Mexico]. *Salud Publica De Mexico*, *63*(4), 486–497. https://doi.org/10.21149/12297

Elvia, L. F., Sioban, H. D., Bernardo, H. P., & Carillo Constanza, S. (2000). Organochlorine pesticide exposure in rural and urban areas in Mexico. *Journal of Exposure Analysis and Environmental Epidemiology, 10*(4), 394–399. https://doi.org/10.1038/sj.jea.7500103

Gamlin, J., Diaz Romo, P., & Hesketh, T. (2007). Exposure of young children working on Mexican tobacco plantations to organophosphorous and carbamic pesticides, indicated by cholinesterase depression. *Child: Care, Health and Development, 33*(3), 246–248. https://doi.org/10.1111/j.1365-2214.2006.00702.x

Gladen, B. C., Ragan, N. B., & Rogan, W. J. (2000). Pubertal growth and development and prenatal and lactational exposure to polychlorinated biphenyls and dichlorodiphenyl dichloroethene. *The Journal of Pediatrics, 136*(4), 490–496. https://doi.org/10.1016/s0022-3476(00)90012-x

Gladen, B. C., Klebanoff, M. A., Hediger, M. L., Katz, S. H., Barr, D. B., Davis, M. D., & Longnecker, M. P. (2004). Prenatal DDT exposure in relation to anthropometric and pubertal measures in adolescent males. *Environmental Health Perspectives, 112*(17), 1761–1767. https://doi.org/10.1289/ehp.7287

Harley, K. G., Engel, S. M., Vedar, M. G., Eskenazi, B., Whyatt, R. M., Lanphear, B. P., Bradman, A., Rauh, V. A., Yolton, K., Hornung, R. W., Wetmur, J. G., Chen, J., Holland, N. T., Barr, D. B., Perera, F. P., & Wolff, M. S. (2016). Prenatal exposure to organophosphorous pesticides and fetal growth: Pooled results from four longitudinal birth cohort studies. *Environmental Health Perspectives, 124*, 1084–1092. https://doi.org/10.1289/ehp.1409362

Herrero-Mercado, M., Waliszewski, S. M., Caba, M., Martínez-Valenzuela, C., & Hernández-Chalate, F. (2010a). Organochlorine pesticide levels in umbilical cord blood of newborn in Veracruz, Mexico. *Bulletin of Environmental Contamination and Toxicology, 85*(4), 367–371. https://doi.org/10.1007/s00128-010-0108-8

Herrero-Mercado, M., Waliszewski, S. M., Valencia-Quintana, R., Caba, M., Hernández-Chalate, F., García-Aguilar, E., & Villalba, R. (2010b). Organochlorine pesticide levels in adipose tissue of pregnant women in Veracruz, Mexico. *Bulletin of Environmental Contamination and Toxicology, 84*(6), 652–656. https://doi.org/10.1007/s00128-010-0028-7

Herrero-Mercado, M., Waliszewski, S. M., Caba, M., Martínez-Valenzuela, C., Gómez Arroyo, S., Villalobos Pietrini, R., Cantú Martínez, P. C., & Hernández-Chalate, F. (2011). Organochlorine pesticide gradient levels among maternal adipose tissue, maternal blood serum and umbilical blood serum. *Bulletin of Environmental Contamination and Toxicology, 86*(3), 289–293. https://doi.org/10.1007/s00128-011-0204-4

Jusko, T. A., Koepsell, T. D., Baker, R. J., Greenfield, T. A., Willman, E. J., Charles, M. J., Teplin, S. W., Checkoway, H., & Hertz-Picciotto, I. (2006). Maternal DDT exposures in relation to fetal and 5-year growth. *Epidemiology (Cambridge, MA), 17*(6), 692–700. https://doi.org/10.1097/01.ede.0000232226.06807.90

Kadawathagedara, M., de Lauzon-Guillain, B., & Botton, J. (2018). Environmental contaminants and child's growth. *Journal of Developmental Origins of Health and Disease, 9*(6), 632–641. Cambridge University Press. ff10.1017/S2040174418000995ff. ffhal-02904542f.

Karmaus, W., Asakevich, S., Indurkhya, A., Witten, J., & Kruse, H. (2002). Childhood growth and exposure to dichlorodiphenyl dichloroethene and polychlorinated biphenyls. *The Journal of Pediatrics, 140*(1), 33–39. https://doi.org/10.1067/mpd.2002.120764

Karmaus, W., Osuch, J. R., Eneli, I., Mudd, L. M., Zhang, J., Mikucki, D., Haan, P., & Davis, S. (2009). Maternal levels of dichlorodiphenyl-dichloroethylene (DDE) may increase weight and body mass index in adult female offspring. *Occupational and Environmental Medicine, 66*(3), 143–149. https://doi.org/10.1136/oem.2008.041921

Lacasaña, M., Vázquez-Grameix, H., Borja-Aburto, V. H., Blanco-Muñoz, J., Romieu, I., Aguilar-Garduño, C., & García, A. M. (2006). Maternal and paternal occupational exposure to agricultural work and the risk of anencephaly. *Occupational and Environmental Medicine, 63*(10), 649–656. https://doi.org/10.1136/oem.2005.023333

Lamb, M. R., Taylor, S., Liu, X., Wolff, M. S., Borrell, L., Matte, T. D., Susser, E. S., & Factor-Litvak, P. (2006). Prenatal exposure to polychlorinated biphenyls and postnatal growth: A structural analysis. *Environmental Health Perspectives, 114*(5), 779–785. https://doi.org/10.1289/ehp.8488

Levario-Carrillo, M., Amato, D., Ostrosky-Wegman, P., González-Horta, C., Corona, Y., & Sanin, L. H. (2004). Relation between pesticide exposure and intrauterine growth retardation. *Chemosphere, 55*(10), 1421–1427. https://doi.org/10.1016/j.chemosphere.2003.11.027

Lopez-Espinosa, M.-J., Murcia, M., Iñiguez, C., Vizcaino, E., Llop, S., Vioque, J., Grimalt, J. O., Rebagliato, M., & Ballester, F. (2011). Prenatal exposure to organochlorine compounds and birth size. *Pediatrics, 128*(1), e127–e134. https://doi.org/10.1542/peds.2010-1951

Medina-Carrilo, L, Rivas-Solis, F, & Fernández-Argüelles, R. (2002). [Risk for congenital malformations in pregnant women exposed to pesticides in the state od Nayarit, Mexico]. *Ginecologia Y Obstetricia De Mexico*, *70*, 538–544.

Mendez, M. A., Garcia-Esteban, R., Guxens, M., Vrijheid, M., Kogevinas, M., Goñi, F., Fochs, S., & Sunyer, J. (2011). Prenatal organochlorine compound exposure, rapid weight gain, and overweight in infancy. *Environmental Health Perspectives, 119*(2), 272–278. https://doi.org/10.1289/ehp.1002169

Meza-Montenegro, M. M., Valenzuela-Quintanar, A. I., Balderas-Cortés, J. J., Yañez-Estrada, L., Gutiérrez-Coronado, M. L., Cuevas-Robles, A., & Gandolfi, A. J. (2013). Exposure assessment of organochlorine pesticides, arsenic, and lead in children from the major agricultural areas in Sonora, Mexico. *Archives of Environmental Contamination and Toxicology, 64*(3), 519–527. https://doi.org/10.1007/s00244-012-9846-4

Neff, R. A., Hartle, J. C., Laestadius, L. I., Dolan, K., Rosenthal, A. C., & Nachman, K. C. (2012). A comparative study of allowable pesticide residue levels on produce in the United States. *Global Health, 8*, 2. https://doi.org/10.1186/1744-8603-8-2

Pascale, A., & Laborde, A. (2020). Impact of pesticide exposure in childhood. *Reviews on Environmental Health, 35*(3), 221–227. https://doi.org/10.1515/reveh-2020-0011. PMID: 32598326.).

Polanco Rodríguez, Á. G., Inmaculada Riba López, M., Angel DelValls Casillas, T., León, J. A. A., Anjan Kumar Prusty, B., & Álvarez Cervera, F. J. (2017). Levels of persistent organic pollutants in breast milk of Maya women in Yucatan, Mexico. *Environmental Monitoring and Assessment, 189*(2), 59. https://doi.org/10.1007/s10661-017-5768-y

Ribas-Fitó, N., Gladen, B. C., Brock, J. W., Klebanoff, M. A., & Longnecker, M. P. (2006). Prenatal exposure to 1,1-dichloro-2,2-bis (p-chlorophenyl)ethylene (p,p′-DDE) in relation to child growth. *International Journal of Epidemiology, 35*(4), 853–858. https://doi.org/10.1093/ije/dyl067

Rodas-Ortíz, J. P., Ceja-Moreno, V., González-Navarrete, R. L., Alvarado-Mejía, J., Rodríguez-Hernández, M. E., & Gold-Bouchot, G. (2008). Organochlorine pesticides and polychlorinated biphenyls levels in human milk from Chelem, Yucatán, México. *Bulletin of Environmental Contamination and Toxicology, 80*(3), 255–259. https://doi.org/10.1007/s00128-007-9356-7

Sagiv, S. K., Tolbert, P. E., Altshul, L. M., & Korrick, S. A. (2007). Organochlorine exposures during pregnancy and infant size at birth. *Epidemiology (Cambridge, MA), 18*(1), 120–129. https://doi.org/10.1097/01.ede.0000249769.15001.7c

Salazar-García, F., Gallardo-Díaz, E., Cerón-Mireles, P., Loomis, D., & Borja-Aburto, V. H. (2004). Reproductive effects of occupational DDT exposure among male malaria control workers. *Environmental Health Perspectives, 112*(5), 542–547. https://doi.org/10.1289/ehp.112-1241918

Sierra-Diaz, E., Celis-de la Rosa, A. D. J., Lozano-Kasten, F., Trasande, L., Peregrina-Lucano, A. A., Sandoval-Pinto, E., & Gonzalez-Chavez, H. (2019). Urinary pesticide levels in children and adolescents residing in two agricultural communities in Mexico. *International Journal of Environmental Research and Public Health, 16*(4), E562. https://doi.org/10.3390/ijerph16040562

Torres-Arreola, L., Berkowitz, G., Torres-Sánchez, L., López-Cervantes, M., Cebrián, M. E., Uribe, M., & López-Carrillo, L. (2003). Preterm birth in relation to maternal organochlorine serum levels. *Annals of Epidemiology, 13*(3), 158–162. https://doi.org/10.1016/s1047-2797(02)00424-6

Uldbjerg, C. S., Koch, T., Lim, Y.-H., Gregersen, L. S., Olesen, C. S., Andersson, A. M., Frederiksen, H., Coull, B. A., Hauser, R., Juul, A., & Bräuner, E. V. (2022). Prenatal and postnatal exposures to endocrine disrupting chemicals and timing of pubertal onset in girls and boys: A systematic review and meta-analysis. *Human Reproduction Update, 28*(5), 687–716. https://doi.org/10.1093/humupd/dmac013

USEPA. (2016). *Pesticides industry sales and usage: 2008–212 market estimates*. United States Environmental Protection Agency. From https://www.epa.gov/sites/default/files/2017-01/documents/pesticides-industry-sales-usage-2016_0.pdf

Waliszewski, S. M., Pardío, V. T., Waliszewski, K. N., Chantiri, J. N., Aguirre, A. A., Infanzón, R. M., Rivera J. (1997). Organochlorine pesticide residues in cow's milk and butter in Mexico. *Science of the Total Environment, 208*(1-2), 127–132. https://doi.org/10.1016/s0048-9697(97)00270-2. PMID: 9496657

Waliszewski, S. M., Valencia Quintana, R., Corona, C. A., Herrero, M., Sánchez, K., Aguirre, H., Aldave, I. A., Gomez Arroyo, S., & Villalobos Pietrini, R. (2010). Comparison of organochlorine pesticide levels in human adipose tissue of inhabitants from Veracruz and Puebla, Mexico. *Archives of Environmental Contamination and Toxicology, 58*(1), 230–236. https://doi.org/10.1007/s00244-009-9325-8

Waliszewski, S. M., Caba, M., Herrero-Mercado, M., Saldariaga-Noreña, H., Meza, E., Zepeda, R., Martínez-Valenzuela, C., Infanzon, R., & Hernández-Chalate, F. (2011). Monitoring of organochlorine pesticide residue levels in adipose tissue of Veracruz, Mexico inhabitants. *Bulletin of Environmental Contamination and Toxicology, 87*(5), 539–544. https://doi.org/10.1007/s00128-011-0341-9

Waliszewski, S. M., Caba, M., Rodríguez Díaz, S. S., Saldarriaga-Noreña, H., Meza, E., Zepeda, R., & Infanzón, R. (2012). Levels of organochlorine pesticides residues in human adipose tissue, data from Tabasco, Mexico. *Bulletin of Environmental Contamination and Toxicology, 89*(5), 1062–1067. https://doi.org/10.1007/s00128-012-0803-8

Waliszewski, S. M., Caba, M., Saldarriaga-Noreña, H., Martínez, A. J., Meza, E., Valencia Quintana, R., & Zepeda, R. (2014). Organochlorine pesticide level differences among female inhabitants from Veracruz, Puebla and Tabasco, Mexico. *Bulletin of Environmental Contamination and Toxicology, 93*(2), 233–237. https://doi.org/10.1007/s00128-014-1309-3

West, C. N., Schell, L. M., & Gallo, M. V. (2021). Sex differences in the association of measures of sexual maturation to common toxicants: Lead, dichloro-diphenyl-trichloroethane (DDT), dichloro-diphenyl-dichloroethylene (DDE), and polychlorinated biphenyls (PCBs). *Annals of Human Biology, 48*(6), 485–502. https://doi.org/10.1080/03014460.2021.1998623

Part II
Methods of Human Growth and Development

Chapter 6
Reference Curves of Growth from Colombian National Surveys and Anthropometric Secular Trends

Javier Rosique Gracia, Edisson Alonso Montoya Granda, and Andrés Felipe García Pineda

6.1 Introduction

Anthropometry is related to environmental and welfare characteristics of populations (Baten & Blum, 2012) as economic studies and anthropometric history show (Komlos & Baten, 2004). Human body size displays an amazing variation across populations all over the continents, as a results of their exposure to varying environments, heritability make-up, evolutionary processes, nutrition, and cultural behavior. These forceful factors act through the specific periods of growth and development, from prenatal and infancy to adolescence, to enhance or retard adult size that can be explained in the perspective of human evolution (Little, 2020). However, human biology and health studies pay attention on biological explanations on how anthropometric measures are achieved during human growth because of the ontogeny modulation processes (Cole, 2000; Martorell & Habicht, 1986; Rona et al., 2003). In fact, most of the changes that increased height are stablished in late childhood (Cole, 2000).

Growth studies have been developed with an aim to generate growth references as a tool for assessing the well-being of individuals and communities and to monitor their progress in achieving goals or to enhance social equality of health and nutrition as proposed Garza and De Onis (2004). The marked vulnerability of children and young in Latin American communities and in Colombia makes necessary to evaluate growth periodically by updating growth references for that purpose. Although growth standards proposed by the WHO Multicentre Growth Reference Study Group (2006) for height, weight, BMI, and head circumference for 0–5 years and the further reference extension for 5–19 years (de Onis et al., 2007) are the main

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S. Datta Banik (ed.), *Human Growth and Nutrition in Latin American and Caribbean Countries*, https://doi.org/10.1007/978-3-031-27848-8_6

tools used to assess children and young growth status. In Colombia, the interest in developing local growth references is increasing among pediatricians for clinical reasons (Durán et al., 2016), and among anthropologists to study regional and ethnic differences (Rosique et al., 2012) and secular trend from a historical point of view (Acosta & Meisel, 2013).

National data of anthropometric measurements to evaluate growth of children and adolescents can be found in the surveys conducted by the *Instituto Colombiano de Bienestar Familiar* (ICBF) that were done to know the nutritional condition of Colombian people representing a wider age range (0–64 years). These surveys were known as ENSIN 2005, 2010 and 2015 (ICBF, 2005, 2011, 2015) and they permitted an insight to the study of growth status together with nutritional status of the whole age span until senescence. ENSIN surveys were used to study comparatively nutrition transition from a public health perspective to follow trends in overweight and obesity (Parra et al., 2015) and in food consumption (Herrán et al., 2020). However, the survey from ICBF (2015) can be used to obtain national growth references because it was the last national survey on public health and it has a great potential to estimate secular trend. Moreover, other growth surveys produced references for local use in the department of Casanare (Ireton & Carrillo, 2014) affording centile curves fitted by the LMS method (Cole, 1988) and in a national range, there are references based mainly on urban samples published to develop national growth references from Colombia (Durán et al., 2016) to afford tools (tables and curves) to follow growth of height, weight, BMI, and head circumference for pediatric purposes. These reference curves were fitted following the recommendations of Rigby and Stasinopoulos (2005) to apply generalized additive models for location, scale, and shape (GAMLSS) and can be used for secular trend comparisons at the national level. Other local references for height, weight and BMI of children and adolescents from Central Colombia have also been developed for public health purposes to monitor growth of children from middle altitude in Central Colombia (Díaz-Bonilla et al., 2018). Moreover, Colombian researchers have paid attention to other anthropometric and nutritional variables to obtain local growth reference curves of fat percentage (Escobar-Cardozo et al., 2016), waist circumference and waist-to-height ratios (Ramírez-Vélez et al., 2017).

Since the observations of Tanner (1962, p. 143), 60 years ago, explaining secular increase in height by the effects of war cessation and related famine in Europe there have been many other studies asserting that the whole process of growth has been progressively speeding up in children from different decades meanwhile the welfare conditions and nutrition were steady inside populations. With respect to secular trends, it has been reported (N.C.D. & Risk, 2016) that the largest gain in adult height over a century (1886–1996) has occurred in South Korea and Iran. In contrast, there was little change in adult height in some sub-Saharan African countries and in South Asia over the same century. In the study of Baten and Blum (2012) from 1810 to 1989 heights in Latin American and Caribbean regions were in-between the heights of Central Asia and South Asia, being those of South Asia the shortest heights.

Historical data were analyzed by Keep and Bogin (1999) in a vast chronological and geographical study of the Americas pointing out the decline in adult stature from the Conquest to 1939 and then a subsequent positive trend in stature until 1989. However, children stature showed negative secular trends in some countries of Central America in the 70s and 80s and continued latter due to inequalities (Mansukoski et al., 2020). However, there are few studies of height trends or other anthropometric trends either in adults or children in many low- and middle-income countries in the Americas or beyond. Some researchers approached to this kind of studies on secular trend in stature in Mexican-American children (Malina & Zavaleta, 1980) and then the focus spread to many countries such as Mexico (McCullough, 1982), Guatemala (Bogin & Macvean, 1982), Venezuela (Landaeta-Jiménez et al., 2002), Chile (Dittmar, 1998), Argentina (Agrelo et al., 1999; Bejarano et al., 1996; Guimarey et al., 2014), and more recently on nutritional status like secular increase of overweight in Brazil (Silveira et al., 2014) and obesity in Argentina (Orden et al., 2019). The interest of improving nutrition in the Americas up to trigger secular trend, with positive results in body size, has been increasing due to the founded intent of overcome the relationship between leg length and dementia in Brazil (Scazufca et al., 2008) and other Latin American countries (Prince et al., 2018). Moreover, there is a recognized tradition on the study of the secular trend of biological maturation in the age at menarche in Chile (Ossa et al., 2010), Colombia (Villamor et al., 2009) and México (Marván et al., 2020).

In the case of Colombian research, the first studies on secular trend were performed to understand biological ageing and the yearly loss of stature with age in rural Colombia (Himes & Mueller, 1977). Other kind of studies on anthropometry were underpinned by social researchers to examine changes in economic history (Meisel-Roca & Vega, 2004) and found an increase between 8 and 9 cm in adult height from 1910 to 1984. The data source in those studies worked with the biometric data reported in the registers of the National ID Card and focused on the mirror relationship between mean height and GDP (Gross Domestic Product) variation or other similar indicators of well-being. In auxological studies, Ireton and Carrillo (2014) reported secular variations in height and weight in Casanare between 1992 and 2001. Recently, in Colombia and other middle-income countries, researchers focused on secular trends of nutritional conditions such as body fat distribution (Bender et al., 2020) reporting from 1988–1989 and 2007–2008; a shift of fat accumulation on upper body of women, and the increase of obesity from 2005 to 2010 mainly in urban areas and the Atlantic Coast of Colombia was observed (Kasper et al., 2013).

The aim of the present paper is to construct national growth references and analyze the ability of the original database of the nutritional survey ENSIN 2015, designed and developed by ICBF (2015) to afford national references and to determine secular changes in growth during a decade by comparing Colombian national data from 2005 to 2015, focusing on height, weight, and BMI.

6.2 Methods

Height, weight, and BMI data from the database of ENSIN 2015 were used to develop growth reference curves by means of the application of the LMS program v.1.29 (Institute of Child Health). The cross-sectional sample consisted of 30,115 males aged 2.00 to 24.00 years and 28,522 females aged 2.00 to 23.00 years. After the exclusion of outliers and missing values, the final useful samples for the application of the LMS method remained between 90.7% and 94.0% of the initial samples depending on the measure (Table 6.1). The characteristics of the cross-sectional survey and population background can be found in (ICBF, 2015). The objective of the fitting was the construction of growth curves for age by each variable, by means of plotting a set of 7 smoothed centiles equal spaced, 1sd apart, covering the range of ±3sd. These set of 7 centiles are the usual cutoff lines used in growth graphics to locate individuals and to assign z-scores with the purpose of growth evaluation. The calculation methods employed a smoothing fitting because empirical centile curves are irregular and because the theoretical growth models are continuous functions whether they be structural or non-structural models.

The LMS method (Cole, 1988) is based on the use of transformations of original data to the normal distribution (Box & Cox, 1982) through the calculation of a skewness parameter. The three parameters, L, M, and S are the L power of Box-Cox transformation, the Median (M parameter), and the Coefficient of Variation (S parameter). The smoothed functions of age are obtained by a global fit of the whole sample points by age. The parameters solved by the method of maximum penalized likelihood generates values of L, M, and S that are smoothed over age. A key point of the fit is to select the initial values of the parameters to start the recurrent cycles of estimation of the final parameters. Initial values are edf (equivalent degree of freedom) according to the software terms. In the present study, initial edf where set to L = 3, M = 5 and S = 3 for height, weight, and BMI. The usual procedure when fitting the data step by step to the model is to observe the change in Deviance (D) when the fitting cycles stop after selecting the rescaled age option or any transformation of original age, if the change in D is greater than 5 units, it is considered a significant fitting. The present study found adequate the rescaled age only when fitting height and weight, because BMI performed much better with the original age. However, to maximize the change in D several runs were performed by adding one unit to the edf in the following order: firstly, change edf of M, then S and finally the edf of L. After changing the edf of each parameter, the Deviance should be observed to appreciate if the change in D can be taken as significant. The change in D is equivalent to the minimization of residuals of the fit, and therefore the change should be <0. These final parameters are then used to construct the desired percentiles by the proper functions. The specific parameter values by age can be displayed by the software to monitor cycles (Fig. 6.1).

These smoothed functions following the algorithm of Cole (1990) are written below, where t_i is the age, and Y_i is the value of the anthropometric variable corresponding to a selected centile curve, and Z is the desired percentile position in

Table 6.1 Number of subjects (n) in the initial samples (cases in databases) of the Survey (ENSIN 2015) showing missing and outliers excluded

	Survey (0–64.9 years)			Growth sample							
Variables	Sex	Initial	Valid	Missing and outliers	Initial	Valid	Missing and outliers	Excluded	Final	Final LMS edf	Deviance change
Weight-for-age	Males	66,461	57,455	9,006	30,115	27,444	2,671	131	27,313	6–8-4	−1680.3
	Females	71,118	66,356	4,762	28,522	26,925	1,597	139	26,786	5–8-4	−1474.0
Height-for-age	Males	66,461	57,455	9,006	30,115	27,452	2,663	122	27,330	3–10-8	−2823.2
	Females	71,118	66,356	4,762	28,522	26,952	1,570	134	26,818	7–9-7	−2622.3
BMI-for-age	Males	66,461	57,455	9,006	30,115	27,415	2,700	51	27,364	4–10-4	−436.9
	Females	71,118	66,356	4,762	28,522	26,912	1,610	123	26,789	4–8-6	−474.8

Growth samples of the suitable ages (2–24.0 years for males and 2–23.0 years for females) included in the fitting procedure are also labeled as initial, valid (after excluding missing and outliers) and final samples useful to apply the LMS model. Label of excluded subjects stands for the rejected outliers to approach normality. Parameters representing goodness of fit are shown, final *edf* (equivalent degrees of freedom) for L, M, S parameters and the total change in Deviance inside the significant range ($p < 0.05$)

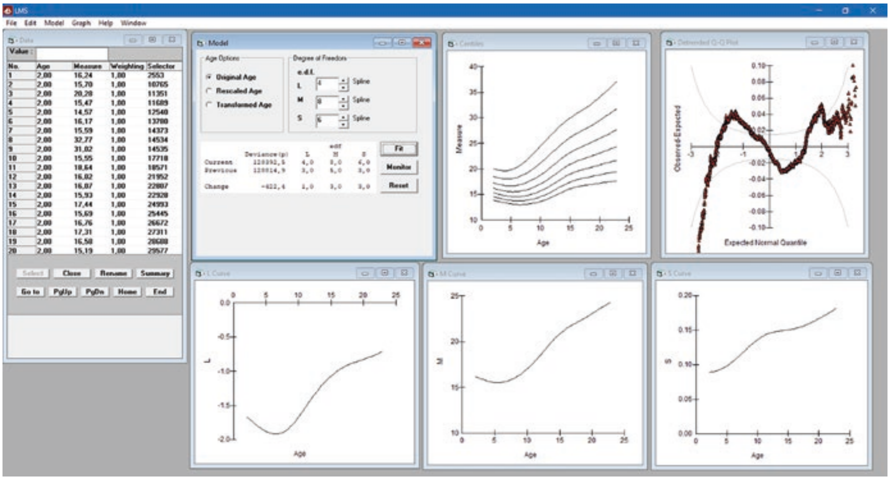

Fig. 6.1 Graphics displayed by the LMS v.1.29 when running a series of fitting cycles. This example on the fitting procedure of female sample of BMI-for-age shows a detrended Q-Q plot in the right corner that can be improved by excluding cases, however the worm-shape displayed approaches to normality

standard deviation units referred to the normal distribution, and they can give the value of the variable at the desired percentile, considering age by age two possible distributions: with skewness ($L \neq 0$) or without ($L = 0$).

$$Y_i(t_i) = M(t_i)\cdot\left(1 + L(t_i)\cdot S(t_i)\cdot Z_\alpha\right)^{1/L(t_i)} \quad \text{when} \quad L(t_i) \neq 0$$

$$Y_i(t_i) = M(t_i)\cdot \exp\left(S(t_i)\cdot Z_\alpha\right) \quad \text{when} \quad L(t_i) = 0$$

In the LMS program v.1.29, *File* module and command *export*, were used to save properly the seven centiles by age, 1sd apart, in *.txt format (or *.ept equivalent), and then they were transferred through Excel® to draw the graphic curves. On the contrary, for any given value of the anthropometric variable, the corresponding z score (Z_i) can be calculated as:

$$Z_i = \frac{\left[y_i / M(t_i)\right]^{L(T_j)} - 1}{L(t_i)S(t_i)} \quad \text{when} \quad L(t_i) \neq 0$$

$$Z_i = \frac{1}{S(t_i)} \log_e\left[y_i / M(t_i)\right] \quad \text{when} \quad L(t_i) = 0$$

The range of data ±3z by age helps to clean almost all the outliers when fit large samples. Data fitting to the model improves with the identification and deletion of outliers because some extreme points could be overrepresented in the final fitting and is worth to reduce them when lie out of ±3sd of the Q-Q normal plot (Van Buuren & Fredriks, 2001). However, when skewness is high it is a hard work, and it is enough to improve the shape of very extremes because in that case skewness is also a characteristic of the data collected.

When there are many short subjects as in national Colombian samples it is worthy to observe the detrended Q-Q plot displayed in LMS v.129, it shows an M shape for height and BMI instead of a S-shape or a worm-shape, and to improve the fitting it is better to exclude outliers until the plot approaches the characteristic worm-shape as in the example on Fig. 6.1. Considering data in the range of ±3z or ± 4z age by age to perform the fit helps to improve the worm-shape of normal residuals with the usual head-up, tail-down described in van Buuren and Fredriks (2001).

The present study checked the goodness of fit of the LMS model both graphically and by means of the change in Deviance (D), a function based in – 2log P (penalized likelihood). Deviance has a chi-square distribution with the equivalent degrees of freedom assigned to the change in D that can be read directly when running the fitting cycles by the software.

The acceleration curve afforded by the LMS analysis was used to calculate graphically the population parameters related to the shape of the spurt, when the acceleration line crosses the x-axis, the abscise is the age at peak. This had only a descriptive purpose, considering that the sample data were collected cross-sectionally.

Secular changes in Height, Weight, and BMI

To compare the smoothed growth curves obtained by the present study of ENSIN 2015 with those of the previous survey of ENSIN 2005, data on height, weight, and BMI were analyzed from the database (ICBF, 2005) by fitting the original data by means of the LMS pro v.1.29 (Institute of Child Health). Firstly, the set of growth data of each variable was extracted. Males ranged from 2.00 to 24.00 years (sample size 28,195 subjects), and females ranged from 2.00 to 22.49 years (sample size 29,482 subjects). Final sample sizes (27,986 males and 29,209 females) were fitted by the LMS model after cleaning outliers, age by age, and moreover identifying and excluding some extremes graphically by the detrended Q-Q plot of the data graph option afforded by the software. The fitting was significant due to change in Deviance for all the variables. Secular changes were studied by computing differences after a decade of anthropometric variation (2005–2015) in terms of the Median smoothed curve lines. These differences should be intended as a biological mirror of the social and economic changes during the decade from 2005 to 2015, and a proper understanding needed an interdisciplinary approach.

6.3 Results

The final number of subjects in the analyses after excluding outliers and extremes to improve normalization were shown in Table 6.1. Missing values found in the original database of age or anthropometry were excluded and most extreme outliers of the survey data were also excluded. The values of goodness of fit (change in Deviance, D) after running the total fitting cycles on each anthropometric variable were obtained by the difference between the first and the last cycle yielding a change in D values <0 and significant ($p < 0.05$). The appropriate final edf of the fitted parameters L, M and S, are also shown in Table 6.1 by sex. BMI centile curves did not follow the expected change in Deviance by rescaling ages and only allowed a little change when worked out centile curves with transforming procedures of age ($y = offset + age^{(1.5)}$), so it was decided to fit BMI for both sexes by the original age. The fit of height-for-age yielded the greater reduction of residuals in the seven centile curves with respect to weight and BMI (Table 6.1).

Height-for-Age

After fitting the LMS model to the height data by age in both sexes, the M curve reached a steady asymptote in both sexes at different ages, i.e., from 22.0 years in males and 21.5 in females. The shape of the centile curves described properly the variance increase during puberty as a belly of the seven growth curves (11–14 years in males and 9–12 years in females) before final height is reached (Fig. 6.2). Data showed negative asymmetry in the whole range of age, due to the accumulation of short subjects by age with heights lower than the median. Normalization reduced asymmetry by fitting the L curve. Male's asymmetry showed a slight decrease from 5 to 13 years, while females' asymmetry decreased from 5 to 10 years and again from 17 years onwards. Fitting parameters obtained and the corresponding final sd cutoff lines values for males and females are shown in Table 6.2. Final height at 23 years was 169.66 cm in males and 156.99 cm in females. Sexual dimorphism of attained height at 2 years was 1.41 cm and then at 23 years reached 12.66 cm. The mean age at peak, i.e., at the highest increment in height spurt, was 13.4 years for males and 10.7 for females, and the mean age at take-off: 9.3 years for males and 7.4 years for females.

Figure 6.2 shows the plot of medians of the pediatric references constructed by Durán et al. (2016) and the study of Díaz-Bonilla et al. (2018) against the national reference curves of the present study. Both medians lied in the range of normal growth (M ± 1sd) of the reference of height-for-age. The median line of Díaz-Bonilla et al. (2018) approaches the present study (mean differences: 1.25 cm in males and 1.07 cm in females), and mainly up to 10 years of age, while the smoothed mean from Durán et al. (2016) is higher all over the age range (mean differences: 3.11 cm in males and 2.45 cm in females). Moreover from 9 to 13 years, in males, the smoothed mean from Durán et al. (2016) reaches the +1sd cutoff line of the present study. Final height was lower to both compared studies, i.e., when contrasted with Durán et al. (2016) al 20 years, 3.07 cm in males and 2.69 in girls, and

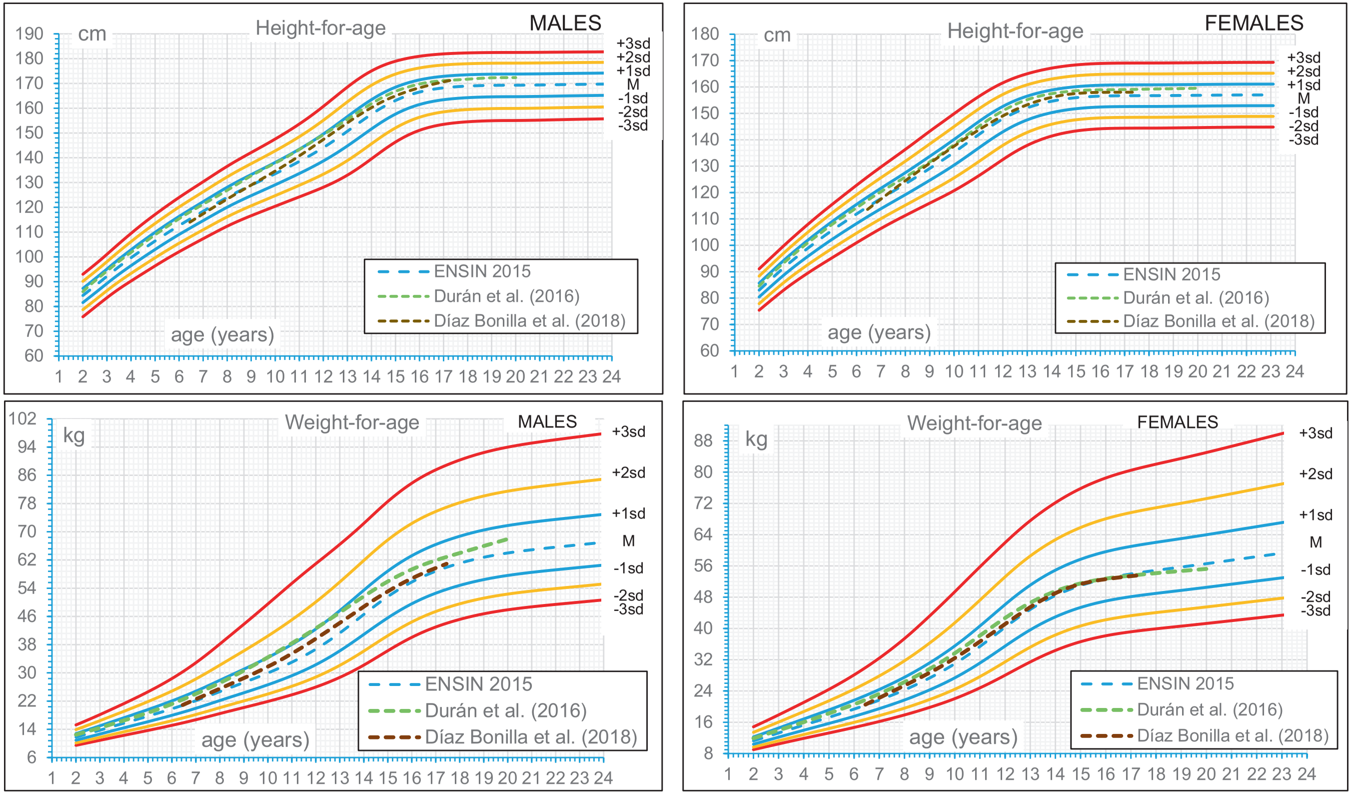

Fig. 6.2 Graphs of the growth curves of height and weight for age in both sexes. To compare the position of the M smoothed lines from the reference growth studies of Durán et al. (2016) and Díaz-Bonilla et al. (2018) against the present national reference from ENSIN 2015 the seven smoothed centile lines, equally spaced, were drawn by the application of LMS method

Table 6.2 Height-for-age of Colombian males and females

Age	Male height (cm)-for-age									Female height (cm)-for-age								
(years)	L	M	S	−3sd	−2sd	−1sd	+1sd	+2sd	+3sd	L	M	S	−3sd	−2sd	−1sd	+1sd	+2sd	+3sd
2.00	1.03	84.43	0.05	75.83	78.70	81.57	87.29	90.14	92.99	0.38	83.02	0.05	75.42	77.90	80.43	85.65	88.34	91.08
3.00	0.76	92.18	0.05	83.52	86.39	89.27	95.12	98.07	101.05	1.14	91.42	0.05	82.98	85.80	88.62	94.20	96.98	99.75
4.00	0.52	99.63	0.05	90.25	93.33	96.46	102.86	106.14	109.46	1.44	98.91	0.05	89.50	92.68	95.82	101.96	104.97	107.94
5.00	0.36	106.40	0.05	96.35	99.63	102.98	109.89	113.46	117.10	1.55	105.69	0.05	95.31	98.84	102.30	109.03	112.31	115.54
6.00	0.27	112.64	0.05	102.07	105.51	109.03	116.33	120.11	123.98	1.02	111.90	0.05	100.99	104.63	108.26	115.53	119.15	122.78
7.00	0.23	118.40	0.05	107.33	110.93	114.62	122.28	126.25	130.32	0.44	117.72	0.05	106.40	110.10	113.87	121.64	125.63	129.69
8.00	0.24	124.01	0.05	112.37	116.15	120.03	128.09	132.27	136.55	0.14	123.29	0.05	111.32	115.19	119.18	127.52	131.87	136.34
9.00	0.28	128.92	0.05	116.62	120.62	124.72	133.22	137.62	142.12	0.34	129.12	0.05	115.98	120.26	124.64	133.71	138.41	143.21
10.00	0.36	133.57	0.05	120.44	124.72	129.09	138.14	142.81	147.58	0.94	135.25	0.05	120.72	125.55	130.40	140.11	144.99	149.87
11.00	0.48	138.51	0.05	124.21	128.89	133.65	143.46	148.49	153.62	1.72	141.87	0.05	126.29	131.63	136.82	146.79	151.59	156.29
12.00	0.67	144.11	0.06	128.11	133.37	138.71	149.59	155.13	160.73	2.23	147.90	0.05	132.49	137.86	142.99	152.62	157.16	161.55
13.00	0.94	150.69	0.06	132.99	138.88	144.78	156.62	162.56	168.52	2.09	152.10	0.04	137.87	142.78	147.52	156.53	160.83	165.00
14.00	1.26	157.55	0.06	139.55	145.62	151.62	163.43	169.25	175.02	1.60	154.59	0.04	141.39	145.87	150.27	158.84	163.02	167.14
15.00	1.54	163.10	0.05	146.34	152.04	157.62	168.47	173.76	178.96	1.19	155.94	0.04	143.33	147.55	151.76	160.10	164.24	168.36
16.00	1.74	166.51	0.04	151.08	156.35	161.49	171.43	176.24	180.96	1.00	156.53	0.04	144.16	148.29	152.41	160.66	164.78	168.90
17.00	1.84	168.21	0.04	153.49	158.52	163.43	172.88	177.44	181.91	0.95	156.69	0.04	144.39	148.48	152.58	160.81	164.92	169.05
18.00	1.89	168.93	0.04	154.53	159.46	164.25	173.49	177.95	182.31	0.94	156.72	0.04	144.42	148.52	152.61	160.83	164.95	169.07
19.00	1.91	169.22	0.04	154.95	159.83	164.58	173.73	178.15	182.47	0.92	156.77	0.04	144.49	148.57	152.67	160.87	164.99	169.12
20.00	1.91	169.28	0.04	155.04	159.91	164.66	173.79	178.19	182.50	0.90	156.84	0.04	144.60	148.67	152.75	160.95	165.06	169.19
21.00	1.92	169.38	0.04	155.18	160.04	164.77	173.87	178.26	182.56	0.87	156.92	0.04	144.71	148.77	152.84	161.02	165.14	169.26
22.00	1.93	169.53	0.04	155.40	160.24	164.94	174.00	178.37	182.64	0.85	156.98	0.04	144.79	148.84	152.90	161.07	165.18	169.31
23.00	1.94	169.66	0.04	155.59	160.41	165.09	174.11	178.46	182.71	0.85	156.99	0.04	144.81	148.86	152.92	161.09	165.20	169.32

Values of fitting parameters L, M, S by age. L = Box-Cox power L, M = Median (p50), S = Coefficient of variation in direct units, sd = standard deviation cut-off lines when contrasted with Díaz-Bonilla et al. (2018), 2.95 cm in males and 1.26 cm in females.

Weight-for-Age

The M curve and the set of centiles did not reach a steady asymptote, as expected, for both sexes because weight could increase during decades after youth. In both sexes data showed positive asymmetry in the whole range of age, due to the accumulation of heavy subjects with weights louder than the median with decreasing frequencies. Asymmetry showed an increase around 10 years, in both sexes and decreased at 15 years. Fitting parameters obtained and the corresponding final sd line values for references of males and females are shown in Table 6.3. Expected median weight (sd = 0) at 23 years was 59.89 kg in males and 52.95 kg in females. Sexual dimorphism of attained weight at 2 years was 0.54 kg and then at 23 years reached 6.94 kg with the same direction of height dimorphism. The mean age at peak of weight increment was 13.8 years for males and 11.8 for females, and the mean age at take-off: 8.6 years for males and 5.2 years for females.

Figure 6.2 shows the plot of medians of the previous studies against the national reference curves developed in the present study. Both medians lied in the range of normal growth (M ± 1sd) of the reference of weight-for-age. The median line of Díaz-Bonilla et al. (2018) approaches the present study in females (mean differences: 0.44 kg) and has a higher difference with the median line of the present study in males (mean differences: 1.37 kg) with respect to the smoothed mean of Durán et al. (2016). However, the median line from Durán et al. (2016) it is also closer to the female median line (mean differences: 1.01 kg) of weight-for-age of the present study, than in males (mean differences: 2.69 kg). From 9 to 13 years of age, in males, the smoothed mean line from Durán et al. (2016) approaches de cutoff line of +1sd of the present study.

BMI-for-Age

The M curve and the set of centiles show, as expected, for both sexes a wave shape ending with an increasing slope. In both sexes, data showed positive asymmetry as in weight in the whole range of age. Asymmetry showed a decrease around 5 years, in both sexes. Fitting parameters obtained and the corresponding final sd line values for references of males and females are shown in Table 6.4. Expected median (sd = 0) at 23 years was 23.35 kg/m^2 in males and 24.36 kg/m^2 in females. Sexual dimorphism of attained BMI at 2 years was 0.30 kg/m^2 being greater values in males and then at 23 years reached 1.01 kg/m^2 with the opposite direction of dimorphism. The velocity and acceleration curves afforded by the LMS analysis did not show a clear spurt because the wave shape of the centiles. However, during puberty the highest increment of BMI was shown at 15.3 years for males and 12.6 for females.

The previous studies compared were plotted in Fig. 6.3 against the present study and yielded in both sexes a normal weight classification of the smoothed central curves. In males, the smoothed mean of BMI from Durán et al. (2016) approaches the median value obtained in the present study up to 5 years of age (range of differences: 0.06–0.34 kg/m^2) and thereafter has an increased higher value (the range of differences increases from 0.36 to 1.31 kg/m^2). However, at 18 years and thereafter

Table 6.3 Weight-for-age of Colombian males and females

Age	Male weight (kg)-for-age									Female weight (kg)-for-age								
(years)	L	M	S	−3sd	−2sd	−1sd	+1sd	+2sd	+3sd	L	M	S	−3sd	−2sd	−1sd	+1sd	+2sd	+3sd
2.00	−0.66	11.79	0.12	9.47	10.15	10.92	12.78	13.92	15.24	−0.85	11.25	0.12	9.00	9.65	10.39	12.25	13.43	14.84
3.00	−0.69	13.75	0.13	10.89	11.72	12.67	15.00	16.46	18.17	−0.86	13.26	0.13	10.46	11.26	12.19	14.53	16.05	17.89
4.00	−0.74	15.74	0.14	12.30	13.29	14.42	17.28	19.11	21.30	−0.88	15.28	0.14	11.89	12.85	13.96	16.84	18.74	21.08
5.00	−0.81	17.73	0.14	13.68	14.83	16.16	19.60	21.85	24.63	−0.89	17.27	0.15	13.26	14.38	15.70	19.16	21.49	24.41
6.00	−0.92	19.82	0.15	15.13	16.43	17.97	22.06	24.84	28.39	−0.91	19.37	0.16	14.67	15.97	17.51	21.64	24.47	28.12
7.00	−1.04	22.13	0.16	16.72	18.20	19.97	24.82	28.28	32.88	−0.94	21.67	0.17	16.20	17.69	19.49	24.38	27.84	32.41
8.00	−1.14	24.69	0.17	18.47	20.13	22.16	27.91	32.20	38.19	−0.95	24.26	0.18	17.87	19.60	21.69	27.51	31.72	37.41
9.00	−1.19	27.27	0.18	20.18	22.05	24.36	31.06	36.24	43.80	−0.91	27.33	0.19	19.80	21.82	24.28	31.20	36.27	43.19
10.00	−1.18	29.96	0.19	21.90	24.02	26.63	34.36	40.45	49.54	−0.79	30.97	0.20	22.04	24.44	27.36	35.52	41.44	49.38
11.00	−1.09	33.02	0.20	23.79	26.21	29.20	38.06	45.04	55.36	−0.61	35.39	0.20	24.79	27.68	31.16	40.63	47.24	55.77
12.00	−0.91	36.72	0.20	25.98	28.82	32.32	42.43	50.10	60.95	−0.43	40.30	0.20	28.03	31.45	35.48	46.12	53.20	61.95
13.00	−0.64	41.31	0.20	28.73	32.13	36.25	47.66	55.77	66.44	−0.37	44.86	0.19	31.43	35.21	39.63	51.08	58.54	67.58
14.00	−0.44	46.56	0.20	32.20	36.17	40.90	53.43	61.86	72.36	−0.41	48.42	0.18	34.38	38.33	42.96	54.91	62.71	72.18
15.00	−0.46	51.61	0.19	36.28	40.55	45.60	58.86	67.69	78.58	−0.50	50.98	0.18	36.61	40.64	45.37	57.70	65.83	75.80
16.00	−0.57	55.75	0.18	40.07	44.43	49.59	63.20	72.35	83.76	−0.57	52.75	0.18	38.13	42.21	47.02	59.64	68.06	78.50
17.00	−0.68	58.82	0.17	43.01	47.40	52.59	66.39	75.75	87.55	−0.62	53.95	0.18	39.15	43.27	48.14	60.99	69.65	80.47
18.00	−0.75	61.08	0.17	45.16	49.57	54.80	68.73	78.25	90.33	−0.65	54.87	0.18	39.91	44.07	48.98	62.04	70.89	82.04
19.00	−0.81	62.76	0.17	46.75	51.18	56.44	70.49	80.13	92.45	−0.68	55.71	0.18	40.59	44.78	49.74	63.00	72.04	83.50
20.00	−0.84	63.98	0.16	47.88	52.34	57.62	71.77	81.50	93.99	−0.71	56.58	0.18	41.28	45.51	50.53	63.98	73.23	85.02
21.00	−0.87	64.89	0.16	48.72	53.19	58.50	72.72	82.53	95.14	−0.74	57.47	0.18	41.99	46.25	51.33	65.01	74.47	86.61
22.00	−0.89	65.63	0.16	49.41	53.89	59.22	73.50	83.37	96.09	−0.77	58.37	0.18	42.69	47.00	52.14	66.05	75.73	88.23
23.00	−0.91	66.32	0.16	50.05	54.55	59.89	74.23	84.15	96.97	−0.80	59.26	0.18	43.39	47.74	52.95	67.08	76.98	89.85

Values of fitting parameters L, M, S by age. L = Box-Cox power L, M = Median (p50), S = Coefficient of variation in direct units, sd = standard deviation cut-off lines

Table 6.4 BMI-for-age of Colombian males and females

Age	Male BMI (kg/m²)-for-age									Female BMI (kg/m²)-for-age								
(years)	L	M	S	-3sd	-2sd	-1sd	+1sd	+2sd	+3sd	L	M	S	-3sd	-2sd	-1sd	+1sd	+2sd	+3sd
2.00	−1.02	16.53	0.08	14.34	15.00	15.73	17.42	18.42	19.53	−1.80	16.24	0.08	14.15	14.76	15.45	17.15	18.21	19.49
3.00	−1.28	16.18	0.08	13.94	14.61	15.35	17.12	18.20	19.44	−1.86	15.90	0.08	13.80	14.41	15.10	16.84	17.95	19.30
4.00	−1.55	15.90	0.09	13.62	14.29	15.04	16.90	18.08	19.49	−1.91	15.65	0.09	13.49	14.11	14.82	16.63	17.81	19.27
5.00	−1.79	15.72	0.09	13.39	14.06	14.83	16.79	18.09	19.71	−1.96	15.52	0.09	13.26	13.90	14.64	16.57	17.86	19.51
6.00	−2.01	15.68	0.10	13.27	13.95	14.74	16.83	18.28	20.18	−1.99	15.54	0.10	13.13	13.81	14.60	16.69	18.14	20.05
7.00	−2.18	15.81	0.11	13.30	13.99	14.82	17.06	18.69	20.95	−1.99	15.70	0.11	13.10	13.82	14.67	16.98	18.62	20.87
8.00	−2.29	16.10	0.11	13.45	14.17	15.03	17.46	19.29	21.96	−1.94	16.00	0.12	13.18	13.95	14.87	17.42	19.30	21.92
9.00	−2.34	16.42	0.12	13.63	14.38	15.28	17.89	19.93	23.02	−1.86	16.44	0.13	13.37	14.20	15.20	18.02	20.12	23.13
10.00	−2.33	16.78	0.12	13.83	14.62	15.57	18.35	20.57	24.03	−1.75	17.01	0.13	13.66	14.56	15.66	18.74	21.06	24.38
11.00	−2.27	17.19	0.13	14.09	14.91	15.92	18.86	21.22	24.95	−1.62	17.70	0.14	14.06	15.04	16.23	19.57	22.07	25.63
12.00	−2.17	17.65	0.13	14.38	15.25	16.31	19.41	21.88	25.74	−1.48	18.49	0.14	14.56	15.63	16.91	20.50	23.14	26.84
13.00	−2.05	18.17	0.13	14.74	15.65	16.77	20.01	22.56	26.45	−1.35	19.34	0.15	15.13	16.27	17.65	21.45	24.21	27.98
14.00	−1.92	18.77	0.13	15.15	16.12	17.30	20.68	23.29	27.17	−1.23	20.14	0.15	15.68	16.90	18.36	22.35	25.19	28.99
15.00	−1.78	19.43	0.13	15.62	16.65	17.89	21.40	24.07	27.91	−1.14	20.84	0.15	16.15	17.45	18.98	23.13	26.04	29.86
16.00	−1.66	20.09	0.13	16.09	17.17	18.48	22.14	24.85	28.67	−1.05	21.40	0.15	16.51	17.86	19.47	23.77	26.75	30.61
17.00	−1.55	20.71	0.14	16.52	17.67	19.04	22.83	25.59	29.41	−0.99	21.84	0.15	16.76	18.17	19.84	24.29	27.36	31.31
18.00	−1.44	21.29	0.14	16.91	18.11	19.55	23.47	26.29	30.12	−0.94	22.23	0.15	16.94	18.41	20.14	24.78	27.96	32.05
19.00	−1.35	21.82	0.14	17.26	18.51	20.01	24.07	26.96	30.81	−0.91	22.62	0.16	17.12	18.64	20.45	25.29	28.62	32.91
20.00	−1.26	22.27	0.14	17.52	18.83	20.39	24.59	27.54	31.43	−0.88	23.06	0.16	17.30	18.89	20.78	25.85	29.36	33.89
21.00	−1.18	22.65	0.14	17.73	19.09	20.70	25.03	28.05	31.99	−0.85	23.50	0.17	17.48	19.14	21.11	26.44	30.15	34.95
22.00	−1.11	23.00	0.14	17.91	19.32	20.99	25.46	28.55	32.55	−0.83	23.94	0.17	17.63	19.36	21.43	27.04	30.96	36.06
23.00	−1.04	23.35	0.15	18.09	19.55	21.28	25.88	29.05	33.12	−0.80	24.36	0.18	17.76	19.57	21.73	27.62	31.76	37.17

Values of fitting parameters L, M, S by age. L = Box-Cox power L, M = Median (p50), S = Coefficient of variation in direct units, sd = standard deviation cut-off lines, BMI = Body Mass Index expressed in kg/m²

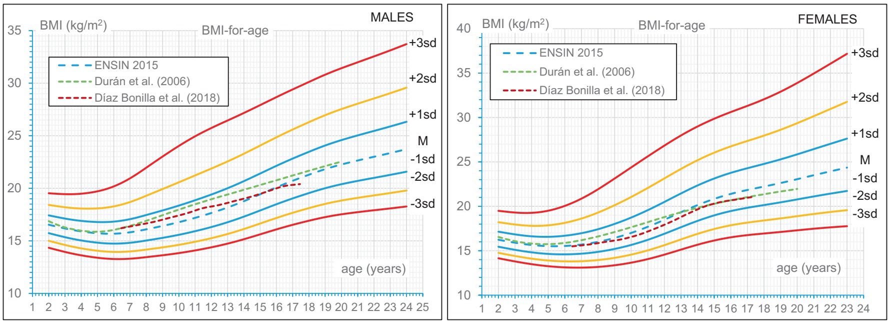

Fig. 6.3 Graphs of the growth curves of BMI-for-age in both sexes. To compare the position of the M smoothed lines from the reference growth studies of Durán et al. (2016) and Díaz-Bonilla et al. (2018) against the present national reference from ENSIN 2015 the seven smoothed centile lines, equally spaced, were drawn by the application of LMS method

approaches again to the present study, showing final differences about 0.31 kg/m². The study from Díaz-Bonilla et al. (2018) has, in males, a higher median than the present study only up to 14 years of age (mean differences 0.57 kg/m²), and thereafter is almost indistinguishable to the present study (mean differences −0.09 kg/m²). In females, the smoothed mean of Durán et al. (2016) approaches the present study up to 6 years (range of differences: 0.15–0.31 kg/m²) and from 11 to 14 years (mean differences 0.13 kg/m²), on the contrary from 6 to 11 years has higher values of BMI (mean differences 0.54 kg/m²), and from 14 to 20 years has lower values (mean differences −0.80 kg/m²), because crosses the median. The median value from Díaz-Bonilla et al. (2018) is near to the present study in females up to 9 years (mean differences −0.15 kg/m²) of age and thereafter remains below (mean differences −0.62 kg/m²).

Changes Observed After a Decade

Differences of smoothed medians between the two national surveys (ENSIN 2005 and 2015), are shown in Table 6.5. Height changes by age were small in boys and girls (<1% at 22 years). Positive increments were found up to 4 years of age (mean change: 0.32 cm in males and 0.25 cm in females) and after puberty between 15 and 23 years in males (mean change: 0.31 cm) and between 13 and 22 years in females (mean change: 0.71 cm). Negative changes were also found at some ages from 5 to 15 years in males (mean change: −1.0 cm) and females (mean change: −1.38 cm). Weight increments by age were higher than 1.0 kg only after 17 years in males and 11 years in females. Finally, youths, at 22 years, had increments of 2.20 kg in males and 3.95 kg in females, that was an increase of 3.5% and 7.3% over the weight in 2005. Negative changes in weight were found from 5 to 8 years and 14 years in males (mean change: −0.23 kg) and females (mean change: −0.29 kg). BMI increments were always positive and higher than 0.50 kg/m² from 19 years onwards in males and 18 in females. BMI at 22 years increased 0.70 kg/m² in males and 1.34 kg/m² in females, these increments were between 3.1% and 5.9% over the BMI in 2005.

Table 6.5 Attained smoothed medians by age of height (H) in cm, weight (W) in kg and BMI (I) in kg/m^2 from the national surveys (ENSIN 2005 and 2015) compared by the row differences (D) after 10 years from 2005 to 2015

Age	Males									Females								
(years)	H_{2005}	H_{2015}	W_{2005}	W_{2015}	I_{2005}	I_{2015}	D_H	D_W	D_{BMI}	H_{2005}	H_{2015}	W_{2005}	W_{2015}	I_{2005}	I_{2015}	D_H	D_W	D_{BMI}
2	83.85	84.43	11.55	11.79	16.40	16.53	0.58	0.24	0.13	82.97	83.02	11.06	11.25	16.08	16.24	0.05	0.19	0.16
3	91.88	92.18	13.57	13.75	16.03	16.18	0.30	0.18	0.15	90.82	91.42	13.03	13.26	15.78	15.90	0.60	0.23	0.12
4	99.56	99.63	15.52	15.74	15.67	15.90	0.07	0.22	0.23	98.82	98.91	15.11	15.28	15.48	15.65	0.09	0.17	0.17
5	108.00	106.40	17.93	17.73	15.46	15.72	−1.60	−0.20	0.26	107.32	105.69	17.47	17.27	15.27	15.52	−1.63	−0.20	0.25
6	114.71	112.64	20.30	19.82	15.45	15.68	−2.07	−0.48	0.23	114.09	111.90	19.79	19.37	15.26	15.54	−2.19	−0.42	0.28
7	119.98	118.40	22.52	22.13	15.59	15.81	−1.58	−0.39	0.22	119.58	117.72	22.05	21.67	15.43	15.70	−1.86	−0.38	0.27
8	124.89	124.01	24.76	24.69	15.82	16.10	−0.88	−0.07	0.28	124.74	123.29	24.42	24.26	15.71	16.00	−1.45	−0.16	0.29
9	129.72	128.92	27.21	27.27	16.11	16.42	−0.80	0.06	0.31	130.22	129.12	27.17	27.33	16.08	16.44	−1.10	0.16	0.36
10	134.38	133.57	29.84	29.96	16.46	16.78	−0.81	0.12	0.32	136.24	135.25	30.63	30.97	16.60	17.01	−0.99	0.34	0.41
11	139.19	138.51	32.70	33.02	16.85	17.19	−0.68	0.32	0.34	142.30	141.87	34.80	35.39	17.26	17.70	−0.43	0.59	0.44
12	144.92	144.11	36.38	36.72	17.33	17.65	−0.80	0.34	0.32	147.34	147.90	39.08	40.30	18.02	18.49	0.56	1.22	0.47
13	151.66	150.69	41.22	41.31	17.91	18.17	−0.97	0.09	0.26	151.10	152.10	43.22	44.86	18.87	19.34	1.00	1.64	0.47
14	158.24	157.55	46.59	46.56	18.55	18.77	−0.69	−0.03	0.22	153.71	154.59	46.96	48.42	19.75	20.14	0.88	1.46	0.39
15	163.24	163.10	51.42	51.61	19.20	19.43	−0.14	0.19	0.23	155.21	155.94	49.69	50.98	20.52	20.84	0.73	1.29	0.32
16	166.30	166.51	55.15	55.75	19.82	20.09	0.21	0.60	0.27	155.86	156.53	51.45	52.75	21.10	21.40	0.67	1.30	0.30
17	167.93	168.21	57.82	58.82	20.38	20.71	0.27	1.00	0.33	156.03	156.69	52.49	53.95	21.48	21.84	0.66	1.46	0.36
18	168.65	168.93	59.60	61.08	20.85	21.29	0.28	1.48	0.44	156.05	156.72	53.09	54.87	21.73	22.23	0.67	1.78	0.50
19	168.89	169.22	60.86	62.76	21.26	21.82	0.32	1.90	0.56	156.09	156.77	53.45	55.71	21.91	22.62	0.68	2.26	0.71
20	168.96	169.28	61.84	63.98	21.63	22.27	0.32	2.14	0.64	156.15	156.84	53.75	56.58	22.09	23.06	0.69	2.83	0.97
21	169.02	169.38	62.67	64.89	21.97	22.65	0.36	2.22	0.68	156.25	156.92	54.06	57.47	22.32	23.50	0.67	3.41	1.18
22	169.17	169.53	63.43	65.63	22.30	23.00	0.36	2.20	0.70	156.41	156.98	54.42	58.37	22.60	23.94	0.57	3.95	1.34
23	169.34	169.66	64.12	66.32	22.61	23.35	0.32	2.20	0.74	–	156.99	–	59.26	–	24.36	–	–	–

6.4 Discussion

National growth References

The LMS fitting procedure of the available growth data of the national nutritional survey ENSIN 2015 can draw growth curves with specific characteristics and produced differences with other wide Colombian studies with field work within the period 2009–2013, like the pediatric national reference (Durán et al., 2016) and the urban study from Bogota published by Díaz-Bonilla et al. (2018). This comparative analysis of growth parameters is retrospective. The present study did not used the comparison with WHO references because growth curves of the excellent reference from Durán et al. (2016) follows quite near the international WHO curves except for final mean growth parameters (at 18 years) when WHO standards had higher values in all anthropometrics, excluding BMI-for-age which is very close to the pediatric reference.

The application of the LMS method to data from ENSIN 2015 followed quite closely the steps used by Díaz-Bonilla et al. (2018) and Ireton and Carrillo (2014) but has differences with the method of Durán et al. (2016) because it used the GAMLSS method, although firstly was prone to use the LMS (Briceño et al., 2012) in curves fitting. Methodology could have influenced the final differences in centile growth patterns in Figs. 6.2 and 6.3 because when compared M curves they had different shapes after childhood. A possible explanation can arise because the national pediatric references used a different smoothing method and selected only urban children (from the four bigger cities), with the aim of including well-grown children and adolescents of middle and upper socioeconomic levels. Differences in BMI patterns of growth between the present study and BMI curves from Díaz-Bonilla et al. (2018) could be explained due to the influence of middle altitude on growing in children from the Andean region.

The pediatric national reference (Durán et al., 2016), and the study from Díaz-Bonilla et al. (2018) yielded higher final height in both sexes, mainly, because the urban origin of the samples in contrast to ENSIN 2015 which includes a great proportion of rural subjects, above 30%. Inequalities in health and biological outcomes between rural and urban populations in Colombia are well known. The ecological perspective can be applied to the rural-urban biological differences because the interaction of human biology with disparities in health. In the rural national sample of this survey, food insecurity was 1.2 times higher than in the urban sample. The ENSIN 2015 (ICBF, 2015) reported at the household level 52.4% of food insecurity at the national range and therefore the references analyzed here are not a standard of well grown children, they could be used to monitor public health and to evaluate rural children.

The effect of including children from low socioeconomic strata in a reference sample can be shown by the analysis of other cross-sectional growth study from Bogota constructed by Fernández-Ortega and Ruiz (2012). The former yielded lower mean final height compared to the present study (1.7 cm in males at 18 years) and (2.6 cm in females at 17 years) probably due to the socioeconomic status. A height differential among all these intrapopulation growth studies is in the range of

3 cm in both sexes, far from the observed worldwide differential, 19–20 cm, among the tallest and shortest populations (N.C.D. & Risk, 2016), and therefore the differences here can be attributed to the ecological factors rather than genetic backgrounds. Other reasons like the heterogeneity in maturation among the compared studies would have little effects because the correlation between early or late maturation and adult size is weak and it is possible for both early and late maturing to reach the same stature (Bielicki & Hauspie, 1994) comparing final statures after 18 years.

Differences in final attained weight and BMI had an interaction effect with gender because in females both compared studies had lower final values (Figs. 6.2 and 6.3), on the contrary male' values from the urban studies were higher except for BMI of males from Díaz-Bonilla et al. (2018). The origin of the interaction could be a possible consequence of gender differential in different environments being the wide national level (a mixing of urban and rural effects) influencing over females' soft tissues and urban ecosystems triggering the increase of soft tissues over male biology.

However, differences in the methodology of smoothing the curves of growth are also present in the mean differential pattern of growth among the M curves (Figs. 6.2 and 6.3). The wide diffusion of the LMS method (Cole, 1988; Cole & Green, 1992) to fit growth curves influenced over time others that were not similar methods to show in the publications using LMS parameters with a similar nomenclature but different meaning. Moreover, the LMS method was applied with differences among authors but do not show how was the exact procedure, as in Fernández-Ortega and Ruíz (2012). This problem limits comparison among methods. Nomenclature confusion arises because LMS method is not the acronym of Least Mean Squares because it stands for the parameters used in the development of centile functions. In fact, the first production of LMS parameters by the growth study of CDC-2000 had such bias and did not follow the usual steps proposed by Cole (1988) to yield the published LMS parameters (Flegal & Cole, 2013). It should be remembered that firstly the LMS parameters permit to produce the curves and are not calculated after smoothing the curves (Cole & Green, 1992).

Using height-for-age references is useful in monitoring public health parameters in Colombia because growth deficiencies remain high and mainly because adult final height is still low with respect to other countries. This is due to some reasons raised by Deaton (2007) when pointed out that restriction of height by malnutrition and disease may no longer be important in many countries, but the process is certainly far from complete in others, where infant and child mortality rates remain high, and average nutritional intake is low. Moreover, the research on how to draw appropriate national references for weight and BMI, or other anthropometrics is also useful to monitor the increase in overweight and obesity in Colombian populations. Adult ages (from 20 years onwards) are the focus of interest in the first references in Colombia for height, weight, BMI, and waist circumference constructed with the LMS method from a national database of 2010 by Ramírez-Vélez et al. (2016). Anthropometric references of specific ethnic groups are also necessary and that are rare in Colombia, except for the first references for Nasa people from 10 to 17 years constructed by Ramos-Sepúlveda et al. (2016).

Secular Changes

Studies on secular changes often raised some questions on how much the increase is, the tendencies during time, and the leading problems on why it happens (Floud et al., 1990). With respect to the first question, a decade of anthropometric variation is a short secular period of observation and observed changes were small and only more evident when involved soft tissues from 18 years onwards. There were in general positive increments, except for weight and height after 4 years and during late childhood in both sexes, thereafter, increments turned to be positive until youth. A moderate or low anthropometric variation could be the result, in the ecological perspective of the interaction of biology and social determinants with some detrimental outcomes and some positive ones. Household economy in the decade, faced increments in the consumer price index (CPI) from 4.85 in 2005 to 6.77 in 2015. Moreover, the GDP (Gross Domestic Product) per capita in Colombia showed in the same decade a moderate increment of 7.8% per year. The possible influence of the variation of CPI on reducing height and triggering changes in fat during growth could be found to some extent in a coastal Colombian village (Rosique-Gracia et al., 2020), and similar biological outcomes could be involved in a wide national range.

Before the onset of industrialization, adult height change (1910–1984) in Colombia was approx. 7.9 cm in males and 8.8 cm in females (Meisel-Roca & Vega, 2004), i.e., 1.07–1.19 cm/decade, in contrast to 0.36–0.57 cm in one decade in the present study. Women in both studies experienced a slightly higher increment as a biological consequence of removing some gender limits and starting the way steering to gender parity. These changes can be viewed in terms of relative increases showing that in the last century were around 4% and < 1% in the present study at the beginning of the present century. The study of Ireton and Carrillo (2014) in successive surveys in Yopal (Casanare) with short secular intervals (around 5 years) found at the end of the last decade at 18 years, increments in females of 2.3% and decrements in males of −0.8%. If in the study from Yopal, increments can be supposed uniform in time, we could work out relative increases per decade at the end of the last century of 4.6% in females and − 1.6% in males. Increments in height around 1 cm/decade are considered a fair estimation of mean secular trend in Latin America, mainly in Mexico, Chile, Peru, and Colombia, in the last decades, by a study to determine the relationship between genotypes and phenotypes (Ruiz-Linares et al., 2014). The low increases observed in the present study are parallel to the trends in structural determinants such as the above-mentioned trends in CPI and GDP. Moreover, national trends in food consumption were not positive between 2005 and 2015 because the consumption prevalence of meat, milk, legumes, and other energetic foods in children diminished (Herrán et al., 2020) in the period.

Explanations of body size increase over time in humans have been issued and can be summarized in multiple environmental effects of ecological factors involving fetal growth or childhood. Large women who have large pelvis can deliver larger full-term fetuses. Hence, selection for human birth size is linked to maternal pelvic size and body size, a form of co-evolution that occurred as a part of human fetal evolution (Little, 2020). However, in a short scale of time, explanations of the large increase in heights in some regions like in Europe and North America over the last two centuries is clearly not driven by changes in gene pools, even those associated with migration, but by changes in the disease and nutritional environments (Deaton, 2007). On the contrary, despite nutritional deprivation in Africa there has not been a selection outcome to reduce adult heights, in the past decades. Moreover, there is a need of wider perspectives of selection. Some studies on adult height pointed out relating taller people to enhanced longevity, low risk of heart disease (Paajanen et al., 2010), but higher risk of some cancers (Batty et al., 2010).

Monitoring secular changes in Colombian populations is a way to evaluate the success of food and health programs in public health. However, it seems desirable to change the tendency found in this study of a low increase of mean national adult height over a decade (<1%). Stunting (0–5 years) decreased in Colombia from 2005 to 2015 by a rate of 50% (ICBF, 2015) but the effect on adult height was of less importance. Some factors of importance in ecological perspective are summarized here, in the following observations. The decline of family size in Colombia has been quite slow in the period; family size and parity seem to be linked to the increments in the number of short children because later parity children are successively shorter than early parity children (Savage et al., 2013). Birth weight is another possible reason on low biological outcomes in secular changes that need more research because there is a clear relationship between birth weight and length and adult weight and height (Eide et al., 2005). In fact, rates of low birth weight decreased slowly between 2008 and 2018 in Colombia from 2.8% to 2.1% (Guanizo-Herreño et al., 2021) and are still present in every socioeconomic stratum. Other ecological factors are possible reasons to consider, i.e., the tendencies in food consumption are triggering a secular increase in overweight and obesity and skeletal growth cannot be fueled by this change. Vecino-Ortíz and Arroyo-Ariza (2018) found that overweight and obesity increased in 10% in the study period (2005–2015) and found a correlation with the increment of soda beverages production in Colombia around the same period. These changes, are the result of nutrition transition and the little effect on height increments of most human environments in Colombia, except for some urban children.

Finally, with respect to the secular trend in maturation parameters as the age at menarche in girls, indicates that the trend for earlier sexual maturation over the last half century in Colombia has a high correlation with the increase in GDP per capita by year, and attained 12.6 years at the beginning of the present century. At the same time, girls tended to delay menarche when born in decades with high violence and homicide cases (Villamor et al., 2009). While, in US, racial differences are significant, with African American girls having menarche earlier than white girls (Herman-Giddens, 2006), in Colombia data on ethnicity pointed out to some indigenous groups with a clear early age at menarche, 11.3 years in Tule indigenous natives (Arias-Valencia, 2001). Whatever the intrapopulation heterogeneity is, lowering ages of sexual maturity in girls does not correspond to better health conditions and could indicate overweight or environmental contaminants (endocrine disrupters), or even decreased physical activity (Herman-Giddens, 2006). Infant soy-based formulas are other possible theoretical points to explain a non-healthy model of earlier maturation. In contrast to girls, boys appear to have later development if overweight (Wang, 2002). These aspects of human environments can be changed to improve growth and maturation parameters of children.

6.5 Conclusion

The national nutritional surveys from ENSIN can be used to construct references without clinical purposes but useful in public health to follow up parameters of secular changes and nutrition transition in Colombia, because the quality of including rural and urban children to monitor growth of height, weight, and BMI at the local level. The original data included a great proportion of outliers and extremes to be excluded and therefore, the emphasis when using this kind of national databases should be done in modeling the growth curves with growth specific software to calculate fitted expected values. The LMS model is a good solution, however if methodological information on how it is used is absent it will be difficult to perform comparisons between local references. The comparison of local growth studies can be viewed as a way of studying intrapopulation heterogeneity of growth due to different environmental settings and this is a useful task in anthropology and human ecology. The beginning of the present century is experiencing low secular changes in height with respect to the final of the last century. A raise of concern is the negative secular change in the period of study 2005–2015 or indeed little variation in height and weight during late childhood and until puberty. This concern could be solved by the national growth monitoring programs for children beyond the 5 years of age to improve their final growth. Improving the quality of human environments for growth, and mitigating inequity in food, nutrition, health, and economy could enhance the process of secular trend that seems almost stopped for adult height and powered in weight and BMI changes because of the nutrition transition.

Acknowledgements Thanks to the Group "*Gestión del Conocimiento y Fuentes de Información*" belonging to the Health Ministry of Colombia, for providing on July 2019 the ENSIN databases in their three versions 2005, 2010 and 2015. Thanks to the partial funding provided by the CODI of the University of Antioquia by the project "*Desempeño alimentario y nutricional en el pueblo indígena wayuu*" code 2018-23121 registered by the CISH (*Centro de Investigación Sociales y Humanas*) from the *Facultad de Ciencias Sociales y Humanas*, and finally, thanks to the project 2020–2021 with code BUPP-ES84190021 (*Sostenibilidad del Grupo de Investigación MASO*). Thanks to professor E. Rebato from the University of Basque Country, in Bilbao, to enable the use the LMS program v.1.26 and learning on its applications.

References

Acosta, K., & Meisel, A. (2013). Anthropometric measurements by ethnicity in Colombia, 1965–1990. *Economics and Human Biology, 11*(4), 416–425. https://doi.org/10.1016/j.ehb.2013.03.006

Agrelo, F., Pascual, L. R., Lobo, B., & Sabulsky, J. (1999). Talla final de mujeres de Córdoba, Argentina, y exploración de la tendencia secular (1978–1988). *Pan American Journal of Public Health, 5*(1), 17–22. https://doi.org/10.1590/S1020-49891999000100003

Arias-Valencia, M. M. (2001). Reproductive behavior of ethic groups in Antioquia, Columbia. *Salud Pública de México, 43*(4), 268–278. https://doi.org/10.1590/s0036-36342001000400003

Baten, J., & Blum, M. (2012). Growing tall but unequal: New findings and new background evidence on anthropometric welfare in 156 countries, 1810–1989. *Economic History of Developing Regions, 27*(sup 1), S66–S85. https://doi.org/10.1080/20780389.2012.657489

Batty, G. D., Barzi, F., Woodward, M., Jamrozik, K., Woo, J., Kim, H. C., Ueshima, H., Huxley, R. R., & Asia Pacific Cohort Studies Collaboration. (2010). Adult height and cancer mortality in Asia: The Asia Pacific Cohort Studies Collaboration. *Annals of Oncology, 21*, 646–654. https://doi.org/10.1093/annonc/mdp363. PMID: 19889610.

Bejarano, I., Dipierri, J., & Ocampo, S. (1996). Variación regional de la tendencia secular de la talla adulta masculina en la provincia de Jujuy. *Revista Argentina de Antropología Biológica, 1*(1), 7–18. https://doi.org/10.17139/raab.1996.001.1

Bender, R. L., Bekelman, T. A., Sandberg, P. A., Dufour, D. L., & Reina, J. C. (2020). Shift in body fat distribution from lower body to upper body among urban Colombian women, 1988–1989 to 2007–2008. *Public Health Nutrition, 23*(8), 1320–1328. https://doi.org/10.1017/S1368980019004099

Bielicki, T., & Hauspie, R. C. (1994). On the independence of adult stature from the timing of the adolescent growth spurt. *American Journal of Human Biology, 6*, 245–247. https://doi.org/10.1002/ajhb.1310060213

Bogin, B., & Keep, R. (1999). Eight thousand years of economic and political history in Latin America revealed by anthropometry. *Annals of Human Biology, 26*(4), 333–351. https://doi.org/10.1080/030144699282651

Bogin, B., & Macvean, R. B. (1982). Ethnic and secular influences on the size and maturity of seven-year-old children living in Guatemala City. *American Journal of Physical Anthropology, 59*(4), 393–398. https://doi.org/10.1002/ajpa.1330590409

Box, G. E., & Cox, D. R. (1982). An analysis of transformations revisited, rebutted. *Journal of the American Statistical Association, 77*(377), 209–210. https://doi.org/10.1080/01621459.1982.10477788

Briceño, G., Durán, P., Colón, E., Line, D., Merker, A., Abad, V., Chahín, S., Del Toro, K., Matallana, A., Llano, M., Lema, A., Soder, O., Céspedes, J., & Hagenäs, L. (2012). Protocolo del estudio para establecer estándares normativos de crecimiento de niños colombianos sanos. *Pediatria, 45*(4), 235–242. https://doi.org/10.1016/s0120-4912(15)30021-5

Cole, T. J. (1988). Fitting smoothed centile curves to reference data. *Journal of the Royal Statistical Society: Series A (Statistics in Society), 151*(3), 385–418. https://doi.org/10.2307/2982992

Cole, T. J. (1990). The LMS method for constructing normalized growth standards. *European Journal of Clinical Nutrition, 44*(1), 45–60.

Cole, T. J. (2000). Secular trends in growth. *The Proceedings of the Nutrition Society, 59*(2), 317–324. https://doi.org/10.1017/S0029665100000355

Cole, T. J., & Green, P. J. (1992). Smoothing reference centile curves: The LMS method and penalized likelihood. *Statistics in Medicine, 11*(10), 1305–1319. https://doi.org/10.1002/sim.4780111005

de Onis, M., Onyango, A. W., Borghi, E., Siyam, A., Nishida, C., & Siekmann, J. (2007). Development of a WHO growth reference for school-aged children and adolescents. *Bulletin of the World Health Organization, 85*, 660–667. Tables for height, weight and body mass index for age, 5–19 years. http://www.who.int/growthref/en/

Deaton, A. (2007). Height, health, and development. *Proceedings of the National Academy of Sciences of the United States of America, 104*(33), 13232–13237. https://doi.org/10.1073/pnas.0611500104

Díaz-Bonilla, E., Galvis, C. L. T., Carrillo, J. P., & Bola, M. C. (2018). Peso, estatura e índice de masa corporal de niños y adolescentes de moderada altitud de Colombia. *Archivos Argentinos de Pediatría, 116*(2), 241–250. https://doi.org/10.5546/aap.2018.e241

Dittmar, M. (1998). Secular growth changes in the stature and weight of Amerindian schoolchildren and adults in the Chilean Andes, 1972–1987. *American Journal of Human Biology, 10*(5), 607–617. https://doi.org/10.1002/(SICI)1520-6300(1998)10:5<607::AID-AJHB7>3.0.CO;2-A

Durán, P., Merker, A., Briceño, G., Colón, E., Line, D. Abad, V., Del Toro, K., Chahín, S. Matallana, A.M. Lema, A. Llano, M. Céspedes, J., & Hagenäs, L. (2016). Colombian reference growth curves for height, weight, body mass index and head circumference. *Acta Paediatrica, International Journal of Paediatrics, 105*(3), e116–e125. https://doi.org/10.1111/apa.13269

Eide, M. G., Øyen, N., Skjaerven, R., Nilsen, S. T., Bjerkedal, T., & Tell, G. S. (2005). Size at birth and gestational age as predictors of adult height and weight. *Epidemiology, 16*, 175–181. https://doi.org/10.1097/01.ede.0000152524.89074.bf

Escobar-Cardozo, G. D., Correa-Bautista, J. E., González-Jiménez, E., Schmidt-RioValle, J., & Ramírez-Vélez, R. (2016). Percentiles de grasa corporal por bioimpedancia eléctrica en niños y adolescentes de Bogotá, Colombia: Estudio FUPRECOL. *Archivos Argentinos de Pediatría, 114*(2), 135–142. https://doi.org/10.5546/aap.2016.135

Fernández-Ortega, J., & Ruiz Arias, F. (2012). Estudio transversal de crecimiento de los escolares bogotanos: Valores de estatura, peso e índice de masa corporal de los siete a los dieciocho años. *Universidad y Salud, 14*(1), 21–41.

Flegal, K. M., & Cole, T. J. (2013). Construction of LMS parameters for the Centers for Disease Control and Prevention 2000 growth charts. *National Health Statistics Reports, 63*, 1–4.

Floud, R., Wachter, K., & Gregory, A. (1990). *Height, health and history*. Cambridge University Press.

Garza, C., & de Onis, M. (2004). Rationale for developing a new international growth reference. *Food and Nutrition Bulletin, 25*(Suppl. 1), 5–13. https://doi.org/10.1177/15648265040251s102

Guarnizo-Herreño, C. C., Torres, G., & Buitrago, G. (2021). Socioeconomic inequalities in birth outcomes: An 11-year analysis in Colombia. *PLoS One, 16*(7). https://doi.org/10.1371/journal.pone.0255150

Guimarey, L. M., Castro, L. E., Torres, M. F., Cesani, M. F., Luis, M. A., Quintero, F. A., & Oyhenart, E. E. (2014). Secular changes in body size and body composition in schoolchildren from la Plata City (Argentina). *Anthropologischer Anzeiger, 71*(3), 287–301. https://doi.org/10.1127/0003-5548/2014/0364

Herman-Giddens, M. E. (2006). Recent data on pubertal milestones in United States children: The secular trend toward earlier development. *International Journal of Andrology, 29*(1), 241–246. https://doi.org/10.1111/j.1365-2605.2005.00575.x

Herrán, O. F., Bermúdez, J. N., & Zea, M. d. P. (2020). Cambios alimentarios en Colombia, resultados de dos encuestas nacionales de nutrición, 2010–2015. *Revista de La Universidad Industrial de Santander. Salud, 52*(1), 21–31. https://doi.org/10.18273/revsal.v52n1-2020004

Himes, J., & Mueller, H. (1977). Aging and secular change in adult stature in rural Colombia. *American Journal of Physical Anthropology, 46*(2), 275–279. https://doi.org/10.1002/ajpa.1330460208

ICBF. (2005). *Encuesta nacional de la situación nutricional en Colombia ENSIN 2005*. Instituto Colombiano de Bienestar Familiar (ICBF). http://www.icbf.gov.co/portal/page/portal/PortalICBF/NormatividadGestion/ENSIN1/ENSIN2005/LIBRO_2005.pdf

ICBF. (2011). *Resumen Ejecutivo. Encuesta nacional de la situación nutricional en Colombia ENSIN 2010* (512p). Instituto Colombiano de Bienestar Familiar (ICBF).

ICBF. (2015). *Encuesta nacional de la situación nutricional ENSIN 2015*. Ministerio de Salud y Protección Social (Min Salud), Departamento Administrativo Para La Prosperidad Social (DPS), Instituto Nacional de Salud (INS), Instituto Colombiano de Bienestar Familiar (ICBF), Universidad Nacional de Colombia (UNAL), No. 1: 46. http://www.prosperidadsocial.gov.co/temporales/Encuesta Nacional de la Situación Nutricional – ENSIN 2015.pdf

Ireton, M.-J., & Carrillo, J. C. (2014). Referencias de crecimiento físico en escolares de El Yopal, Casanare – Colombia durante el periodo 1992–2001. In *In Universidad Nacional de Colombia*. Universidad Nacional de Colombia.

Kasper, N. M., Herrán, O. F., & Villamor, E. (2013). Obesity prevalence in Colombian adults is increasing fastest in lower socio-economic status groups and urban residents: Results from two nationally representative surveys. *Public Health Nutrition, 17*(11), 2398–2406. https://doi.org/10.1017/S1368980013003418

Komlos, J., & Baten, J. (2004). Looking backward and looking forward: anthropo- metric research and the development of social science history. *Social Science History, 28*(2), 191–210.

Landaeta-Jiménez, M., Macias Tomei, C., Fossi, M., García, M., Layrisse, M., & Méndez Castellano, H. (2002). Tendencia en el crecimiento físico y estado nutricional del niño venezolano. *Archivos Venezolanos de Puericultura y Pediatría, 65*(1), 13–20.

Little, M. A. (2020). Evolutionary strategies for body size. *Frontiers in Endocrinology, 11*, 1–14. https://doi.org/10.3389/fendo.2020.00107

Malina, R. M., & Zavaleta, A. N. (1980). Secular trend in the stature and weight of Mexican American children in Texas between 1930 and 1970. *American Journal of Physical Anthropology, 52*(4), 453–461. https://doi.org/10.1002/ajpa.1330520402

Mansukoski, L., Johnson, W., Brooke-Wavell, K., Galvez-Sobral, J. A., Furlán, L., Cole, T. J., & Bogin, B. (2020). Four decades of socio-economic inequality and secular change in the physical growth of Guatemalans. *Public Health Nutrition, 23*(8), 1381–1391. https://doi.org/10.1017/S1368980019003239

Martorell, R., & Habicht, J. P. (1986). Growth in early childhood in developing countries. In: Human growth. A comprehensive treatise. Volume 3. In F. Falkner & J. M. Tanner (Eds.), *Methodology, ecological, genetic, and nutritional effects on growth* (Chapter 12) (2nd ed., pp. 241–262). Plenum Press.

Marván, M. L., Castillo-López, R. L., del-Callejo-Canal, D. D., Canal-Martínez, M. E., & Núñez-de la Mora, A. (2020). Secular trends in age at menarche in 20th century Mexico: differences by ethnicity, area of residency, and socioeconomic status. *American Journal of Human Biology, 32*(6), e23404. https://doi.org/10.1002/ajhb.23404

McCullough, J. M. (1982). Secular trend for stature in adult male Yucatec Maya to 1968. *American Journal of Physical Anthropology, 58*(2), 221–225. https://doi.org/10.1002/ajpa.1330580215

Meisel-Roca, A., & Vega, M. (2004). La estatura de los colombianos: un ensayo de antropometría histórica, 1910–2002. *Documentos de Trabajo Sobre Economía Regional y Urbana, 45*, 1–42. http://repositorio.banrep.gov.co/handle/20.500.12134/3200

N.C.D, & Risk, F. C. (2016). A century of trends in adult human height. *eLife, 5*, 1–29. https://doi.org/10.7554/eLife.13410

Orden, A. B., Lamarque, M. S., & Apezteguía, M. C. (2019). Trend in childhood obesity reflects socioeconomic status in Argentina. *Annals of Human Biology, 46*(7–8), 531–536. https://doi.org/10.1080/03014460.2019.1694070

Ossa, X. M., Munoz, S., Amigo, H., & Bangdiwala, S. I. (2010). Secular trend in age at menarche in indigenous and nonindigenous women in Chile. *American Journal of Human Biology, 22*(5), 688–694. https://doi.org/10.1002/ajhb.21068

Paajanen, T. A., Oksala, N. K., Kuukasjärvi, P., & Karhunen, P. J. (2010). Short stature is associated with coronary heart disease: A systematic review of the literature and a meta-analysis. *European Heart Journal, 31*, 1802–1809. https://doi.org/10.1093/eurheartj/ehq155

Parra, D. C., Iannotti, L., Gomez, L. F., Pachón, H., Haire-Joshu, D., Sarmiento, O. L., Kuhlmann, A. S., & Brownson, R. C. (2015). The nutrition transition in Colombia over a decade: A novel household classification system of anthropometric measures. *Archives of Public Health, 73*(1), 12. https://doi.org/10.1186/s13690-014-0057-5

Prince, M. J., Acosta, D., Guerra, M., Huang, Y., Jimenez-Velazquez, I. Z., Llibre Rodriguez, J. J., Salas, A., Sosa, A. L., Dewey, M. E., Guerchet, M. M., Liu, Z., Llibre Guerra, J. J., & Matthew Prina, A. (2018). Leg length, skull circumference, and the incidence of dementia in Latin America and China: A 10/66 population-based cohort study. *PLoS One, 13*(4), 1–14. https://doi.org/10.1371/journal.pone.0195133

Ramírez-Vélez, R., Correa-Bautista, J. E., Martínez-Torres, J., Méneses-Echavez, J. F., González-Ruiz, K., González-Jiménez, E., Schmidt-Riovalle, J., & Lobelo, F. (2016). LMS tables for waist circumference and waist-height ratio in Colombian adults: Analysis of nationwide data 2010. *European Journal of Clinical Nutrition, 70*(10), 1189–1196. https://doi.org/10.1038/ejcn.2016.46

Ramírez-Vélez, R., Moreno-Jiménez, J., Correa-Bautista, J. E., Martínez-Torres, J., González-Ruiz, K., González-Jiménez, E., Schmidt-RioValle, J., Lobelo, F., & Garcia-Hermoso, A. (2017). Using LMS tables to determine waist circumference and waist-to-height ratios in Colombian children and adolescents: The FUPRECOL study. *BMC Pediatrics, 17*(1), 162. https://doi.org/10.1186/s12887-017-0919-4

Ramos-Sepúlveda, J. A., Ramírez-Vélez, R., Correa-Bautista, J. E., Izquierdo, M., & García-Hermoso, A. (2016). Physical fitness and anthropometric normative values among Colombian-Indian schoolchildren. *BMC Public Health, 16*(1), 962. https://doi.org/10.1186/s12889-016-3652-2

Rigby, R. A., & Stasinopoulos, D. M. (2005). Generalized additive models for location, scale and shape. *Journal of the Royal Statistical Society: Series C: Applied Statistics, 54*, 507–554. https://doi.org/10.1111/j.1467-9876.2005.00510.x

Rona, R. J., Mahabir, D., Rocke, R., Chinn, S., & Gulliford, M. C. (2003). Social inequalities and children's height in Trinidad and Tobago. *European Journal of Clinical Nutrition, 57*(1), 143–150. https://doi.org/10.1038/sj.ejcn.1601508

Rosique-Gracia, J., García-Pineda, A. F., & Villada-Gómez, B. A. (2012). Nutritional status, food pattern and nutrition transition in school children from donmatías (Antioquia). *Revista Colombiana de Antropología, 48*(1), 97–124. https://doi.org/10.22380/2539472X.893

Rosique-Gracia, J., Restrepo-Hernández, N., Arias-Alvarez, A., Pineda-Pineda, A., García-Pineda, A. F. (2020). Un estudio sobre el crecimiento, estado nutricional y composición corporal en menores de quince años de Salgar, Puerto Colombia: variabilidad y determinantes sociales. *Boletín de Antropología, 35*, 143–170. http://dx.doi.org/10.17533/udea.boan.v35n60a08

Ruiz-Linares, A., Adhikari, K., Acuña-Alonzo, V., Quinto-Sanchez, M., Jaramillo, C., Arias, W., Fuentes, M., Pizarro, M., Everardo, P., de Avila, F., Gómez-Valdés, J., León-Mimila, P., Hunemeier, T., Ramallo, V., Silva de Cerqueira, C. C., Burley, M.-W., Konca, E., Zagonel de Oliveira, M., Roberto Veronez, M., Rubio-Codina, M., Attanasio, O., Gibbon, S., Ray, N., Gallo, C., Poletti, G., Rosique, J., Schuler-Faccini, L., Salzano, F. M., Bortolini, M.-C., Canizales-Quinteros, S., Rothhammer, F., Bedoya, G., Balding, D., & Gonzalez-José, R. (2014). Admixture in Latin America: Geographic structure, phenotypic diversity and self-perception of ancestry based on 7,342 individuals. *PLoS Genetics, 10*(9), e1004572. https://doi.org/10.1371/journal.pgen.1004572

Savage, T., Derraik, J. G., Miles, H. L., Mouat, F., Cutfield, W. S., & Hofman, P. L. (2013). Birth order progressively affects childhood height. *Clinical Endocrinology, 79*, 379–385. https://doi.org/10.1111/cen.12156

Scazufca, M., Menezes, P. R., Araya, R., Di Rienzo, V. D., Almeida, O. P., Gunnell, D., & Lawlor, D. A. (2008). Risk factors across the life course and dementia in a Brazilian population: Results from the Sao Paulo ageing and health study (SPAH). *International Journal of Epidemiology, 37*, 879–890. https://doi.org/10.1093/ije/dyn125

Silveira, J. A. C., Colugnati, F. A. B., Cocetti, M., & Taddei, J. A. A. C. (2014). Secular trends and factors associated with overweight among Brazilian preschool children: PNSN-1989, PNDS-1996, and 2006/07. *The Journal of Pediatrics, 90*(3), 258–266. https://doi.org/10.1016/j.jped.2013.09.003

Tanner, J. M. (1962). *Growth at adolescence*. Blackwell Scientific Publications.

Van Buuren, S., & Fredriks, M. (2001). Worm plot: A simple diagnostic device for modelling growth reference curves. *Statistics in Medicine, 20*(8), 1259–1277. https://doi.org/10.1002/sim.746

Vecino-Ortiz, A. I., & Arroyo-Ariza, D. (2018). A tax on sugar sweetened beverages in Colombia: Estimating the impact on overweight and obesity prevalence across socio economic levels. *Social Science & Medicine, 209*(40), 111–116. https://doi.org/10.1016/j.socscimed.2018.05.043

Villamor, E., Chavarro, J. E., & Caro, L. E. (2009). Growing up under generalized violence: An ecological study of homicide rates and secular trends in age at menarche in Colombia, 1940s-1980s. *Economics and Human Biology, 7*(2), 238–245. https://doi.org/10.1016/j.ehb.2009.03.002

Wang, Y. (2002). Is obesity associated with early sexual maturation? A comparison of the association in American boys versus girls. *Pediatrics, 110*, 903–910.

WHO Multicentre Growth Reference Study Group. (2006). WHO Child Growth Standards based on length/height, weight and age. *Acta Paediatrica. Supplement, 450*, 76–85. Tables for length/height, weight, body mass index and head circumference for age, 0–5 years. http://www.who.int/childgrowth/standards/en/

Chapter 7
Anthropometric Indices to Evaluate Nutritional Status and Health Risk of Schoolchildren and Adolescents

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7.1 Introduction

The third Sustainable Development Goal aims to guarantee that people of all ages live healthy lives and promote well-being, focusing on child and maternal health (United Nations & Department of Economic and Social Affairs, 2015). More and more government officials and society itself recognize the economic, ethical, and social benefits of improving early life conditions. Interventions that safeguard children and encourage them to reach their full potential, can improve cognitive and emotional development and educational performance, leading to more productive work, more social mobility, and a reduction in future inequities.

Currently, the global population is exposed to an environment with high availability of ultra-processed foods containing high amounts of energy, sugar, and fats and poor lifestyle habits with low physical activity. These facts negatively influence physical growth and nutrition in children and enhance the risk of adipose tissue accumulation, particularly at the abdominal level. Hence, monitoring child growth is crucial to ensure future health and wellness of children (Black et al., 2017). On the other hand, a significant burden of mortality and morbidity is caused by inadequate growth and nutritional deficiencies, with negative consequences that extend beyond the life cycle and transmit to future generations.

For schoolchildren, anthropometric measures such as body mass index (BMI), waist circumference (WC), and waist-to-height ratio (WHtR) can be the inexpensive

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S. Datta Banik (ed.), *Human Growth and Nutrition in Latin American and Caribbean Countries*, https://doi.org/10.1007/978-3-031-27848-8_7

tools to identify overall and central obesity (Jensen et al., 2016). Due to their relevance for the timely detection of nutritional risk, they are suggested as measures of a pediatric nutritional surveillance system.

7.2 Health Status of Schoolchildren in Latin American Countries

Defining and diagnosing obesity in children can be challenging due to the lack of reference thresholds as in adults and the use of anthropometric measurements compared with reference values for the population. In practical terms, obesity in children is assessed using BMI, an index of weight (kg) divided by height (m) squared, and the results are used to compare against growth charts to determine children's height-adjusted weight status. There are different cut-off points for BMI, established by the CDC, the International Obesity Task Force (IOTF), and WHO. During childhood, BMI constantly changes and therefore, age-and-sex-specific percentiles are used to interpret growth and nutritional status at this stage (Tyson & Frank, 2018).

A study simulating growth trajectories of childhood obesity into adulthood (n = 41,567), representative of the 2016 population in the United States (USA), predicted that 57.3% (95% confidence interval 55.2–60.0) of children at that time had obesity at 35 years and that approximately, half of the predicted obesity prevalence will occur during childhood. This study also showed that it was implausible that kids who are severely obese will not become obese in adulthood (Ward et al., 2017).

In Latin America, children and adolescents are also affected by metabolic disorders and risk of cardiovascular diseases (González Devia et al., 2014; Magana Gomez et al., 2020). In Mexico, the most recent Mexican National Health and Nutrition Survey (ENSANUT, 2018) showed a national prevalence of 35.5% for overweight and obesity, representing 3,920,010 schoolchildren with excess weight. When analyzed by age, obesity showed the highest prevalence at ten years for girls and nine years for boys. The increase in obesity between 1999 and 2018 was 8.6%, equivalent to about a 0.5% increase per year. In contrast to excess weight, anemia persists as a problem in Mexican children with 21.2% (IC95%: 19.6, 23), which means 2,339,657 schoolchildren have anemia, regardless of sex or region. That is worrying since the increment in anemia prevalence from 2012 to 2018 was 11.1% (Barquera et al., 2020).

Similar trend of overweight/obesity prevalence is observed in other Latin American countries. For instance, in Brazil, the reported prevalence of overweight was 30.7%, while abdominal obesity was 9.2% based on waist circumference (WC) but 12.6% based on the waist-to-height ratio (WHtR). Like other reports, boys showed a higher risk of having abdominal obesity than girls. This study found that skipping supper (evening meal) was one of the main risk factors for abdominal obesity (Canuto et al., 2021). In Venezuela, reports from a study indicate a metabolic syndrome (MetS) prevalence of 2.2% in subjects aged 9–18 years and an increased risk of having MetS if abdominal obesity is present (Reyes et al., 2014). Prevalence of dyslipidemias in children was 38%, with a higher prevalence among obese children (54%, $p < 0.01$), and 54% of the studied population had a high atherogenicity risk (measured with the atherogenic index of plasma), in addition to insulin resistance, and excess weight (Sapunar et al., 2018).

Prevalence of MetS in youth is from 4% in general, up to 30–50% in children overweight. However, other reports indicate a different prevalence of 3.3% (range 0–19.2%) of MetS in the whole population, 11.9% (range 2.8–29.3%) among overweight children, and 29.2% (range 10.0–66.0%) in obese people, with a significantly higher prevalence among those with obesity when compared to overweight ($p = 0.012$) and non-obese/non-overweight children ($p < 0.001$). Also, MetS was more prevalent in boys than girls (5.6% versus 2.9%, $p = 0.001$) (Friend et al., 2013). There is no clear evidence of ethnic differences between white and Latin American youth concerning the MetS prevalence, primarily due to the lack of generally accepted diagnostic criteria for this population and the paucity of enough reports across nations that allow comparative studies. In Mexico, a survey carried out among 965 children and adolescents showed that 21.3% of normal weight and 26.1% of overweight/obese children and adolescents had MetS (Rodríguez-Morán et al., 2004). A study in children aged 8–11 years from northwest Mexico found 10.3% of MetS in the sample, using the WHO criteria, which was higher for the general child population than other populations (3–8.4%) (Magana Gomez et al., 2020). An additional summary of health conditions in schoolchildren from Latin American countries is provided in Table 7.1.

7.3 Biological Perspectives of Maturation Associated with Health Risks in Schoolchildren

7.3.1 Physical Maturation, Hormonal Changes, and Adiposity

Skeletal maturity is the most valuable biological indicator of overall maturation and is measured by bone age. In the period between 6 and 12 years, height increases are held similarly until puberty. It is determined by predicting the order of appearance of ossification points developed in bones' epiphyses (growth regions). Some variability is related to ethnic background, but differences in maturity onset are observed in the rate rather than the sequence. Therefore, ossification is driven mainly by genetic factors. External factors and health influence skeletal maturation; for instance, lower socioeconomic level and several diseases have been correlated with delayed bone maturation. Girls have differences in cartilage thickness because it tends to be thinner and decreases at a higher rate than boys. Skeletal maturation and skeletal growth occur parallelly to reach final height when hormonal changes allow epiphyses to fuse towards the end of adolescence (Sinclair & Dangerfield, 1998).

Table 7.1 Prevalence of health and nutritional status of schoolchildren in different Latin-American countries

Health conditions	Mexico (5–11 years, n = 6266) (Barquera et al., 2020)	Mexico (4–11 years, n = 569) (González Cortés et al., 2021)	Brazil (7–9 years, n = 326) (Canuto et al., 2021)	Venezuela (9–18 years, n = 916) (Reyes et al., 2014)	Chile (9–11 years, n = 208) (Sapunar et al., 2018)
Anemia	21.2% (IC95% 19.6, 23.0)	–	–	–	–
Underweight	4.8% (aged <5 years)	7.2%	–	–	0%
Stunted growth	14.2% (aged <5 years)	–	0.6%	–	–
Overweight	18% (girls 18.4%, boys 17.7%)	20%	16% (girls 13.8%, boys 16.9%)	–	38% (girls 36%, boys 40%)
Obesity	17.5% (girls 15%, boys 20.1%)	14%	14.7%	Abdominal obesity 10.2%	33% (girls 27%, boys 40%) and abdominal obesity 26%
Overweight/Obesity combined	35.5%	34%	30.7%	–	71%
High blood pressure	–	40%	–	8.7%	–
MetS	–	–	–	2.2%	–
Prediabetes (impaired fasting glucose)	–	8.6% (4–19 years)	–	3.6%	0%

Puberty onset reflects the beginning of reproductive maturity. Higher socioeconomic status, living in urban areas, and lower altitudes are related to earlier pubertal changes (Alotaibi, 2019). On the other hand, malnourished children, bigger family sizes, and girls who perform vigorous exercises (e.g., competitive athletes or dancers) may have delayed onset of puberty (Klentrou & Plyley, 2003). Although environmental factors are important, the genetic component significantly affects puberty onset, linked with children's overall body size and maturation. This association is more robust with bone age than chronological age. Even though the order of changes in puberty is well established, their timing can be highly variable. For instance, in females, the changes in puberty occur at an average age of 12 years, ranging between 9 and 14 years, in males, the average age of pubertal onset is 12 years and ranges from 10 to 14 years, and usually it is 2 years earlier in girls than boys (Wood et al., 2019). The changes during puberty in girls are marked by a growth spurt first, followed by breast tissue and menarche development. In boys, changes start with an increase in testicle size, later accompanied by a growth spurt.

Usually, girls grow 9.0 cm and boys 10.3 cm per year, which leads to peak growth in 2–3 years after puberty onset, although pubertal changes are not uncommon in both sexes before 13 years (Lee & Houk, 2007). In both cases, changes result from increased sex steroid secretion and gonadotropin.

Middle childhood is characterized by adrenarche, the onset of androgen secretion by the adrenal glands in both sexes occurring around 6–8 years of age (Witchel et al., 2020). At the age of 6 years, brain has almost achieved maximum size. Thus, it receives a minor of the body's glucose post-consumption peak of early childhood; energy then is redirected for muscle mass growth and fat deposits to provide sexual maturity (adiposity rebound) (Giedd & Rapoport, 2010). Androgens, mainly dehydroepiandrosterone (DHEA) and DHEA sulfate (DHEAS), have minor influences on physical development but significantly affect brain performance. Ultimately, adrenarche in middle childhood will lead to heightened sensitivity to the environment and the expression of new genetic factors due to the activation of a multiplicity of hormone-sensitive brain pathways that were dormant since early childhood (Del Giudice, 2015).

At birth, body fat percentage is approximately 12%; at nine months of age, it increases to 22%. After this, it begins to decrease until reaching the minimum reserve of body fat point, which results in a drop and the lowest point in the BMI (Lamb et al., 2011). This point in children‘s growth is the nadir of the BMI curve called adiposity rebound. It usually occurs between ages 5–7 years, and from this point and on, an individual regains fat, which continues throughout puberty, adolescence, and adulthood. The average age of adiposity rebound is 6.0–6.3 years. Hence, if adiposity rebound begins before 5.5 years of age, it is called an early adiposity rebound. It is considered late if it occurs after 7 years of age (Rolland-Cachera et al., 2006).

Pregnancy, maternal obesity, early lactation, adolescence, and the pattern of adiposity accumulation during childhood are critical components of developing obesity. It has been proposed that obesity in infancy has a worse prognosis and response to treatment. Because the longer the time the adipose tissue has been accumulating, the degree of obesity will be higher. The increase in the size of the adipocytes (hypertrophy) will eventually turn to hyperplasia; this is a response of the adipose tissue to the energy overload provided through a hypercaloric diet (Johannsen et al., 2014). The caloric intake overload at any age initially causes the filling of the already existing adipocyte with triglycerides (TGs). When their weight approaches 1.6 μg, cell division and the recruitment of cells from the adipocyte pool of adipoblast continue with the adipogenesis process (Hisaoka, 2014).

Obese and non-obese children under ten years of age with obese parents have twice the risk of being obese adults, which may be related mainly to genetic and environmental factors, primarily food environment (Jia, 2021). Modern lifestyle plays a fundamental role in developing obesity, and genes seem to be important in the onset of early and severe forms of the disease. Phenotypically, children with overweight and obesity are usually taller, have older bone age, experience sexual maturity at an earlier age, and have a more aged physical appearance than children without these conditions (Cook et al., 2003). Characterization of obesity phenotypes could help to consider the differences in the evolution of obesity in various social environments and racial-ethnic contexts and how these factors may be critical markers of the excess risk of developing obesity in some races, both by the difference they show in the consumption and use of energy (Kumanyika, 2007).

7.3.2 Metabolic Syndrome

MetS is a cluster of cardiometabolic risk factors that include elevated WC, dyslipidemia (elevated TGs, reduced high-density lipoprotein-cholesterol (HDL-c), or medical treatment for either), high blood pressure (BP) (or treatment for it), and impaired glucose tolerance according to the harmonized criterion in adults (Alberti et al., 2009). Nevertheless, a widely accepted definition of MetS in children and adolescents remains to be established due to the individual variation in growth patterns, hormonal effects during puberty on insulin sensitivity and lipid profile, and ethnic differences in the components of MetS, making it challenging to establish unified criteria (Flemming et al., 2020). Some authors consider it specific to sex and ethnic groups (Reisinger et al., 2021). In genetical perspective, various genes have been associated with MetS related to lipolysis regulation, thermogenesis, glucose, and muscle metabolism. Genetic and environmental factors on birth weight should not be overlooked; fetal undernutrition can be harmful to the development of pancreatic β-cell function and insulin-sensitive tissues, which could be related to the activation of genes associated with insulin resistance (Chen et al., 2019).

7.3.3 Cardiovascular Risk

Hypertension increases the risk of cardiovascular disease in millions of people worldwide. Factors for increasing blood pressure include obesity, insulin resistance, dyslipidemia, high alcohol consumption, high salt intake (salt-sensitive patients), age, sedentary lifestyle, stress, and low potassium and calcium intake (Rapsomaniki et al., 2014). Though blood pressure is a quantitative characteristic with a critical variation, it has a high correlation with the risk of cardiovascular diseases. In childhood, arterial hypertension or high blood pressure is defined by having at least three readings higher than the 95th centile considering age, height, and sex (Lurbe et al., 2009). Although the clinical manifestations of coronary artery disease, such as angina pectoris or myocardial infarction, usually present from the fourth or fifth stage of life, several studies have shown that atherosclerosis begins in childhood and adolescence. For instance, some cross-sectional and longitudinal studies on young adults have reported early atherosclerosis during autopsies. Some reports indicate that 6 out of 10 overweight adolescents have an additional cardiovascular risk factor such as high blood pressure, dyslipidemia, or hyperinsulinemia (U. S. Preventive Services Task Force et al., 2017). Environmental factors, including smoking, physical inactivity, and inadequate diet, also cause obesity early in life (U. S. Preventive Services Task Force et al., 2020).

Dyslipidemia or hyperlipidemia, characterized by excessive production or decreased clearance of serum lipoproteins can be primary, genetic, or secondary, associated with different diseases. Dyslipidemias may start the atherosclerosis process early in life; thus, early detection of dyslipidemia improves its prognosis and prevents complications in adult life. Increased plasma TGs levels characterize atherogenic dyslipidemia and low HDL-c levels, increased low-density lipoprotein cholesterol (LDL-c), molecules that tend to be smaller and denser than other cholesterol fractions, a situation that increases the risk of atherogenesis (Blokhin & Lentz, 2013).

7.4 Associations of Height, Weight, Lengths, and Circumferences with Nutritional Status

Anthropometric evaluation of growth and nutritional status among schoolchildren is based on the study of a small number of body measurements. The procedures are simple, safe, and non-invasive; they are precise and accurate if standardized protocols are used, and the necessary equipment is inexpensive and portable. Growth measures are used and interpreted depending on whether they are taken on an individual (for therapeutic purposes) or a population (for public health purposes) (Table 7.2). Erroneous anthropometric measurements do not provide precise etiological information. Infection, insufficient dietary intake, psychosocial deprivation, endocrine, metabolic, or exterior disorders could contribute to health, nutritional status and growth of children and adolescents. Poor nutrition, high morbidity from infectious diseases, famine, or outbreaks of infectious diseases such as diarrhea or measles could contribute to the growth abnormalities (WHO, 1995). Therefore, for the selection of anthropometric indices it is important to distinguish between their multiple roles as health and nutrition problems indicators. Anthropometry can be linked to previous exposures (reflection), current processes (concurred), or future occurrences (predictive); it can also be used to predict risk, reward, or reaction.

Table 7.2 Considerations to select anthropometric indicators

For individuals	For populations	For individuals and populations
Screening for interventions. Assessing response to an intervention,	Targeting interventions. Assessing response to an intervention. Identifying determinants of malnutrition. Predicting consequences of malnutrition.	What will be done for the individual or population? For what purpose? Target group and setting. What to measure, what information to collect, and how often.

Information adapted from World Health Organization (1995)

Furthermore, anthropometric outcome markers can be near (proximal or direct) or far away (distal or indirect) from the events of interest.

7.4.1 Anthropometric Measurements and Indices Used to Evaluate Growth

Several measurements, such as supine length of infants, height in children and adolescents, and weight (and head circumference for children from birth to 2 years of age), are used to assess growth and nutritional status in children. With the combination of these direct measurements, different indexes can be calculated. The following are some of the most frequently used indicators to evaluate child growth.

Height-for-age (H/A): used for assessing low-height-for-age or stunting (chronic undernutrition in children).

Weight-for-age (W/A): used for evaluating children under two years of age who may be underweight.

Weight-for-height (W/H): for assessing wasting (acute malnutrition).

The applicability of different indicators is limited by the availability of standards and references from the WHO and the CDC. Among these, the child population is classified into those under 5 years of age (preschoolers) (Table 7.3) and those over

Table 7.3 Availability of growth charts for different anthropometric indicators for children under 5 years of age

Indicator	Institution	Age	Distribution
Length-for-age	WHO	Birth to 2 years	Percentiles and z-score
	CDC	Birth to 36 months	Percentiles
Height-for-age	WHO	2–5 years	Percentiles and z-score
	CDC	2–20 years	Percentiles
Weight-for-age	WHO	Birth to 5 years	Percentiles and z-score
	CDC	Birth to 36 months	Percentiles
Weight-for-length	WHO	Birth to 2 years	Percentiles and z-score
	CDC	Birth to 36 months	Percentiles
Weight-for-height	WHO	2–5 years	Percentiles and z-score
	CDC	2–5 years	Percentiles
Head circumference-for-age	WHO	Birth to 5 years	Percentiles and z-score
	CDC	Birth to 36 months	Percentiles
Arm circumference-for-age	WHO	3 months to 5 years	Percentiles and z-score
Subscapular skinfold-for-age	WHO	3 months to 5 years	Percentiles and z-score
Triceps skinfold-for-age	WHO	3 months to 5 years	Percentiles and z-score
Body mass index-for-age	WHO	Birth to 5 years	Percentiles and z-score
	CDC	2–20 years	Percentiles

WHO World Health Organization, *CDC* Centers for Disease Control and Prevention

Table 7.4 Availability of growth charts for different anthropometric indicators for children above 5 years of age

Indicators	Institution	Age	Distribution
Height-for-age	WHO	5–19 years	Percentiles and z-score
	CDC	2–20 years	Percentiles
Weight-for-age	WHO	5–19 years	Percentiles and z-score
	CDC	2–20 years	Percentiles
Body mass index-for-age	WHO	5–19 years	Percentiles and z-score
	CDC	2–20 years	Percentiles

WHO World Health Organization, *CDC* Centers for Disease Control and Prevention

5 years of age (school children) (Table 7.4). For preschoolers, the main objective is growth monitoring. However, in school children, new interests are added due to their exposure to new environmental factors such as school, social life, stimuli, physical activity, sedentary lifestyle, and changes in eating habits. Additionally, the physiological changes they experience open the field of study to evaluate body composition characteristics and search for new indicators that may be related to the risk of chronic degenerative diseases.

7.4.2 Anthropometric Measurements Used to Assess Body Composition

Human body is made up of two major components: fat mass and fat-free mass. Therefore, different measurements are used to assess body composition characteristics based on these two components. The gold standard methods for determining adiposity and body composition rely on expensive technologies, such as air displacement plethysmography, hydrostatic weighing, magnetic resonance imaging, computed tomography, and dual-energy X-ray absorptiometry (DXA). While these approaches give some of the most reliable body composition estimates, many of them are impractical in pediatric research, particularly in field-based studies. The DXA equipment is costly and not portable, making unsuitable for field studies with limited resources. For schoolchildren, anthropometric measures such as body mass index (BMI), waist circumference (WC), and waist-to-height ratio (WHtR) can be the reliable indicators to identify overall and central obesity (Jensen et al., 2016). Bioelectrical impedance analysis (BIA), which estimates body composition by measuring the impedance of a minute electrical pulse passed through the body, is less expensive and portable; however, the assumptions used to calculate body fat may not be useful for infants.

7.4.3 Body Mass Index (BMI)

BMI, formerly called the Quetelet index, was developed by Adolphe Quetelet during the nineteenth century. It is used to categorize a person as underweight, normal weight, overweight, or obese, based on tissue mass (muscle, fat, and bone) and height. During the 1970s, researchers noticed that BMI appeared to be a good proxy for adiposity and overweight-related problems. Currently, it is commonly used for defining overweight and obese children and adolescents because it correlates well with body fat (BF) and cardiovascular risk factors (Daniels et al., 2009; Field et al., 2003). The low cost of equipment, minimum burden of height and weight measurement, and the ability to combine self-report and clinical measures are advantages of using BMI to quantify adiposity in research. However, BMI cannot distinguish individuals with excess body fat from those with high muscle mass, nor can it reflect the distribution of adipose tissue, and its relationship with body fat is dependent on nutritional status, with a more significant association in overweight and obese children than in lean subjects (Louer et al., 2017).

The weight/height ratio varies with sex and age during childhood, so the cut-off values to classify nutritional status are sex- and age-specific. In children, BMI is compared with z-scores or percentiles. The BMI-for-age cut-off points for children aged 0–5 years were set as the 97th and the 99th percentile for the diagnosis of overweight and obesity, respectively. For those aged 5–19 years, overweight is defined as a BMI-for-age value over +1 SD and obesity as a BMI-for-age value over +2 SD.

There are substantial anthropometric differences between the CDC and WHO reference populations. The CDC 2000 BMI charts were created using data from national surveys conducted between 1963 and 1994. However, because of the developing obesity pandemic in children, BMI statistics were removed from the National Health and Nutrition Examination Survey 1988–1994 for children 72 months and older. As a result, the BMI graphs do not accurately reflect the distribution of BMI values in the general population of children in the 1990s and later (Zemel, 2021). At the same time, the WHO standards represent the best possible growth potential from optimally fed babies (breastfed) residing in optimal living conditions in areas worldwide. The CDC recommends using the WHO growth standard charts for children aged birth to less than 2 years to monitor growth in the United States (Grummer-Strawn et al., 2010). For schoolers, each institution has its own standards and references.

In most children with class 2 and 3 obesity, BMI accurately identifies excess adiposity; however, there was a high degree of discordance in adolescents with obesity and overweight. Excess adiposity raises cardiovascular and metabolic risk factors, regardless of the cut-off point selected (Ryder et al., 2016). Since central obesity is an indicator of cardiometabolic risk, better anthropometric measures than BMI to screen for central obesity are needed. Several studies have suggested that WC and WHtR may be convenient to assess central obesity because they correlate better than other indices with visceral abdominal fat, which is considered the most dyslipidemic and most atherogenic manifestation of adiposity with metabolic risk factors in children (Savva et al., 2000).

7.4.4 Waist-to-Height Ratio (WHtR)

This indicator has received increasing attention in recent years. It was proposed in the 1990s (Hsieh & Yoshinaga, 1995), and currently, with WC, it is the most widely used to evaluate central obesity. It requires only a measuring tape to obtain both WC and height and divide them, whereas measuring BMI requires an anthropometer and weighing scale. WHtR is used because, for a given height, there is an acceptable degree of fat stored in the upper portion of the body (trunk). Compared with BMI and WC, it is not required to be interpreted with specific cut-off points for differentiation by age, sex, and ethnicity. However, in a recent study among 8,091 Korean children and adolescents aged 10–18 years included in a nationally representative survey, the statistical analysis showed that in the 85th–95th percentiles, WHtR were at high risk for elevated WC, elevated blood pressure (BP), elevated TGs, reduced HDL-c, and MetS. Moreover, boys and girls in the ≥95th percentile of WHtR exhibited higher risks for elevated WC, elevated BP, elevated glucose, elevated TGs, reduced HDL-c, and MetS (Lee et al., 2021).

A study among Korean adolescents (10–19 years) found that those non-overweight with the WHtR ≥0.5 had a greater prevalence of multiple cardiometabolic risk factors and MetS than the WHtR <0.5 group. Prevalence of MetS was only 2% in overweight adolescents with a WHtR <0.5, while it increased to 17% in those with a WHtR ≥0.5. These findings imply that WHtR could be used for screening metabolic risk among schoolchildren and adolescents (Chung et al., 2016).

Recently, the correlation of WHtR, WC, and BMI with lipidic and non-lipidic cardio-metabolic risk factors and each adiposity indicator's predictive power was studied in a sample of school-aged Mexican children. A total of 125 children aged 6–12 years were studied. None of the adiposity measures was linked to fasting plasma glucose; however, they were good predictors for high LDL-c, TGs, atherogenic index of plasma, and low HDL-c. Children with WHtR 0.5 had a significant increased risk of having LDL-c ≥ 3.4 mmol/L than those with WHtR <0.5 (odds ratio, OR: 2.82; 95 percent confidence interval, CI: 0.75–7.68; p = 0.003) (Aguilar-Morales et al., 2018).

It has been suggested that WHtR greater than 0.5 may be a global boundary value to screen for cardiovascular disease and diabetes, even in Mexican schoolchildren (Brannsether et al., 2011; Lopez-Gonzalez et al., 2016; Mushtaq et al., 2011). Unlike other anthropometric measurements that allow the diagnosis of obesity or overweight, the significant contribution of sex- and age-specific WHtR percentiles can appropriately estimate cardiometabolic risk and be used in clinical settings at an early age as a considerably simple measurement (Lo et al., 2016).

7.4.5 Waist Circumference

WC is a simple method to assess abdominal adiposity; easy to standardize and apply in a clinical setup. Its advantage over BMI is partially related to BMI, which is a poor indicator of abdominal adiposity. Recently there is a consensus about using WC to estimate risk factors for premature atherosclerosis and CVD in adults due to abdominal obesity (Ross et al., 2020). Authors find that WC is highly linked with all-cause and cardiovascular mortality, with or without BMI adjustment. However, only after adjusting for BMI is the full strength of the association between WC and morbidity and mortality revealed. That is because persons with larger WC values are at an elevated risk of bad health outcomes than those with lower WC values in any given BMI group. Thus, for a given WC, a higher BMI could indicate a phenotype with fewer body subcutaneous adipose tissue increases; on the other hand, a higher BMI for a particular WC may have lower VAT (visceral adipose tissue) levels. These data suggest a mechanism by which lower BMI or hip circumference values for a given WC enhance the likelihood of unfavorable health consequences. Therefore, the combination of BMI and WC is considerably more effective than either measure alone in identifying the highest-risk phenotype of obesity (Eastwood et al., 2014).

What is known about WC values are from studies in adults, and cut-off points of WC for the classification of abdominal adiposity in children and adolescents have not been established yet limiting its use. Studies describing percentile values of WC have shown that measurements may be affected by age, sex, and ethnicity (Fernandez et al., 2004; Ramirez-Velez et al., 2017), which makes the establishment of global reference values difficult.

For comparison between countries, the 90th percentile has been recommended by the International Diabetes Federation as the cut-off point for the diagnosis of abdominal obesity (Zimmet et al., 2007). However, in a study of 13,289 healthy children between 6 and 18 years coming from public schools of middle and low socioeconomic levels in different parts of Argentina, Cuba, Mexico, Spain, and Venezuela, authors observed values of 50th and 90th percentiles higher than those in references for Germany, Tunisia, Greece, and Colombia (Marrodan Serrano et al., 2021). They discuss that this fact could be partly attributed to the measurement site, although the observed differences are much more significant than expected from the technique used.

7.4.6 Neck Circumference

Few studies have evaluated neck circumference (NC) as an indicator of adiposity in children. The NC is positively associated with adults' obstructive sleep apnea, diabetes, and hypertension. Also, this anthropometric measurement has significant positive correlations between NC and BMI in both genders of children and adolescents, as well as high correlations with other indices, such as those that assess central obesity, WC, and arm circumference (Hatipoglu et al., 2010; Lou et al., 2012; Mazicioglu et al., 2010; Nafiu et al., 2010). In a study among 1,102 children (52% were male), NC was significantly correlated with age, BMI, and WC in both boys and girls, although the correlation was more robust in older children. Optimal NC cut-off indicative of high BMI in boys ranged from 28.5 to 39.0 cm, and values in girls ranged from 27.0 to 34.6 cm (Nafiu et al., 2010). Han children aged 7–12 years, NC cut-off values for elevated BMI were between 27.4~31.3 cm in boys and 26.3~31.4 cm in girls (Lou et al., 2012). More recently, a study among Indian children established 30.75 cm and 29.75 cm for boys and girls, respectively, as the cut-off points for screening adolescent obesity (Patnaik et al., 2017).

The NC is a simple technique with good interrater reliability and could be used to screen for overweight and obesity in children. As can be seen, the NC can reliably identify children with high BMI, is significantly correlated with adiposity indices, and is currently being used as a cardiovascular risk screening parameter in schoolchildren and adolescents (Mercan et al., 2022). However, it is still necessary to define cut-off points with national and international validity to be able to compare studies. A conservative approach continues to use percentiles, adjusted for sex, age, and population, as has traditionally been done by using the 90th percentile to diagnose a condition.

7.4.7 Mid-Upper Arm Circumference and Arm Circumference to height Ratio

Anthropometric measurement of the mid-upper arm circumference (MUAC) is also helpful for evaluating undernutrition and excess weight. Initially, it was developed as a practical and straightforward proxy for undernutrition in critical and emergency settings. In addition, unlike WC measurement, it is not affected by respiratory movements and postprandial abdominal distension; therefore, it may be a more reliable index than WC. When MUAC is divided by height, the "unitless" arm circumference-to-height ratio (AHtR) is obtained, which is not correlated with age, and both professionals and common people can easily interpret cut-off points. Furthermore, AHtR is an age-independent index because AHtR had already been adjusted for height. That makes it possible to propose nonage-dependent cut-off points, which are easy and feasible to manipulate for both professionals and laypeople.

Several studies show that both indicators have higher applicability for screening overweight and obese children. In a large study to determine whether MUAC could be used to identify obesity, 7,337 children aged 9–11 years from Australia, Brazil, Canada, China, Colombia, Finland, India, Kenya, Portugal, South Africa, the UK, and the USA, representing countries from low to high income, Human Development Index (0.509 in Kenya to 0.929 in Australia) and inequality (Gini coefficient) were studied. In both boys and girls, MUAC was substantially linked with adiposity indices. The MUAC cut-off value for identifying obesity was 25 cm for both boys and girls. However, the cut-off value for identifying obesity in country-specific analyses ranged from 23.2 cm (boys in South Africa) to 26.2 cm (girls in South Africa). The authors concluded that MUAC is a simple and accurate assessment that may be used to detect obesity in children aged 9–11 years and could be a promising screening technique for obesity (Chaput et al., 2017).

In another study, MUAC and AHtR measurements were assessed in 2,847 Asian children aged 7–12 years. Results showed that in both genders and across all age groups, the accuracy values of MUAC for diagnosing high BMI [as measured by area under the curve (AUC)] were over 0.85 (AUC: about 0.934–0.975). The MUAC threshold values for high BMI were calculated to be around 18.9–23.4 cm in boys and girls. The accuracy of AHtR in detecting high BMI (as measured by AUC) was also over 0.85. (AUC: 0.956 in boys and 0.935 in girls). In both boys and girls, the AHtR threshold values for high BMI were calculated to be 0.15. Authors demonstrate that MUAC and AHtR may be used to identify overweight and obese Han children (Lu et al., 2014).

Also, 3,618 Thais children aged 6–13 years were analyzed to identify optimal cut-off values for MUAC and AHtR to detect overweight and obesity compared to BMI. In both genders, MUAC was associated with age and height ($p = 0.001$), but mainly with body weight ($r = 0.888–0.914$) and BMI ($r = 0.859–0.908$), whereas AHtR was associated with body weight and BMI ($p = 0.001$) but not with age. For boys, MUAC cut-off values for obesity diagnosis ranged from 18.9 to 25.5 cm, and for overweight ranged from 17.2 to 22.4 cm. For girls, cut-off values ranged from 19.8 to 25.4 cm for obesity diagnosis and 18.0–23.2 cm for overweight. The 0.16 and 0.145 AHtR cut-off values for obesity and overweight diagnosis were identified with excellent diagnostic accuracy for both genders, independent of age (Rerksuppaphol & Rerksuppaphol, 2017).

These anthropometric measurements have been tested in different infant populations and ethnicities and showed excellent accuracy in predicting overweight and obesity with high specificity and sensitivity. MUAC and AHtR are simple, inexpensive, and accurate measurements that may be used to identify overweight and obese children.

7.5 Associations and Statistical Limitations for Anthropometric Data

The early identification of excess body fat in the pediatric population is essential for preventing other chronic diseases in adult life. Since visceral fat is strongly associated with cardiometabolic risk, a measure that captures body fat distribution has additional discriminatory value. BMI is a robust predictor of systolic blood pressure (SBP), diastolic blood pressure (DBP), TGs, HDL-c, and insulin, but not total cholesterol, LDL-c, or glucose. However, several studies find that arm and WC, and WHtR are good predictors of blood lipids anthropometric and body composition characteristics that other anthropometric measurements fail to predict (Alves Junior et al., 2017; Barbosa et al., 2012; Chung et al., 2016; Lichtenauer et al., 2018; Lo et al., 2016; Santos et al., 2018).

A study among 5,964 Pakistani children aged 5–12 years evaluated height, weight, WC, waist-to-hip ratio, WHtR, and NC and found that WC had a significant positive correlation with all studied anthropometric parameters. However, WHtR had the highest value (Asif et al., 2018). However, a cross-sectional study conducted among 1,139 schoolchildren aged 6–17 years from Northeastern Brazil found that triceps skinfold thickness has the worst performance in predicting cardiometabolic risk factors, followed by WHtR. The highest accuracies were observed for BMI, WC, and subscapular skinfold, with no significant difference between these indicators (de Quadros et al., 2019). An important consideration for electing circumferences is that errors could exist by the heterogeneity of the measurement technique. In case of BMI, weight and height could be minimally affected by the technique, while for WC, several techniques have been described. An interesting review (Magalhaes et al., 2014) about the influence of measurement technique found studies where the measure was performed at the midpoint between the last rib and the top of the iliac crest, at the minimum circumference between the iliac crest and the rib cage, slightly above the upper lateral border of the right ilium, at the largest frontal extension of the abdomen between the bottom of the rib cage, at the top of the iliac crest, at navel level, and midpoint between the anterosuperior iliac spine and the bottom of the rib cage. Even studies about the influence of the measurement site for WC in its accuracy as an index of visceral and abdominal subcutaneous fat have results depending on the anatomical sites evaluated. WC differed by 10–20% according to measurement site as WC (rib) < WC(middle) < WC(iliac crest) ($p < 0.001$) in children and women. While, the comparison between measurement according to the WHO (midpoint between the lowest rib and immediately above the iliac crest) or NHANES method (point immediately above the iliac crest, respectively) (National Health and Nutrition Examination Survey, 2000; WHO, 1995), found a variation of ±0.41 cm, with a kappa value of 0.95–0.98 (Lopez-Gonzalez et al., 2016).

Another consideration is that WHtR may not offer the same predictive utility in young children as in adolescents or adults. Significant changes in body proportion, related to differential growth of different body segments, naturally occur between birth and the first few years of life. Also, there is a greater secretion of growth hormone during childhood and adolescence, which causes an increase in fat mass, fat-free mass, and height. Thus, rapid growth and significant changes in height may invalidate the relationship between WC and body size. In contrast, height is a more stable measure in adults and adolescents by which to standardize changes in WC (Coles et al., 2020).

The evidence indicates that parameters based on circumferences, particularly WC and WHtR, are the most common tools used to screen for abdominal obesity and offer considerable advantages in predicting risk in the school population

(Domingo-Bolio et al., 2021; Padrón-Martínez et al., 2016; Tanamas et al., 2016). The latter may represent a more suitable tool for the general non-professional population. However, their greater usefulness may depend on the choice of percentiles and cut-off points adapted to each population, the health status (normal weight, overweight, obese) of the schoolchild, and the inclusion of two or more measurements for better risk estimation.

7.6 Prospects for the Use of New Indicators

At the global level, WHO, Pan American Health Organization (PAHO), the United Nations (UN), and the United Nations Children's Fund (UNICEF) are the leading agencies that determine the guidelines to be followed in the field of health, nutrition, and food. The WHO is a historical reference that highlights the relevance of anthropometry in assessing nutrition status, emphasizing its work on the child population due to the social impact of public health problems in children under five and schoolchildren. Its publication, "The Physical State: Use and Interpretation of Anthropometry: Report of a WHO Expert Committee," published in 1995, was a widely consulted and implemented guide at the international level (WHO, 1995). In 2006, WHO leadership stands out with the publication of Child Growth Patterns, based on W/A, H/A, and BMI-for-age (BMI/A) (WHO, 2016).

Height and weight are the most widely used anthropometric measurements for growth and nutritional status assessment in infants, preschoolers, and schoolchildren. Globally, the outcomes of health interventions are measured transversely or longitudinally through indicators such as W/A, H/A, and BMI/A; this is how the UN sets the target of the second Sustainable Development Goal - "Zero Hunger" - based on the decrease in the prevalence of longitudinal stunting and wasting in the child population (United Nations & Department of Economic and Social Affairs, 2015). In 2020, the UNICEF, WHO, and World Bank report declared that progress is insufficient to achieve the 2030 Sustainable Development Goals (UNICEF et al., 2020). Although it is essential to measure the impact of inadequate nutrition through anthropometric indicators, it is convenient to analyze the body composition of the school population since it is widely exposed to foods high in sodium and fats and sugary drinks. The intake of these products promotes the deposit of adipose tissue and alters the intestinal microbiota towards a state of chronic inflammation (Quintero et al., 2016). On the other hand, studies carried out in the Latin American region have shown that the population living in economically developing countries has a higher risk of developing overweight (according to BMI/E) than inhabitants in countries with more economic resources (United Nations Children's Fund, 2021).

In Mexico, the ENSANUT (Mexican National Health and Nutrition Survey) results can be the starting point for multiple intervention studies or the historical reference of the nutritional situation of the Mexican population. For the school population, it collects, analyzes, and reports the result of indicators such as W/A, H/A, and BMI/A (Shamah-Levy et al., 2021). The methodological design shows that the

ENSANUT is limited to collecting the same anthropometric data as international organizations favoring that its results are comparable worldwide, so historically, the ENSANUT is the guiding document that describes the nutritional situation of Mexico to WHO, UN, and UNICEF.

At the international and national levels, decision-making for the prevention or care of short stature, low weight, overweight, and obesity in the school population, focus on analyzing primary anthropometric data such as weight, height or height and BMI. Despite the sufficient scientific evidence that describes the limitations of BMI and invites to assess body composition or adiposity using other anthropometric measurements also easy to apply and accessible such as the average arm circumference, WC, NC, or the WHtR. There is a wide gap between the scientific evidence and anthropometric measurements used by national and international agencies whose data are often used to define food and nutrition guidelines. Therefore, other forms of measurement should be collected by health care practitioners and researchers to aid in understanding the validity of other measures and their worth when used with children. Integrating body composition assessment into public health policies is recommended, highlighting that BMI alone is insufficient to postulate national recommendations applicable to the entire school population. An ideal measurement method for childhood obesity should be simple, inexpensive, easy to use, and acceptable to the participants.

References

Aguilar-Morales, I., Colin-Ramirez, E., Rivera-Mancia, S., Vallejo, M., & Vazquez-Antona, C. (2018). Performance of Waist-To-Height Ratio, Waist Circumference, and Body Mass Index in discriminating Ccrdio-metabolic risk factors in a sample of school-aged Mexican children. *Nutrients, 10*(12), 1850. https://doi.org/10.3390/nu10121850

Alberti, K. G., Eckel, R. H., Grundy, S. M., Zimmet, P. Z., Cleeman, J. I., Donato, K. A., et al. (2009). Harmonizing the metabolic syndrome: a joint interim statement of the International Diabetes Federation Task Force on Epidemiology and Prevention; National Heart, Lung, and Blood Institute; American Heart Association; World Heart Federation; International Atherosclerosis Society; and International Association for the Study of Obesity. *Circulation, 120*(16), 1640–1645. https://doi.org/10.1161/CIRCULATIONAHA.109.192644

Alotaibi, M. F. (2019). Physiology of puberty in boys and girls and pathological disorders affecting its onset. *Journal of Adolescence, 71*, 63–71. https://doi.org/10.1016/j.adolescence.2018.12.007

Alves Junior, C. A., Mocellin, M. C., Goncalves, E. C. A., Silva, D. A., & Trindade, E. B. (2017). Anthropometric indicators as body fat discriminators in children and adolescents: a systematic review and meta-analysis. *Advances in Nutrition, 8*(5), 718–727. https://doi.org/10.3945/an.117.015446

Asif, M., Aslam, M., & Altaf, S. (2018). Evaluation of anthropometric parameters of central obesity in Pakistani children aged 5-12 years, using receiver operating characteristic (ROC) analysis. *Journal of Pediatric Endocrinology & Metabolism, 31*(9), 971–977. https://doi.org/10.1515/jpem-2018-0193

Barbosa, L., Chaves, O. C., & Ribeiro, R. C. L. (2012). Anthropometric and body composition parameters to predict body fat percentage and lipid profile in schoolchildren. *Revista Paulista de Pediatria, 30*, 520–528. https://doi.org/10.1590/S0103-05822012000400010

Barquera, S., Hernández-Barrera, L., Trejo-Valdivia, B., Shamah, T., Campos-Nonato, I., & Rivera-Dommarco, J. (2020). Obesity in Mexico, prevalence and trends in adults. Ensanut 2018-19. *Salud Pública Mex, 62*(6), 682–692. https://doi.org/10.21149/11630

Black, M. M., Walker, S. P., Fernald, L. C. H., Andersen, C. T., DiGirolamo, A. M., Lu, C., et al. (2017). Early childhood development coming of age: science through the life course. *Lancet, 389*(10064), 77–90. https://doi.org/10.1016/S0140-6736(16)31389-7

Blokhin, I. O., & Lentz, S. R. (2013). Mechanisms of thrombosis in obesity. *Current Opinion in Hematology, 20*(5), 437–444. https://doi.org/10.1097/MOH.0b013e3283634443

Brannsether, B., Roelants, M., Bjerknes, R., & Juliusson, P. B. (2011). Waist circumference and waist-to-height ratio in Norwegian children 4-18 years of age: reference values and cut-off levels. *Acta Paediatrica, 100*(12), 1576–1582. https://doi.org/10.1111/j.1651-2227.2011.02370.x

Canuto, M., Silva, A. V. L., Martins, J. V., Fonseca, M. M., Guimaraes, N. S., Soares, A. D. N., & Gomes, J. M. G. (2021). Abdominal obesity-related risk factors in children from public schools of Barbacena, Minas Gerais, Brazil. *Revista Paulista de Pediatria, 40*, e2020354. https://doi.org/10.1590/1984-0462/2022/40/2020354

Chaput, J. P., Katzmarzyk, P. T., Barnes, J. D., Fogelholm, M., Hu, G., Kuriyan, R., et al. (2017). Mid-upper arm circumference as a screening tool for identifying children with obesity: a 12-country study. *Pediatric Obesity, 12*(6), 439–445. https://doi.org/10.1111/ijpo.12162

Chen, T., Wang, F., Chu, Z., Sun, L., Lv, H., Zhou, W., et al. (2019). Circulating spexin decreased and negatively correlated with systemic insulin sensitivity and pancreatic beta cell function in obese children. *Annals of Nutrition & Metabolism, 74*(2), 125–131. https://doi.org/10.1159/000496459

Chung, I. H., Park, S., Park, M. J., & Yoo, E. G. (2016). Waist-to-height ratio as an index for cardiometabolic risk in adolescents: results from the 1998-2008 KNHANES. *Yonsei Medical Journal, 57*(3), 658–663. https://doi.org/10.3349/ymj.2016.57.3.658

Coles, N., Retnakaran, R., Hanley, A., Birken, C., & Hamilton, J. (2020). Evaluation of anthropometric measures for assessment of cardiometabolic risk in early childhood. *Public Health Nutrition, 23*(12), 2100–2108. https://doi.org/10.1017/S1368980019004749

Cook, S., Weitzman, M., Auinger, P., Nguyen, M., & Dietz, W. H. (2003). Prevalence of a metabolic syndrome phenotype in adolescents: findings from the third National Health and nutrition examination Survey, 1988-1994. *Archives of Pediatrics & Adolescent Medicine, 157*(8), 821–827. https://doi.org/10.1001/archpedi.157.8.821

Daniels, S. R., Jacobson, M. S., McCrindle, B. W., Eckel, R. H., & Sanner, B. M. (2009). American Heart Association childhood obesity research summit report. *Circulation, 119*(15), e489–e517. https://doi.org/10.1161/CIRCULATIONAHA.109.192216

de Quadros, T. M. B., Gordia, A. P., Andaki, A. C. R., Mendes, E. L., Mota, J., & Silva, L. R. (2019). Utility of anthropometric indicators to screen for clustered cardiometabolic risk factors in children and adolescents. *Journal of Pediatric Endocrinology & Metabolism, 32*(1), 49–55. https://doi.org/10.1515/jpem-2018-0217

Del Giudice, M. (2015). Attachment in middle childhood: an evolutionary-developmental perspective. *New Directions for Child and Adolescent Development, 2015*(148), 15–30. https://doi.org/10.1002/cad.20101

Domingo-Bolio, V., Medina-Vera, I., Shamah-Levy, T., Moreno-Macias, L., & Avila-Nava, A. (2021). Evaluation of cardiovascular risk by waist-to-height ratio in school-age children. *Metabolic Syndrome and Related Disorders, 19*(10), 531–536. https://doi.org/10.1089/met.2021.0048

Eastwood, S. V., Tillin, T., Wright, A., Mayet, J., Godsland, I., Forouhi, N. G., et al. (2014). Thigh fat and muscle each contribute to excess cardiometabolic risk in south Asians, independent of visceral adipose tissue. *Obesity (Silver Spring), 22*(9), 2071–2079. https://doi.org/10.1002/oby.20796

Fernandez, J. R., Redden, D. T., Pietrobelli, A., & Allison, D. B. (2004). Waist circumference percentiles in nationally representative samples of African-American, European-American, and Mexican-American children and adolescents. *The Journal of Pediatrics, 145*(4), 439–444. https://doi.org/10.1016/j.jpeds.2004.06.044

Field, A. E., Laird, N., Steinberg, E., Fallon, E., Semega-Janneh, M., & Yanovski, J. A. (2003). Which metric of relative weight best captures body fatness in children? *Obesity Research, 11*(11), 1345–1352. https://doi.org/10.1038/oby.2003.182

Flemming, G. M. C., Bussler, S., Körner, A., & Kiess, W. (2020). Definition and early diagnosis of metabolic syndrome in children. *Journal of Pediatric Endocrinology & Metabolism, 33*(7), 821–833. https://doi.org/10.1515/jpem-2019-0552

Friend, A., Craig, L., & Turner, S. (2013). The prevalence of metabolic syndrome in children: a systematic review of the literature. *Metabolic Syndrome and Related Disorders, 11*(2), 71–80. https://doi.org/10.1089/met.2012.0122

Giedd, J. N., & Rapoport, J. L. (2010). Structural MRI of pediatric brain development: What have we learned and where are we going? *Neuron, 67*(5), 728-734 %@ 0896-6273. https://doi.org/10.1016/j.neuron.2010.08.040

González Cortés, C. A., Cossío Torres, P. E., Morales, J. M. V., Batres, M. V., Galván Almazán, G. J., Portales Pérez, D. P., et al. (2021). Prevalencia de la prediabetes y sus comorbilidades en la población pediátrica mexicana. *Nutrición Hospitalaria, 38*(4), 722-728 %@ 0212-1611. https://doi.org/10.20960/nh.03567

González Devia, L. J., Monroy Romero, P. A., Almonacid Urrego, C. C., Orjuela, O. L., Huérfano, M. J., & Mendieta, Z. H. (2014). Comparative study of risk factors related to cardiovascular disease in children from Bogotá, Colombia and Toluca, Mexico. *Revista de la Facultad de Ciencias Médicas Universidad Nacional de Córdoba, 71*(2), 98–105.

Grummer-Strawn, L. M., Reinold, C., Krebs, N. F., & Centers for Disease C, & Prevention. (2010). Use of World Health Organization and CDC growth charts for children aged 0-59 months in the United States. *MMWR - Recommendations and Reports, 59*(RR-9), 1–15. https://www.ncbi.nlm.nih.gov/pubmed/20829749

Hatipoglu, N., Mazicioglu, M. M., Kurtoglu, S., & Kendirci, M. (2010). Neck circumference: An additional tool of screening overweight and obesity in childhood. *European Journal of Pediatrics, 169*(6), 733–739. https://doi.org/10.1007/s00431-009-1104-z

Hisaoka, M. (2014). Lipoblast: morphologic features and diagnostic value. *Journal of UOEH, 36*(2), 115–121. https://doi.org/10.7888/juoeh.36.115

Hsieh, S. D., & Yoshinaga, H. (1995). Abdominal fat distribution and coronary heart disease risk factors in men-waist/height ratio as a simple and useful predictor. *International Journal of Obesity and Related Metabolic Disorders, 19*(8), 585–589. https://www.ncbi.nlm.nih.gov/pubmed/7489031.

Jensen, N. S., Camargo, T. F., & Bergamaschi, D. P. (2016). Comparison of methods to measure body fat in 7-to-10-year-old children: A systematic review. *Public Health, 133*, 3–13. https://doi.org/10.1016/j.puhe.2015.11.025

Jia, P. (2021). Obesogenic environment and childhood obesity. *Obesity Reviews, 22*(Suppl 1), e13158. https://doi.org/10.1111/obr.13158

Johannsen, D. L., Tchoukalova, Y., Tam, C. S., Covington, J. D., Xie, W., Schwarz, J.-M., et al. (2014). Effect of 8 weeks of overfeeding on ectopic fat deposition and insulin sensitivity: testing the "adipose tissue expandability" hypothesis. *Diabetes Care, 37*(10), 2789–2797. %@ 0149-5992. https://doi.org/10.2337/dc14-0761

Klentrou, P., & Plyley, M. (2003). Onset of puberty, menstrual frequency, and body fat in elite rhythmic gymnasts compared with normal controls. *British Journal of Sports Medicine, 37*(6), 490–494. https://doi.org/10.1136/bjsm.37.6.490

Kumanyika, S. K. (2007). The obesity epidemic: Looking in the mirror. *American Journal of Epidemiology, 166*(3), 243–245. https://doi.org/10.1093/aje/kwm169

Lamb, M. M., Ogden, C. L., Carroll, M. D., Lacher, D. A., & Flegal, K. M. (2011). Association of body fat percentage with lipid concentrations in children and adolescents: United States, 1999–2004. *The American Journal of Clinical Nutrition, 94*(3), 877–883. https://doi.org/10.3945/ajcn.111.015776

Lee, H. J., Shim, Y. S., Yoon, J. S., Jeong, H. R., Kang, M. J., & Hwang, I. T. (2021). Distribution of waist-to-height ratio and cardiometabolic risk in children and adolescents: A population-based study. *Scientific Reports, 11*(1), 9524. https://doi.org/10.1038/s41598-021-88951-9

Lee, P. A., & Houk, C. P. (2007). Puberty and its disorders. *Pediatr Endocrinol, 2*, 273–304.

Lichtenauer, M., Wheatley, S. D., Martyn-St James, M., Duncan, M. J., Cobayashi, F., Berg, G., et al. (2018). Efficacy of anthropometric measures for identifying cardiovascular disease risk in adolescents: Review and meta-analysis. *Minerva Pediatrica, 70*(4), 371–382. https://doi.org/10.23736/S0026-4946.18.05175-7

Lo, K., Wong, M., Khalechelvam, P., & Tam, W. (2016). Waist-to-height ratio, body mass index and waist circumference for screening paediatric cardio-metabolic risk factors: A meta-analysis. *Obesity Reviews, 17*(12), 1258–1275. https://doi.org/10.1111/obr.12456

Lopez-Gonzalez, D., Miranda-Lora, A., Klunder-Klunder, M., Queipo-Garcia, G., Bustos-Esquivel, M., Paez-Villa, M., et al. (2016). Diagnostic performance of waist circumference measurements for predicting cardiometabolic risk in Mexican children. *Endocrine Practice, 22*(10), 1170–1176. https://doi.org/10.4158/EP161291.OR

Lou, D. H., Yin, F. Z., Wang, R., Ma, C. M., Liu, X. L., & Lu, Q. (2012). Neck circumference is an accurate and simple index for evaluating overweight and obesity in Han children. *Annals of Human Biology, 39*(2), 161–165. https://doi.org/10.3109/03014460.2012.660990

Louer, A. L., Simon, D. N., Switkowski, K. M., Rifas-Shiman, S. L., Gillman, M. W., & Oken, E. (2017). Assessment of child anthropometry in a large epidemiologic study. *Journal of Visualized Experiments*, (120), 54895. https://doi.org/10.3791/54895

Lu, Q., Wang, R., Lou, D. H., Ma, C. M., Liu, X. L., & Yin, F. Z. (2014). Mid-upper-arm circumference and arm-to-height ratio in evaluation of overweight and obesity in Han children. *Pediatrics and Neonatology, 55*(1), 14–19. https://doi.org/10.1016/j.pedneo.2013.05.004

Lurbe, E., Cifkova, R., Cruickshank, J. K., Dillon, M. J., Ferreira, I., Invitti, C., et al. (2009). Management of high blood pressure in children and adolescents: Recommendations of the European Society of Hypertension. *Journal of Hypertension, 27*(9), 1719–1742. https://doi.org/10.1097/HJH.0b013e32832f4f6b

Magalhaes, E. I., Sant'Ana, L. F., Priore, S. E., & Franceschini, S. C. (2014). [Waist circumference, waist/height ratio, and neck circumference as parameters of central obesity assessment in children] [Perímetro da cintura, relação cintura/estatura e perímetro do pescoço como parâmetros na avaliação da obesidade central em crianças]. *Revista Paulista de Pediatria, 32*(3), 273–281. https://doi.org/10.1590/0103-0582201432320

Magana Gomez, J. A., Moreno-Mascareno, D., Angulo Rojo, C. E., & de la Pena, G. D. (2020). Association of total and high molecular weight adiponectin with components of metabolic syndrome in Mexican children. *Journal of Clinical Research in Pediatric Endocrinology, 12*(2), 180–188. https://doi.org/10.4274/jcrpe.galenos.2019.2019.0113

Marrodan Serrano, M. D., Roman, E., Carmenate, M., Gonzalez-Montero de Espinosa, M., Herraez, A., Alfaro, E. L., et al. (2021). Waist circumference percentiles for Hispanic-American children and comparison with other international references. *American Journal of Human Biology, 33*(3), e23496. https://doi.org/10.1002/ajhb.23496

Mazicioglu, M. M., Kurtoglu, S., Ozturk, A., Hatipoglu, N., Cicek, B., & Ustunbas, H. B. (2010). Percentiles and mean values for neck circumference in Turkish children aged 6-18 years. *Acta Paediatrica, 99*(12), 1847–1853. https://doi.org/10.1111/j.1651-2227.2010.01949.x

Mercan, Y., Kafadar, G. C., Arikan, S. H., & Pancar, N. (2022). An investigation of anthropometric measurements of early adolescents and determination of BMI-for-age-based neck circumference and BMI-for-age-based mid-upper-arm circumference cut-off points. *Clin Nutr ESPEN, 48*, 414–420. https://doi.org/10.1016/j.clnesp.2022.01.008

Mushtaq, M. U., Gull, S., Abdullah, H. M., Shahid, U., Shad, M. A., & Akram, J. (2011). Waist circumference, waist-hip ratio and waist-height ratio percentiles and central obesity among Pakistani children aged five to twelve years. *BMC Pediatrics, 11*, 105. https://doi.org/10.1186/1471-2431-11-105

Nafiu, O. O., Burke, C., Lee, J., Voepel-Lewis, T., Malviya, S., & Tremper, K. K. (2010). Neck circumference as a screening measure for identifying children with high body mass index. *Pediatrics, 126*(2), e306–e310. https://doi.org/10.1542/peds.2010-0242

National Health and Nutrition Examination Survey. (2000). *Anthropometry procedures manual* (December 2000 Ed.). National Health and Nutrition Examination Survey. https://www.cdc.gov/nchs/data/nhanes/bm.pdf

Padrón-Martínez, M., Perea-Martínez, A., & López-Navarrete, G. (2016). Relación cintura/estatura, una herramienta útil para detectar riesgos cardiovascular y metabólico en niños. *Acta Pediátrica de México, 37*(5), 297–301.

Patnaik, L., Pattnaik, S., Rao, E. V., & Sahu, T. (2017). Validating neck circumference and waist circumference as anthropometric measures of overweight/obesity in adolescents. *Indian Pediatrics, 54*(5), 377–380. https://doi.org/10.1007/s13312-017-1110-6

Quintero, F. S., Ariza, A. J., García, F. B., De Molano, N. C., Benavides, M. C., Muñoz, S. C., et al. (2016). Sobrepeso y obesidad: Revisión y puesta al día de la Sociedad Latinoamericana de Gastroenterología, Hepatología y Nutrición Pediátrica (SLAGHNP). *Acta Gastroenterologica Latinoamericana, 46*(2), 131–159.

Ramirez-Velez, R., Moreno-Jimenez, J., Correa-Bautista, J. E., Martinez-Torres, J., Gonzalez-Ruiz, K., Gonzalez-Jimenez, E., et al. (2017). Using LMS tables to determine waist circumference and waist-to-height ratios in Colombian children and adolescents: the FUPRECOL study. *BMC Pediatrics, 17*(1), 162. https://doi.org/10.1186/s12887-017-0919-4

Rapsomaniki, E., Timmis, A., George, J., Pujades-Rodriguez, M., Shah, A. D., Denaxas, S., et al. (2014). Blood pressure and incidence of twelve cardiovascular diseases: lifetime risks, healthy life-years lost, and age-specific associations in 1.25 million people. *Lancet, 383*(9932), 1899–1911. https://doi.org/10.1016/S0140-6736(14)60685-1

Reisinger, C., Nkeh-Chungag, B. N., Fredriksen, P. M., & Goswami, N. (2021). The prevalence of pediatric metabolic syndrome—A critical look on the discrepancies between definitions and its clinical importance. *International Journal of Obesity, 45*(1), 12–24. https://doi.org/10.1038/s41366-020-00713-1

Rerksuppaphol, S., & Rerksuppaphol, L. (2017). Mid-upper-arm circumference and arm-to-height ratio to identify obesity in school-age children. *Clinical Medicine & Research, 15*(3–4), 53–58. https://doi.org/10.3121/cmr.2017.1365

Reyes, M. V., Mederico, M., de Valeri, M. P., Briceño, Y., Zerpa, Y., Gómez-Pérez, R., et al. (2014). Síndrome metabólico en escolares y adolescentes de la ciudad de Mérida-Venezuela: comparación de resultados utilizando valores de referencia locales e internacionales (estudio CREDEFAR). *Endocrinología y Nutrición, 61*(9), 474-485 %@ 1575-0922. https://doi.org/10.1016/j.endonu.2014.03.009

Rodríguez-Morán, M., Salazar-Vázquez, B., Violante, R., & Guerrero-Romero, F. (2004). Metabolic syndrome among children and adolescents aged 10–18 years. *Diabetes Care, 27*(10), 2516–2517. %@ 0149-5992. https://doi.org/10.2337/diacare.27.10.2516

Rolland-Cachera, M. F., Deheeger, M., Maillot, M., & Bellisle, F. (2006). Early adiposity rebound: Causes and consequences for obesity in children and adults. *International Journal of Obesity, 30*(Suppl 4(4)), S11–S17. https://doi.org/10.1038/sj.ijo.0803514

Ross, R., Neeland, I. J., Yamashita, S., Shai, I., Seidell, J., Magni, P., et al. (2020). Waist circumference as a vital sign in clinical practice: a consensus statement from the IAS and ICCR working group on visceral obesity. *Nature Reviews. Endocrinology, 16*(3), 177–189. https://doi.org/10.1038/s41574-019-0310-7

Ryder, J. R., Kaizer, A. M., Rudser, K. D., Daniels, S. R., & Kelly, A. S. (2016). Utility of body mass index in identifying excess adiposity in youth across the obesity spectrum. *The Journal of Pediatrics, 177*(255–261), e252. https://doi.org/10.1016/j.jpeds.2016.06.059

Santos, S., Severo, M., Lopes, C., & Oliveira, A. (2018). Anthropometric indices based on waist circumference as measures of adiposity in children. *Obesity (Silver Spring), 26*(5), 810–813. https://doi.org/10.1002/oby.22170

Sapunar, J., Aguilar-FarÍAs, N., Navarro, J., Araneda, G., ChandÍA-Poblete, D., ManrÍQuez, V., et al. (2018). Alta prevalencia de dislipidemias y riesgo aterogénico en una población infanto-juvenil. *Revista Médica de Chile, 146*(10), 1112–1122. %@ 0034-9887.

Savva, S. C., Tornaritis, M., Savva, M. E., Kourides, Y., Panagi, A., Silikiotou, N., et al. (2000). Waist circumference and waist-to-height ratio are better predictors of cardiovascular disease risk factors in children than body mass index. *International Journal of Obesity and Related Metabolic Disorders, 24*(11), 1453–1458. https://doi.org/10.1038/sj.ijo.0801401

Shamah-Levy, T., Romero-Martínez, M., Barrientos-Gutiérrez, T., Cuevas-Nasu, L., Bautista-Arredondo, S., Colchero, M. A., et al. (2021). *Encuesta Nacional de Salud y Nutrición 2020 sobre Covid-19. Resultados nacionales*. Instituto Nacional de Salud Pública.

Sinclair, D. C., & Dangerfield, P. (1998). *Human growth after birth* (Vol. 2). Oxford University Press.

Tanamas, S. K., Lean, M. E. J., Combet, E., Vlassopoulos, A., Zimmet, P. Z., & Peeters, A. (2016). Changing guards: Time to move beyond body mass index for population monitoring of excess adiposity. *QJM, 109*(7), 443–446. https://doi.org/10.1093/qjmed/hcv201

Tyson, N., & Frank, M. (2018). Childhood and adolescent obesity definitions as related to BMI, evaluation and management options. *Best Practice & Research. Clinical Obstetrics & Gynaecology, 48*, 158–164. https://doi.org/10.1016/j.bpobgyn.2017.06.003

U. S. Preventive Services Task Force, Grossman, D. C., Bibbins-Domingo, K., Curry, S. J., Barry, M. J., Davidson, K. W., et al. (2017). Screening for obesity in children and adolescents: US Preventive Services Task Force tecommendation statement. *JAMA, 317*(23), 2417–2426. https://doi.org/10.1001/jama.2017.6803

U. S. Preventive Services Task Force, Krist, A. H., Davidson, K. W., Mangione, C. M., Barry, M. J., Cabana, M., et al. (2020). Screening for high blood pressure in children and adolescents: US Preventive Services Task Force Recommendation Statement. *JAMA, 324*(18), 1878–1883. https://doi.org/10.1001/jama.2020.20122

UNICEF, World Health Organization, & International Bank for Reconstruction and Development/ The World Bank. (2020). *Levels and trends in child malnutrition: key findings of the 2020 edition of the joint child malnutrition estimates*. World Health Organization.

United Nations, & Department of Economic and Social Affairs. (2015). *The 17 goals. Sustainable development.* United Nations. Retrieved 02/01 from https://sdgs.un.org/goals

United Nations Children's Fund. (2021). *Childhood overweight: A call for prevention in Latin America and the Caribbean*. UNICEF.

Ward, Z. J., Long, M. W., Resch, S. C., Giles, C. M., Cradock, A. L., & Gortmaker, S. L. (2017). Simulation of growth trajectories of childhood obesity into adulthood. *The New England Journal of Medicine, 377*, 2145–2153. https://doi.org/10.1056/NEJMoa1703860

Witchel, S. F., Pinto, B., Burghard, A. C., & Oberfield, S. E. (2020). Update on adrenarche. *Current Opinion in Pediatrics, 32*(4), 574–581. https://doi.org/10.1097/mop.0000000000000928

Wood, C. L., Lane, L. C., & Cheetham, T. (2019). Puberty: Normal physiology (brief overview). *Best Practice & Research. Clinical Endocrinology & Metabolism, 33*(3), 101265. https://doi.org/10.1016/j.beem.2019.03.001

WHO (World Health Organization). (1995). *Physical status: The use of and interpretation of anthropometry, report of a WHO expert committee*. World Health Organization.

WHO. (2016). *Growth reference data for 5–19 years. 2007*. http://www.who.int/growthref/en

Zemel, B. S. (2021). The challenges of interpreting body mass index in children with obesity. *The Journal of Pediatrics, 235*, 21–22. https://doi.org/10.1016/j.jpeds.2021.04.011

Zimmet, P., Alberti, K. G., Kaufman, F., Tajima, N,. Silink, M., Arslanian, S., … Group IDFC. (2007). The metabolic syndrome in children and adolescents – An IDF consensus report. *Pediatric Diabetes, 8*(5), 299–306. https://doi.org/10.1111/j.1399-5448.2007.00271.x

Chapter 8
The Extent of Residual Lower-Extremity Shortening in the Origins of Endemic Stunting Among Guatemalan Preschoolers: A Photographic Examination

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8.1 Introduction

The impact of environmental factors on height, particularly those related to infectious disease, morbidity and nutrition are well established (Azcorra et al., 2013; Batty et al., 2009; Leitch, 1951; Solomons et al., 1993; Vazquez-Vazquez et al., 2013; Wadsworth et al., 2002). In fact, extreme shortness (<-2 SD height-for-age z-scores) is strongly associated with nutritional deficiencies based on WHO criteria to diagnose chronic undernutrition in children. New research challenges the assumptions that nutrition is the main environmental determinant of early child growth retardation (Hermanussen & Bogin, 2014). Bogin (2022) proposes chronic fear of violence and toxic stress due to social-economic-political-emotional (SEPE) inequality and insecurity are the principal factors causing growth deficit in children.

Understanding the role of environmental factors on child stunting requires further understanding of population differences in height, leg, and trunk length. For example, populations of Australian Aborigines and West African ascendency have longer legs relative to height, whereas persons of Native American origin are characterized by relatively long trunk and short legs (Eveleth & Tanner, 1976). It is

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S. Datta Banik (ed.), *Human Growth and Nutrition in Latin American and Caribbean Countries*, https://doi.org/10.1007/978-3-031-27848-8_8

unclear if relatively short legs of Native American populations can be explained, in part, by known adverse dietary conditions and environmental stressors (Azcorra et al., 2013; Leitch, 1951; Solomons et al., 1993; Vazquez-Vazquez et al., 2013; Wadsworth et al., 2002). Understanding of these relationships remains vital to identify the key determinants and to better understand the interplay between nutritional deficiency, infectious disease, and socio-environmental determinants such as fear and stress.

In Guatemala, 47% of the children under five years of age are identified as stunted (Bogin 2022). Amongst children of Maya origin, the prevalence is 61% compared to 31% in Ladino children. Bogin (2022) uses the example of Guatemala to demonstrate likely contributions of SEPE stressors that explain a high prevalence of stunting in Guatemala, particularly among the Maya population. Improved methods for determining leg and trunk lengths are particularly relevant to Guatemala, a population of particular interest to understand the potential impacts of SEPE stressors on child growth.

Among children, evaluation of body segments is important to understand, not only the biological processes of stunting, but also the impact of broader environmental determinants that have not been included in prevention strategies. Measuring trunk and leg lengths presents a number of challenges. One approach commonly used to distinguish the trunk from the leg component is the sitting height ratio (SHR). This ratio compares sitting height (the numerator) in relation to standing height (the denominator), with sitting height measured as the distance from the seat of a chair to the crown of the head of a seated participant (Lohman et al., 1988). The use of sitting height to determine trunk length has obvious limitations. For example, the thickness of the buttocks (due to fatness) varies from person to person, independent of the growth of the trunk (Bogin & Varela-Silva, 2008), introducing random error into the measurement. Nevertheless, the SHR is most routinely used because it is simple to estimate.

Alternatively, a photograph offers an approach that can be taken from a distance, while allowing a visual inspection of total stature and body proportions which can provide important information regarding the diagnosis of individuals with short stature (De Arriba Muñoz et al., 2013). Providing a static record of the height measurement, along with a marker indicating the division between trunk and legs, photographic methods could help in the advancement of existing methodologies in the assessment of biological stunting. Additionally, once the apparatus is in place, studies have shown the photographic recording of measurements is quick, accurate and cost-effective (Gittoes et al., 2009; Hung et al., 2004; Normand et al., 2007; Van Maanen et al., 1996) in adults. Furthermore, photographic measurements are considered non-invasive, easily reproducible, and objective method (Pausic et al., 2010; Schaaf et al., 2010). The present study applies photographic imaging method to compare the trunk-to-leg ratio of preschool children from public and private schools in the Western Highlands of Guatemala.

8.2 Participants and Methods

Social and Geographic Settings

This study was conducted in the Western highlands of Guatemala, in the urban areas of the cities of Quetzaltenango and Sololá. These were chosen to reflect two contrasting populations with respect to socio-economic status and ethnicity, reflecting the diversity of highland populations, with anticipated contrasts in attained growth and body composition characteristics of children in the preschool years. Sololá is a city of over 55,000 inhabitants. It is the capital of the province by the same name and is situated at an altitude of 2100 m overlooking Lake Atitlán, 140 km from the national capital. Although the region is renowned for lakeside tourism, the basic economy of the city is commerce, with subsistence farming in the surrounding hamlets. Majority of the population is indigenous with *Kakchiquel* being the predominant Mayan language. Quetzaltenango is a city of 350,000 nested in a highland valley at 2500 m above sea-level, some 210 km from the capital and 95 km west of Sololá. It is also the capital city of a province of the same name. Its urban population is predominantly non-indigenous, of European descent, particularly amongst the middle- and upper economic classes. The economy is diverse, with the most important sectors being finance, manufacturing, services, higher education and horticultural (vegetable) production.

Recruitment and Selection of Participants

Children aged 4–7 years were recruited at preschool centers in both cities. In Guatemala, education is mandatory for children aged seven years and older. In 2015, 559,865 children were registered for the preschool level. The schools were selected to reflect the contrasting socioeconomic status (SES) of the two locations, selecting public preschools from lower income Sololá and, in contrast, private preschools reflecting the middle- and upper-income section in the relatively higher income community of Quetzaltenango. The clientele in the preschools differed: in Sololá most children were of Maya ethnic background, whereas in Quetzaltenango more families had European descent. In total, 249 children were selected for the study during March to June 2015.

Ethical approval was obtained from the Human Subjects Committee from the Centre for Studies of Sensory Impairment, Aging and Metabolism (CeSSIAM, Guatemala). The study protocol was approved by the local school authorities in both the public and private institution sectors. Informed consent forms were signed by the parents or guardians with pen or fingerprint after the nature, purpose, benefits, and inconveniences associated with the study were explained in either Spanish or *Kakchiquel*. In addition to the parental consent, only children who willingly and freely cooperated with measurements were included in the study, based on principles of child assent.

Demographic Data Collection

A child's exact age, recorded in decimals, was determined based on the date of birth and the date of the measurements taken. These data were derived from a questionnaire which was completed by, or with input from, the child's caregiver or parent prior to the height measurement using anthropometry and photographic imaging technique. Overall, Quetzaltenango represented children from mostly European descent of middle-upper income class and Sololá represented low-income participants who were predominately Maya descendants. Therefore, a child's socio-economic and ethnic backgrounds were defined by the type of preschool (private versus public) and location (Quetzaltenango versus Sololá). Thus, children attending private preschools in Quetzaltenango were identified as the representatives of the households with relatively higher SES, whereas children attending public preschools in Sololá were identified as representing low SES. To ensure comparability between study sites, children from Quetzaltenango were matched with their Sololá-counter peers based on age (rounded to age at last birthday) and sex.

Conventional Standing Height Measurement

Child's height was measured following a standard protocol (Eveleth & Tanner, 1976) by a trained researcher. A wall stadiometer was constructed at each study site. It consisted of metric tape, fixed on a wall in the perpendicular position, as tested with a bubble level. The child was measured while standing without shoes, backside against the wall, and gaze fixed in the Frankfort plane. A plastic carpenter's square was lowered onto the scalp on the crown of the head. Corresponding height at the intersection with the tape was read to the nearest 1.0 cm.

Photographic Imaging Techniques and Height Estimation

A wooden platform with 25 × 25 × 40 cm dimensions was constructed to evaluate feet off the ground to get a clearer indication of the sole of the foot. On the back surface of the platform, a rectangular post was projected 125 cm above the surface of the platform (150 cm from the base), inset eccentrically 10 cm from the front edge of the platform (front as defined by closest to the camera lens). A white, plastic metric tape was smoothed and permanently mounted on the front surface of the post marking heights of 80–125 cm, selected to include the low and high centile extremes of stature from 48 to 95 months old from the WHO Growth Standard (2006). This tape has clearly visible, a dominant division marker at each cm, and a minor division at the corresponding 0.5 cm. In addition, to make the sequence of 5 cm units more discernable, a fixed coded sequence of white and four pastel colors was marked onto the metric tape to distinguish the difference between for example, 85- and 90 cm (Fig. 8.1).

For the photographic session, the subject was guided to ascend to the platform. The feet were placed together, with the right foot as close to the front of the platform surface as possible. Appropriate positioning included standing sideways, for a sagittal view, with straight posture, with hands crossed in front of the chest to ensure visibility of the marker at the iliac crest and focusing his or her eyes on an assistant standing several meters to the far right of the camera, to enforce the Frankfort Plane gaze (Fig. 8.2).

A digital camera (Nikon Coolpix L830, Nikon, Tokyo, Japan), mounted vertically on a tripod with bubble level (Triopo GT-2804, Triopo, Zheijang, China), was used for taking the photographic images. If the bubble was positioned between the two

Fig. 8.1 Wooden platform for height measurement

Fig. 8.2 Photographic height estimate

vertical lines, the tripod was considered horizontal. For the purpose of body-segment, the camera height was approximately parallel to the position of the iliac crest marker for the average preschooler, and it was set back about three meters (focal distance) from the child on the platform. The zoom function was manipulated if necessary to maximize the image of the child on the screen. Then, several pictures were taken of each child. The best photograph of each child was color printed on photographic paper (Canon MP-101, size 8.5″ × 11 inches) with a Canon MP-101 color printer (Canon IP100, Canon Inc., Tokyo, Japan) for measurement. Photographic height was determined, in cm, from photo print-out, using a square ruler (Truper E-8X12, Truper, Mexico City, Mexico), projecting from the crown of the head to a number on the mounted metric tape.

Validation of Photographic Height Estimate Against Actual Standing Height and Reproducibility of Multiple Repeat Measurements of Height on the Photo Image

Photographic height was validated against actual standing height to make sure that the method met the exigencies to get the best photography for the body-segment agenda. The intra-level reproducibility of the method was determined by repeated height measurement (3 times) on the same subsample of 50 photos by the first author, referred to as Rater A. To assess inter-rater reliability, three different raters (Rater A, B and C) each measured a new set of 50 images, independently, one time.

Estimation of Body-Segment Ratios and Trunk and Leg Lengths Derived from Photographic-Image

Another aspect of the photographic procedure as explained above was the horizontal placement of a colored sticker on the ridge of child's iliac crest as an anatomical landmark to distinguish the trunk from the legs. The iliac crest was identified by gently touching the child's hipbone. To ensure the visibility of the colored stickers on the photograph, stickers in contrasting colors to the child's clothes, were used (Fig. 8.2).

After the photo was printed, the lengths of interest on the image were measured with a transparent plastic metric ruler to the nearest millimeter (mm) on a flat surface. Two direct measurements were recorded with the ruler parallel to the perpendicular axis in the photograph: 1, the length from the crown of the head to the sole of the foot to define the total length; and 2, the length from the sole of the foot to the level of the colored sticker on the photograph, which identified the iliac crest (hip), i.e., a proxy landmark to measure leg length. Both were expressed in mm. Trunk length was determined as the difference, i.e., by subtracting leg length in mm from total length in mm.

The trunk-to-leg ratio was calculated by dividing the trunk length in mm by the leg length in mm and expressed as a fraction without units. The absolute length of various segments was estimated by using the measured standing height in cm, and applying the relative segment length from the ratio.

Reproducibility Evaluation for Multiple Repeat Measurements of Body Segments of the Same Images

The first author, Rater A, was the primary rater and measured all photo images. In order to determine the intra-rater reproducibility, she measured a subsample of 60 images and then separately repeated the measurements on the same subsample, separately, two more times. Next, to assess inter-rater reliability three different raters (Rater A, B and C) measured a new set of 60 images, independently, one time.

Data Handling and Statistical Analyses
SPSS version 22.0 (IBM Corp, 2013) was used for all statistical analyses. Pearson's correlation coefficients and Lin concordance coefficients were carried out to demonstrate the degree of association between conventional standing height and height estimated by the photographic analysis. These analyses were needed to justify body segment measurement and analysis of comparison between study sites.

The reproducibility of the photographic method, both on intra- and inter-rater level, for height and body segments estimation was also determined using Pearson correlation coefficients and Lin concordance correlations. Abovementioned analyses were conducted using the photos of the whole study sample ($n = 249$).

The pair-matched study sample consisting of 102 matched-pairing was used to compute descriptive statistics to show demographic, anthropometric and body segment ratio characteristics (mean ± standard deviation and median). In addition, children were classified as stunted or non-stunted based on the WHO definition (2006) as follows. Stunting is defined as height-for-age z-score (HAZ) ≤ -2 in relation to the WHO median value. Building upon the photographic methods and the pair-matched sample, associations and comparisons were made regarding the trunk-to-leg ratio that are expected to change with age (Huelke, 1998), particularly in a population with a high degree of growth retardation as measured by HAZ. Therefore, Spearman rank-order correlations were carried out to examine the association of trunk-to-leg ratio with age and HAZ. The differences in trunk-to-leg ratio between settings and sex (i.e., both within and across setting) were assessed using Student's t-tests. These tests were also used to evaluate the differences in trunk-and leg length between stunted and non-stunted children.

8.3 Results

Validation of Photographic Height Estimate Versus Actual Measured Height
A total of 249 participants were measured and photographed, 115 in Sololá and 134 in Quetzaltenango using the described procedures. A subsample of derived photos was used to validate photographic height against actual measured height, as evaluated by Pearson's correlation coefficients and Lin concordance coefficients. These measures reported statistically significant and high order-values of 0.988 (Pearson) and 0.987 (Lin), respectively.

Intra- and Inter-Rater Reproducibility of Photographic Height Estimation
In terms of individual associations across repeated measuring, Pearson and Lin Concordance coefficient values were consistently higher than 0.9 and statistically significant ($p < 0.05$) among the rounds of measurements of one rater, e.g., round I vs. II, I vs. III, and II vs. III. Correlations in the highest order (>0.9; $p < 0.05$) were also found across the pairs of raters, e.g. A vs. B, A vs. C, and B vs. C.

Intra- and Inter-Rater Reproducibility of Body Segment Estimations from Photographic Images

Intra-rater reliability was determined following three rounds of comparisons in which the same rater assessed total length and leg length in mm and their ratio using a photographic method. For Pearson product-moment correlation these respective values were for both measures, i.e., total length and leg length, and within all rounds consistently higher than 0.99 and statistically significant ($p < 0.05$). Similar values and significance were reported when using Lin concordance coefficients. A slight reduction occurred when the ratio was used, however, the obtained values were still in the highest order of accuracy (>0.9).

The inter-rater reproducibility evaluation for trunk and leg length and their ratio showed similar patterns of correspondence with Pearson and Lin correlation values consistently higher than 0.990 ($p < 0.05$) between all raters and for both the measures of total length and leg length. Again, a slight reduction occurred when the ratio was the question of repeatability, but these values were still in the highest order of accuracy (>0.9).

Demographic, Anthropometric and Body-Segment Ratio Characteristics of the Selected, Match-Paired Children from Sololá and Quetzaltenango

A strategy of matched pairing was undertaken as described above (Table 8.1) for the purpose of the body segment analysis between study sites. This yielded a final sample of 204 participants, 102 (56 boys and 46 girls) from each geographical location. The median age for each sample was ~6.0 y. Forty-five children, 13 in Sololá and 32 in Quetzaltenango, did not have a natural match in the opposite site, and were not included in this analysis. Table 8.1 shows the mean- and median values on age, height, trunk-to-leg ratio, trunk-to-stature ratio, trunk- and leg in absolute length. All statistical comparisons are based on mean differences. Due to skewed distributions, median differences are emphasized and are used as the basis of percentage differences in the text. Table 8.1 shows that the mean values of age are identical in Quetzaltenango and Sololá, in accordance with the pair-matched study design. Mean differences in height show that, on average, the Sololá children were shorter as compared to the children from Quetzaltenango ($p < 0.001$), also after stratifying for sex ($p < 0.001$).

Description and Comparisons of the Body Segments

The lower part of Table 8.1 relates to body segment estimations in both absolute and ratio terms. These results show that the Quetzaltenango children have on average longer trunks ($p < 0.05$) and legs ($p < 0.001$) and lower trunk-to-leg ratios ($p < 0.001$) than their Sololá peers. Correspondingly, the trunk-to-stature ratio in Quetzaltenango was also significantly lower than in their Sololá peers ($p < 0.001$).

After stratifying by sex, the patterns of SES comparisons remained, and were statistically significant except for the mean differences in trunk length comparing boys from Quetzaltenango with boys from Sololá. The median difference in trunk length of 0.5 cm, represents 1.0% of the Quetzaltenango median. In contrast, the median difference for leg length was 5.2 cm, representing 8.1% of the Quetzaltenango median.

Table 8.1 Demographic-, anthropometric- and body segment ratio characteristics across setting and sex and within setting and sex based on the pair-matched study sample (n = 204)

Variables		Sololá						Quetzaltenango					
		All (n = 102)		Boys (n = 56)		Girls (n = 46)		All (n = 102)		Boys (n = 56)		Girls (n = 46)	
		mean ± SD	[median]	mean ± SD	[median]	mean ± SD	[median]	mean ± SD	[median]	mean ± SD	[median]	mean ± SD	[median]
Age	(years)	6.0 ± 1.0	[6.0]	6.0 ± 1.0	[6.0]	6.0 ± 1.0	[6.0]	6.1 ± 1.0	[6.2]	6.0 ± 1.0	[6.0]	6.1 ± 0.9	[6.2]
Height	(cm)[a]	106.6 ± 6.6[b]	[107.0]	107.1 ± 7.1[c]	[108.0]	105.8 ± 6.0[c]	[105.5]	114.0 ± 7.0[b]	[114.0]	113.7 ± 7.9[c]	[114.0]	114.3 ± 6.1[c]	[114.0]
HAZ [a]		−1.74 ± 1.0[b]	[−1.83]	−1.69 ± 1.0[D]	[−1.77]	−1.80 ± 1.0[c]	[−2.03]	−0.40 ± 0.9[b]	[−0.43]	−0.43 ± 1.0[c]	[−0.42]	−0.36 ± 0.9[c]	[−0.46]
Trunk length	(cm)	47.9 ± 2.8[d]	[48.0]	48.6 ± 2.9[e]	[48.6]	47.1 ± 2.5[e,f]	[47.4]	49.1 ± 2.9[d]	[48.5]	49.5 ± 3.1	[48.8]	48.6 ± 2.5[f]	[48.3]
Leg length	(cm)	58.7 ± 5.0[b]	[59.1]	58.7 ± 5.4[c]	[59.4]	58.6 ± 4.5[c]	[58.6]	64.9 ± 5.8[b]	[64.3]	64.2 ± 6.2[c]	[64.2]	65.7 ± 5.2[c]	[64.9]
Trunk-to-leg ratio		0.82 ± 0.07[b]	[0.82]	0.83 ± 0.07 [c]	[0.82]	0.81 ± 0.06 [c]	[0.80]	0.76 ± 0.07[b]	[0.76]	0.78 ± 0.07 [C,D]	[0.78]	0.74 ± 0.07[c,e]	[0.74]
Trunk-to-stature ratio		0.45 ± 0.02[b]	[0.45]	0.45 ± 0.02[c]	[0.45]	0.45 ± 0.02[c]	[0.44]	0.43 ± 0.02[b]	[0.43]	0.44 ± 0.02 C,D	[0.44]	0.43 ± 0.02[c,e]	[0.43]
		%		%		%		%		%		%	
% stunted		46.1[b]		42.9[c]		50.0[c]		5.9[b]		7.1[c]		4.4[c]	

[a]Height-for-age z-score. Height measured by a stadiometer
[b]Significant difference ($p < 0.001$) across setting
[c]Significant difference ($p < 0.001$) across setting within the same sex
[d]Significant difference ($p < 0.05$) across setting
[e]Significant difference ($p < 0.05$) across sex within the same setting
[f]Significant difference ($p < 0.05$) across setting within the same sex
[g]*SD* standard deviation

The results from the study sites differed when comparing the results of boys and girls. In Sololá but not in Quetzaltenango, the boys had a higher mean trunk length ($p < 0.05$) than the girls. In Quetzaltenango, but not in Sololá, the mean trunk-to-leg ratio was higher in boys ($p < 0.05$). Consistent with the findings for trunk-to-leg ratio results, boys in Quetzaltenango also had a significantly higher mean trunk-to-stature ratio ($p < 0.05$),

Cross-Variable Associations with Body Segments
The last row of Table 8.1 shows that the Quetzaltenango children have a lower prevalence of stunting than their Sololá peers. Further analyses below explore trunk-to-leg ratio in relations to age and HAZ. A Spearman rank-order correlation coefficient (rs) showed a significant inverse relationship with trunk-to-leg ratio of rs = −0.27 ($p = 0.005$) in Sololá with age as the first variable. The corresponding association in Quetzaltenango was a correlation coefficient of rs = −0.46 ($p < 0.001$) (data not shown).

In analysis on the whole sample, combining all children irrespective of stunting status or location, the two variables were inversely and significantly correlated with rs = −0.38 ($p < 0.001$). These bivariate results are illustrated graphically in Figs. 8.3a and 8.3b, showing the results from all children in a scatterplot with regression lines illustrating the shape of the relationship between HAZ and trunk-to-leg ratio. Figure 8.3a shows the bivariate regression plotting the linear relationship between HAZ and trunk to-leg-ratio in a linear ($R^2 = 0.179$) and Fig. 8.3b shows the quadratic regression ($R^2 = .192$). Further comparisons between stunted and non-stunted children shows a median difference in trunk-to-leg of 0.07, with stunted children having relatively longer trunks.

8.4 Discussion

These results show photographic-image approach has high validity compared to measured height, and high intra- and inter-observer reproducibility. Additionally, across samples of age- and sex-matched preschool children in two distinct environmental and economic settings in the Western Highlands of Guatemala – one exclusively of Maya-descent and the other of largely European ascent – illustrates the feasibility of this approach in this age-group. It also generally confirms the basic tenet that linear growth in the former is retarded via a differential effect on elongation of the lower extremities. The median difference between the two populations in leg length of 5.2 cm represents 8.1% of the Quetzaltenango median and was by far the largest percentage difference in any anthropometric measurement.

This study was most relevant for Guatemala, which has the highest rate of stunting in Latin-America (Unicef WHO World Bank, 2014; World Bank, 2010) combined with high rates of poverty (World Bank, 2011) and inequality (World Bank, 2011) in a population that is at least 40% of Maya origin. Focusing on poverty and inequality it was pointed out in 1993 by Solomons et al. that poor sanitation and

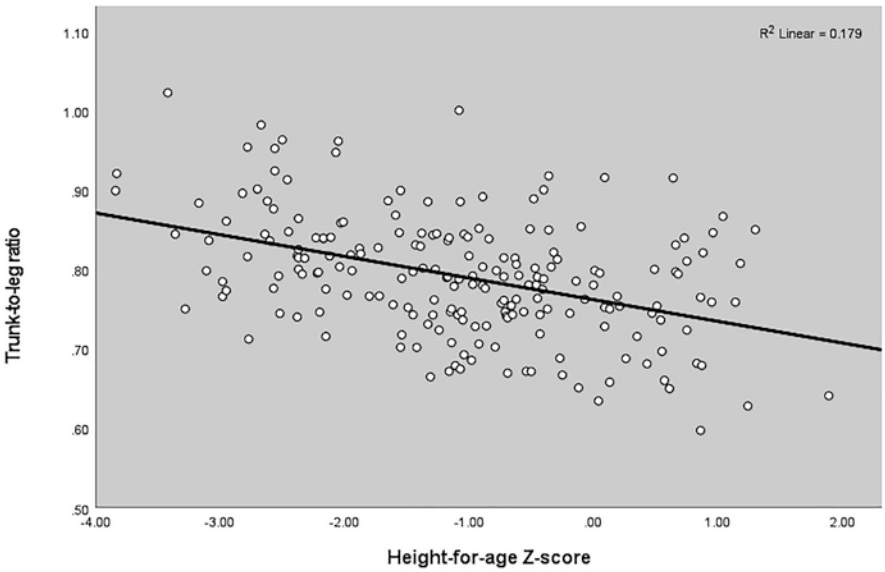

Fig. 8.3a Scatterplot and linear regression of the association between HAZ and trunk-to-leg ratio

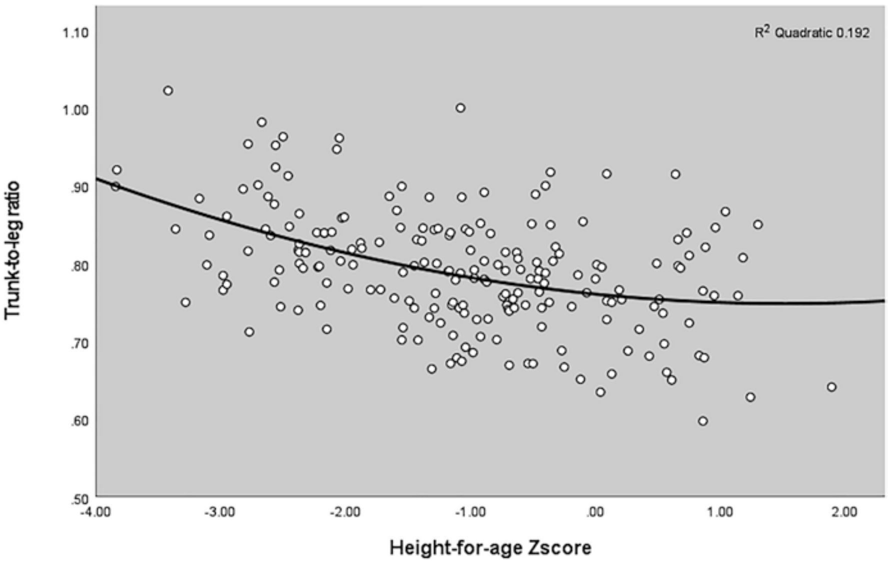

Fig. 8.3b Scatterplot and quadratic regression line of the association between HAZ and trunk-to-leg ratio

hygiene in Guatemala had the effects of reduced growth through immunostimulation by the ambient microbial burden. The mechanism for stress-induced growth retardation has been elucidated by the rodent study (Odiere et al., 2010). Inflammatory- and stress factors interfere with the hormonal cascade for long-bone elongation.

Although there is a hygiene and sanitation gap between Sololá and Quetzaltenango, it is not absolute. The study of Bogin et al. (2002) is illuminating in comparison of two populations with the same Guatemalan Maya ethnicity having different socioeconomic backgrounds. Their study involved comparing height and leg length of children of Maya parents who were born in the United States to their peers born in Guatemala. Using the reported data (Bogin et al., 2002), we derived results for 5–7 years old, showing a 14.0% difference in mean leg length for the Guatemalan Maya children. Our data, using median differences, showed an 8.1% difference in leg length. In order to compare more directly, data were recalculated using a mean difference finding a 10.6% difference in populations leg length. Bogin et al. (2002) attribute these differences mainly to the improvements in the quality of environment because the ethnicity of the population was common, and the country of birth (Guatemala vs. USA) was the unique variable. A comparison of these results, within and outside of Guatemala, show results that are consistent with Bogin's (2022) hypothesis that SEPE stressors may explain some of the stunting in Guatemalan populations of Maya descent.

After geographic setting, age was the most powerful determinant of body segments. This association seems biologically plausible and is consistent with previous research (Fredriks et al., 2005). In the pre-pubertal years, the growth occurs more in the lower limbs rather than in the trunk ultimately leading to lower trunk-to-leg ratios. What is not readily explainable to us is the almost twofold stronger age-association with the Quetzaltenango group versus that in Sololá. We speculate that a steadier growth pattern for the more advantaged children supports stronger association with age.

The fact that the moving force behind shortening of stature is the differential change in elongation between the trunk and the legs could not be more clearly confirmed than in this association across the whole sample (Fig. 8.2), and its isolation in comparison across the stunted and non-student participants. The goodness of fit model did not substantially improve the degree of association.

A somewhat original finding of this study was the three-fold higher odds of having a higher trunk-to-leg ratio in overtly stunted children. However, the two-fold higher odds of having a higher trunk-to-leg ratio attributed to living in Sololá after adjusting for stunting implies the population differences cannot be explained by the extreme growth faltering resulting in a −2 HAZ. These results could be explained by changes in the trunk-to-height ratio due to lesser degrees of growth faltering, in the absence of clinical stunting. Alternatively, some of the difference could also be due to biological differences in trunk-to-leg ratio related to the ethnic differences in populations living in Quetzaltenango and Sololá.

In addition to the aforementioned elements of construct validity and human biology, results demonstrated superb reproducibility as shown by the intra-and inter- rater reproducibility and the narrow coefficients of variation. Virtually any carefully trained observer could achieve consistent measurements from photographic images. One could speculate that digital computer applications for linear measurement would be even more exact and reliable than human measurements.

The feasibility of our method has a potentially practical importance. Our realization was that 74% of the (7.0 cm) difference in height was explained by the difference (5.2 cm) in leg length, raises an interesting opportunity; the photographic imaging method focusing on the legs may provide a more sensitive approach to monitor nutrition- and health interventions than measurement of the entire standing height. This is analogous to the technique of the knee-to-heel-length meter developed by Michaelsen et al. (1991) to sensitively gauge growth of pre-term babies.

Strengths and Limitations

A strong feature is that this is one of the few studies on the assessment of body segments using photographic imaging. Comparison is enhanced by the age- and sex-matched design recruiting preschool children in two distinct environmental and economic settings, and the variance in body size was indeed broad.

The sophisticated equipment used (e.g., camera, tripod, color-printer, stadiometer platform) is a strength, because of the high-quality photography and a limitation was economic constraint that precluded purchase or construction of the necessary instruments.

There are both practical- and theoretical issues in the anatomical landmark of the iliac crest. On the practical side the adherence of the marker sticker to clothing was problematic and required replacing after falling off. Moreover, when excessive abdominal fat exists in an overweight child it could have interfered with the proper placement of the marker. An additional limitation could be related to reproducibility of the placement of the marker on the iliac crest. Due to time constraints, the marker was placed only once by the same researcher, therefore, it was not possible to determine intra- or inter-rater reproducibility of marker placement. However, differences in placement might have consequences for body proportion definition and its ratios and interpretations.

On the theoretical side, there are some anatomical considerations in the various conventions for defining segments that are important, especially in quantitative comparison with other body-segment literature. All approaches to anthropometric definitions of “leg length” have some discrepancies. The femur actually inserts somewhere above the ischial prominence the lowest segment of the pelvis and the below the iliac crest, the highest segment, but closer to the former. Since sitting height does not provide a true estimate of lower extremities as the trunk is variably increased by thickness of the muscle (gluteus) and subcutaneous fat of the buttocks in the seated participants. Sitting height produces a relatively longer trunk value, and consequently a relative underestimation of the leg. Conversely, in the present convention with children, using the upper prominence of the pelvis will produce a relatively shorter trunk value, consequently a relative overestimation of leg. As such, the ratios generated here will not be analogous to those obtained with conventional sitting height. In fact, the level of insertion of the femur can be better approximated by deep palpation and marking on the surface of the hip, but this represents a less decorous and more invasive procedure in both adults and children. The relative ease of marking the iliac crest, assisted by the child, is the most innocuous selection of a landmark for leg demarcation we could devise.

8.5 Conclusion

Photographic imaging is a participant- and user-friendly method to assess the relative length of the trunk and lower extremities of young children. Analysis of body segment ratio data obtained from photographic imaging is consistent with pre-established and expected findings regarding age, ethnicity and environmental exposure differentials providing construct validity for its application. This approach in biological anthropology could emerge as a feasible alternative to sitting height and other measures for preschool children in other settings.

Acknowledgements We would like to thank the staff and students from the Xolbé Elementary School in Sololá and El Clearmont, Villa Educativa, Pascual Bilingüe, Centro TeTe and Eco School Qanill in Quetzaltenango for supporting and participating in this study. We are grateful to CeSSIAM's staff in Quetzaltenango, especially with Elena Díaz, and Deborah Fuentes. We would also like to thank Rosario Saquí from UVG-Altiplano for her valuable contribution to the fieldwork at the Xolbé Elementary School in Sololá. We are grateful to the Hormel Food Company for the donation of the photographic equipment used in the investigation.

Authorship Contributor Statement JJSB collected and analyzed the data and wrote the article, NWS conceived the idea, supervised the collection of data and contributed in all aspects to the writing, MRGM and MNO co-supervised data collection, analysis and interpretation of results, RG helped with taking photographic measurements and with the evaluation of the method, HBR helped with the evaluation of the method, CMD contributed to the co-supervision including the plan for analysis, replication of analysis and interpretation and write-up of the findings. All data are archived locally at the CeSSIAM offices in Guatemala.

Grant Sponsorship: Photographic equipment was donated by the Hormel Food Company (Austin, Minnesota, United States).

References

Azcorra, H., Varela-Silva, M. I., Rodriguez, L., Bogin, B., & Dickinson, F. (2013). Nutritional status of Maya children, their mothers, and their grandmothers residing in the City of Merida, Mexico: Revisiting the leg-length hypothesis. *American Journal of Human Biology, 25*, 659–665. https://doi.org/10.1002/ajhb.22427

Batty, G. D., Shipley, M. J., Gunnell, D., Huxley, R., Kivimaki, M., Woodward, M., Lee, C. M., & Smith, G. D. (2009). Height, wealth, and health: An overview with new data from three longitudinal studies. *Economics and Human Biology, 7*, 137–152. https://doi.org/10.1016/j.ehb.2009.06.004

Bogin, B. (2022). Fear, violence, inequality, and stunting in Guatemala. *American Journal of Human Biology, 34*(2), e23627. https://doi.org/10.1002/ajhb.23627

Bogin, B., & Varela-Silva, M. I. (2008). Fatness biases the use of estimated leg length as an epidemiological marker for adults in the NHANES III sample. *International Journal of Epidemiology, 37*, 201–209. https://doi.org/10.1093/ije/dym254

Bogin, B., Smith, P., Orden, A. B., Varela Silva, M. I., & Loucky, J. (2002). Rapid change in height and body proportions of Maya American children. *American Journal of Human Biology, 14*, 753–761. https://doi.org/10.1002/ajhb.10092

De Arriba Muñoz, A., Dominguez Cajal, M., Rueda Caballero, C., Labarta Aizpun, J. I., Mayayo Dehesa, E., & Ferrandez Longas, A. (2013). Sitting/standing height ratio in Spanish children from birth to adulthood. *Archivos Argentinos De Pediatria, 111*(4), 309–314. https://doi.org/10.5546/aap.2013.eng.309

Eveleth, P. B., & Tanner, J. M. (1976). *Worldwide variation in human growth*. Cambridge University Press Archive. https://doi.org/10.1017/CBO9780511629105

Fredriks, A. M., Van Buuren, S., Van Heel, W. J. M., Dijkman-Neerincx, R. H. M., Verloove-Vanhorick, S. P., & Wit, J. M. (2005). Nationwide age references for sitting height, leg length, and sitting height/height ratio, and their diagnostic value for disproportionate growth disorders. *Archives of Disease in Childhood, 90*, 807–812. https://doi.org/10.1136/adc.2004.050799

Gittoes, M. J., Bezodis, I. N., & Wilson, C. (2009). An image-based approach to obtaining anthropometric measurements for inertia modeling. *Journal of Applied Biomechanics, 25*, 265–270. https://doi.org/10.1123/jab.25.3.265

Hermanussen, M., & Bogin, B. (2014). Auxology – An editorial. *Italian Journal of Pediatrics, 40*, 1–3. https://doi.org/10.1186/1824-7288-40-8

Huelke, D. F. (1998). An overview of anatomical considerations of infants and children in the adult world of automobile safety design. *Annual Proceedings. Association for the Advancement of Automotive Medicine, 42*, 93–113. PMCID: PMC3400202.

Hung, P. C.-Y., Witana, C. P., & Goonetilleke, R. S. (2004). Anthropometric measurements from photographic images. *Work with Computing Systems, 29*, 764–769. https://www.ieda.ust.hk/dfaculty/ravi/papers/wwcs2004_1.pdf

Leitch, I. (1951). Growth and health. *The British Journal of Nutrition, 5*, 142–151. https://doi.org/10.1079/bjn19510017

Lohman, T., Roache, A., & Martorell, R. (1988). *Anthropometric standardization reference manual* (pp. 3–24). Human Kinetics Books. Champaign. https://doi.org/10.1249/00005768-199208000-00020

Michaelsen, K. F., Skov, L., Badsberg, J. H., & Jørgensen, M. (1991). Short-term measurement of linear growth in preterm infants: validation of a hand-held knemometer. *Pediatric Research, 30*(5):464–468. https://doi.org/10.1203/00006450-199111000-00013. PMID: 1754302

Normand, M. C., Descarreaux, M., Harrison, D. D., Harrison, D. E., Perron, D. L., Ferrantelli, J. R., & Janik, T. J. (2007). Three dimensional evaluation of posture in standing with the PosturePrint: An intra- and inter-examiner reproducibility study. *Chiropractic and Osteopathy, 15*, 15. https://doi.org/10.1186/1746-1340-15-15

Odiere, M., Koski, K., Weiler, H., & Scott, M. (2010). Concurrent nematode infection and pregnancy induce physiological responses that impair linear growth in the murine foetus. *Parasitology, 137*, 991–1002. https://doi.org/10.1017/S0031182009991764

Pausic, J., Pedisic, Z., & Dizdar, D. (2010). Reproducibility of a photographic method for assessing standing posture of elementary school students. *Journal of Manipulative and Physiological Therapeutics, 33*, 425–431. https://doi.org/10.1016/j.jmpt.2010.06.002

Schaaf, H., Wilbrand, J. F., Boedeker, R. H., & Howaldt, H. P. (2010). Accuracy of photographic assessment compared with standard anthropometric measurements in nonsynostotic cranial deformities. *The Cleft Palate-Craniofacial Journal, 47*, 447–453. https://doi.org/10.1597/09-026

Solomons, N. W., Mazariegos, M., Brown, K. H., & Klasing, K. (1993). The underprivileged, developing country child: environmental contamination and growth failure revisited. *Nutrition Reviews, 51*, 327–332. https://doi.org/10.1111/j.1753-4887.1993.tb03758.x

Unicef WHO World Bank. (2014). *Joint Child Malnutrition Estimates* [Online]. Available: http://data.worldbank.org/child-malnutrition. Accessed July 2015

Van Maanen, C. J., Zonnenberg, A. J., Elvers, J. W., & Oostendorp, R. A. (1996). Intra/interrater reproducibility of measurements on body posture photographs. *Cranio, 14*, 326–331. https://doi.org/10.1080/08869634.1996.11745985

Vazquez-Vazquez, A., Azcorra, H., Falfan, I., Argaez, J., Kantun, D., & Dickinson, F. (2013). Effects of Maya ancestry and environmental variables on knee height and body proportionality in growing individuals in Merida, Yucatan. *American Journal of Human Biology, 25*, 586–593. https://doi.org/10.1002/ajhb.22417

Wadsworth, M. E. J., Hardy, R. J., Paul, A. A., Marshall, S. F., & Cole, T. J. (2002). Leg and trunk length at 43 years in relation to childhood health, diet and family circumstances; evidence from the 1946 national birth cohort. *International Journal of Epidemiology, 31*, 383–390. PMID: 11980800.

World Bank. (2010). *Nutrition at glance: Guatemala 2010* [Online]. The World Bank Available: http://siteresourcesworldbankorg/INTLACREGTOPNUT/Resources/Guatemala4-20-10pdf. Accessed Feb 2015

World Bank. (2011). *World development indicators: Guatemala* [Online]. Available: http://data.worldbank.org/country/guatemala

World Health Organization. (2006). *WHO Child Growth Standards: Length/height-for-age, weight-for-age, weight-for-length, weight-for-height and body mass index-for-age: Methods and development*. Geneva: WHO. https://www.who.int/publications/i/item/924154693X

Chapter 9
Evaluation of Maturation Among Adolescent Athletes

César Octavio Ramos-García, Daniel López-Plaza, Carlos Abraham Herrera-Amante, and Fernando Alacid

9.1 Introduction

Performance of athletes largely depends on their physical and physiological characteristics albeit a complex combination of determinants that range from their morphological characteristics to the kinematics and biomechanical processes also influence sports performance (Ackland et al., 2003; Malina, 1994; Michael et al., 2009; Robinson et al., 2002). For competition and training, athletes at younger age are commonly categorized by their chronological age (CA) or relative age (RA), according to the date of birth. However, individuals within same CA may differ in biological maturity (BM); some of them maturing earlier and some others have relatively delayed maturity (Cumming et al., 2021; Malina et al., 2004a; Malina, 1994). Therefore, tempo of BM among young athletes competing at the same age category

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S. Datta Banik (ed.), *Human Growth and Nutrition in Latin American and Caribbean Countries*, https://doi.org/10.1007/978-3-031-27848-8_9

might be significantly different, with some of them reaching maturity ahead of others, leading to individual differences through the maturation process that impacts both physical and psychosocial developments (Bailey et al., 2003; Baxter-Jones et al., 2020; Malina et al., 2015; Sherar et al., 2010). Variations in maturation should be considered in the process of talent identification and evaluation.

9.2 Maturation

Maturation is the process that starts since conception and continues until late adolescence. It can be measured throughout a variety of different biological systems (e.g., sexual, somatic, skeletal) (Malina et al., 2004a). Status, timing, and tempo are the characteristics that altogether define maturation. Status indicates the current maturation state, whereas timing indicates specific maturational events at a certain age (e.g., menarche, age at peak height velocity or APHV, etc.). Finally, tempo indicates maturation progress rate (Malina et al., 2015).

Variation in maturity status, timing and tempo are mainly under genetic regulation, although each can be influenced by the factors such as poverty, famine or stress (Malina et al., 2004a). Skeletal age is an established indicator of maturity status in youth and in children of the same CA that can vary by as much as 6 years (Cumming et al., 2021), opening the possibility for the oldest athlete within an age group to also be the least mature, or vice-versa. Additionally, maturation is not tantamount to RA since it is determined by the date of birth and the cut of date for a specific age group, while maturation is primarily a function of genotype, which may interact with environmental factors. Thus, it is possible to observe the least mature athletes within an age group and yet also the oldest one in terms of CA and vice-versa (Baxter-Jones et al., 2020; Figueiredo et al., 2019; Peña-González et al., 2018). The independent nature of RA and maturation constructs is also apparent in associated selection biases. Whereas RA effects are present from early childhood and are generally maintained through adolescence, maturity selection biases only emerge from the onset of puberty and tend to increase with age (Baxter-Jones et al., 2020).

In young athletes, maturational development significantly influences the physical, physiological, and morphological attributes. However, the physical and psychological consequences of maturation process are not same in boys and girls. Boys who mature earlier than their peers, tend to be taller and heavier at the final stages of adolescence. Additionally, they tend to come across an intense growth spurt through higher increases in lean mass, weight, and height (Malina et al., 2004a). This presents potential athletic advantages to those young athletes with an early maturing process, especially those between 11 and 14 years of age (i.e., greater strength, size, speed, and power) when maturity-based differences reach their peak (Malina et al., 2015). In addition, early maturing athletes tend to have higher perceptions of their physique (Cumming et al., 2012, 2018), and consequently a tendency to get involved and selected into sports disciplines and competitions where greater power, strength, and size are advantageous attributes (Cumming et al., 2018; Malina et al., 2015). Similarly, girls who mature early are heavier and taller, leading them to experience a more exalted pubertal growth spurt than their peers (Malina et al., 2004a). However, increase of body mass is essentially attributable to adipose tissue, with proportionally smaller gains in lean mass than boys. Consequently, differences in agility, power, and speed are insignificant among girls of distinct maturity status (Baxter-Jones et al., 2002; Malina et al., 2004b). Unlike boys, early mature girls may present negative perceptions of attractiveness, fitness, and sports performance, leading them to present weakened self-esteem (Cumming et al., 2011; Smart et al., 2012).

As mentioned before, early matured athletes, in particular boys, tend to perform better on speed, strength, and power tests. As a consequence, coaches also tend to assign higher performance scores to early maturing athletes during competitions (Malina et al., 2015). Therefore, individual disparities in maturation status may contribute to increased injury risk and inequity in competence, particularly for those with late maturation (Lloyd & Oliver, 2012; Malina, 2009). Proposals to match youth athletes based on maturity and physical attributes rather than CA have a long tradition and have been labelled "bio-banding" (Abbott et al., 2019; Baxter-Jones, 1995; Cumming et al., 2018; Figueiredo et al., 2010; Giudicelli et al., 2020; Malina et al., 2019; Rogol et al., 2018; Romann et al., 2020). For that objective, BM can be estimated using three methods: (a) skeletal maturity, (b) sexual maturity, and (c) somatic maturation.

9.3 Skeletal Maturity

It is also called bone maturation, and it is based on an intricate network of physiological mechanisms characterized by a well-described sequence of growth and development of ossification centers. Each bone segment sets up its maturation process at the main ossification center and reaches its final form over different development and remodeling phases, common among many maturation centers (epiphysis) in the same bone. Even though numerous body areas have been explored throughout the decades aiming at to define a consistent and universal method to estimate bone age, radiography of knee and wrist joints has emerged as the gold standard technique (Aicardi et al., 2000; Benedick et al., 2021; Cavallo et al., 2021). However, this method has several limitations, such as the need for x-radiation, specialized health personnel, interpretation of the results by means of an atlas, or the differences in the results depending on the assessment methods (Aicardi et al., 2000; Benedick et al., 2021; Lloyd et al., 2014; Malina et al., 2012).

Evaluation of skeletal maturity in prepubescents by wrist joint characteristics is based mainly on the epiphyseal size of the phalanges as they relate to the adjacent metaphysis. Throughout that stage, and until the end of puberty, ossification centers of the epiphysis become thicker and wider, as much as the metaphysis. The degree of epiphyseal fusion of ulna and radius set the basis for skeletal maturity evaluation

(Furdock et al., 2021, 2022; Knapik et al., 2018). The growing skeleton needs to adjust the accelerated development during puberty because of the quick hormonal changes. Bone mass may be double by the end of puberty and therefore, that stage has a crucial role in skeletal development (Saggese et al., 2002). About 40% of adult bone mass is reached in the course of pubertal development (Gordon et al., 1991). Bone maturation takes place in such a way that after rapid pubertal growth spurt, the epiphyseal growth plate becomes mature, and consequently, linear growth ceases. However, all factors and mechanisms involved are not entirely understood (Cavallo et al., 2021).

Systematic training of young athletes and its impacts on bone joints has been generally debated and included as a framework for potential harm for the epiphyseal plate, hampering the normal bone or skeletal growth (Rocha et al., 2021). However, the evidence is far from reaching a definite conclusion on this subject. Several methods have been built to obtain a bone maturation score from the hand and wrist joint x-ray studies (Greulich & Pyle, 1959; Tanner et al., 1994, 1997; Tanner, 1962). Among those, three methods have demonstrated to be the most reliable ones and are used worldwide: the Fels method (Roche et al., 1988), Greulich–Pyle method (GP) (Greulich & Pyle, 1959), and Tanner–Whitehouse (TW) (Tanner, 1983). Ethnicity, sex, pubertal age, and even experience of researcher seem to have strong associations with the use of these methods, conferring them a considerable intraindividual variability (Awais et al., 2014; Bull et al., 1999; Kim et al., 2015; King et al., 1994; Loder et al., 1993; Mansourvar et al., 2014; Mughal et al., 2014; Ontell et al., 1996; Patil et al., 2012; Pinchi et al., 2014; Soegiharto et al., 2008). Therefore, the development of newer methods supported by technological advancements such as artificial intelligence (Lee & Lee, 2021) and ultrasound (Wan et al., 2019), might be used to guide practitioners in their day-to-day practice approach and assessment.

9.4 Sexual Maturity

Through the observation of secondary sexual characteristics of an individual (breast, genitalia, and pubic hair), it is possible to evaluate sexual maturation or sexual age according to the procedures described by Tanner (1962). However, some limitations are associated with sexual maturation assessment since the external evaluation of sexual characteristics of individuals requires an invasion of privacy by an experienced physician and in some cases subjective that may not be reliable.

It has been suggested that intensive training and exercise throughout the maturation process could impact the timing of sexual maturation and, therefore, pubertal progression in youth athletes, particularly girls (Malina, 1994). Physiological events related to sexual maturation (menarche, pubic hair, and breast development) are clearly related to somatic and skeletal maturation (Malina et al., 1991; Tanner, 1962). For instance, menarche occurs within a reasonably tight span of skeletal ages, typically about a year after the age peak height velocity (APHV)

(Blom et al., 2021; Pallavee & Samal, 2018). Therefore, focusing on sexual maturation and exclusion of other indicators of BM during puberty, evaluation of adolescent growth spurt may not be the best approach in athletes and youths having high physical activity (Geithner et al., 1998).

9.5 Somatic Maturation

It is important to acknowledge the perceived, observed and reported inappropriateness, invasiveness, and often unethical approach of sexual maturity assessment, and negligible radiation exposure with skeletal age. In addition, logistical difficulties inherent to those methods for conducting longitudinal studies lead to an increasing interest in anthropometric evaluation of maturity status and timing. For instance, maturation status can be estimated by calculating the percentage of predicted adult height attained at the time of observation. Also, predicted maturity offset/time before/after the APHV can be used to estimate maturity timing (Table 9.1) (Malina et al., 2015; Mirwald et al., 2002).

The APHV refers to the estimated CA at a maximum growth rate in height during the adolescent spurt (Malina et al., 1991). Growth accelerates until it reaches a peak (PHV), decelerating after that and eventually terminating in the late adolescence and early 20s (Malina et al., 2015). This method is the only one considered “non-invasive” that can be used before, during and after puberty for the assessment of biological maturation (Malina, 2011). The somatic maturation of an individual can be identified from the evolution of morphological variables such as body weight, height and body dimensions (Lloyd et al., 2014).

The CA at which an individual reaches its maximum height growth or APHV has been defined in previous study (Mirwald et al., 2002) and can be calculated based on the growth of the anthropometric variables, as mentioned above. Usually and as a reference, the APHV occurs approximately at 12 years of age in girls and 14 years of age in boys (Malina et al., 2004a; Malina, 1994), but not all individuals reach the APHV in the same CA (Malina et al., 2015; Mirwald et al., 2002). Comparing the CA with the APHV, biological maturation status can be obtained. As a result, three

Table 9.1 Multiple linear regression models for predicting maturity offset from anthropometric variables (Mirwald et al., 2002)

Models	Maturity offset (Age-months)
Model 1 (APHV ♂)	−29.769 + 0.0003007 × leg length and sitting height interaction – 0.01177 × age and leg length interaction + 0.01639 × age and sitting height interaction + 0.445 × leg by height ratio
Model 2 (APHV ♀)	−16.364 + 0.0002309 × leg length and sitting height interaction + 0.006277 × age and sitting height interaction + 0.179 × leg by height ratio + 0.0009428 × age and weight interaction

APHV: age at peak height velocity

Table 9.2 Maturation groups according to de APHV (Sherar et al., 2005)

	Early	Average	Late
APHV (boys)	<13 (−1)	13–15	>15 (+1)
APHV (girls)	<11 (−1)	11–13	>13 (+1)

APHV: age at peak height velocity; Numbers in parenthesis indicate the difference between CA and APHV

maturation groups can be identified: "early maturers", "average maturers", or "late maturers" (Table 9.2) (Sherar et al., 2005).

In addition, Sherar et al. (2005) determined that there was a decreasing growth trend as the maturation progressed (early > middle > late). Also, from the same basic anthropometric parameters, it is possible to determine the final adult height with a single measurement (Sherar et al., 2005) and also using the height of the parents (Khamis & Roche, 1994). However, this predicted estimate of maturity status – specifically predicted maturity offset (time before or after APHV) has major limitations when compared to observed APHV in several longitudinal series. In addition, use of percentage of predicted adult height (based on the Fels Longitudinal series) and compare it with maturity offset (based on two Canadian and one Belgian sample) has certain limitations (Koziel & Malina, 2018; Malina et al., 2020, 2021). The estimates are not equivalent, one is an estimate of maturity timing and the other is an estimate of maturity status.

9.6 Maturity Status in Young Athletes

Different studies have identified the direct influence of BM on the evolution of physical condition and performance (Baxter-Jones et al., 2020; Figueiredo et al., 2019; Fransen et al., 2018; Malina et al., 2013, 2015; Myburgh et al., 2016; Teunissen et al., 2020). This evolution is, to a great extent, a consequence of the growth of body dimensions and the changes in the nervous system. Research on adolescent athlete's bone maturity is somewhat vast, more so for boys than girls though, with an exception for gymnasts (Malina, 2011; Malina et al., 2005, 2012, 2013; Myburgh et al., 2016; Rash et al., 2008).

Most of the physical capacities experience their greatest evolution around the APHV and slightly before it (Mirwald et al., 2002; Welsman & Armstrong, 2000). Therefore, field tests focused on assessing physical fitness must be applied taking into the consideration of APHV to monitor changes and evolution of physical capabilities. The most significant development may be observed in speed (Malina et al., 2015), aerobic capacity (Bar-Or, 1987; Falk & Bar-Or, 1993) or motor coordination (Katzmarzyk et al., 1997). However, other attributes such as strength or anaerobic capacity seem to evolve slightly after APHV during the metabolic specialization process (Armstrong et al., 1997; Bennett et al., 2019; Philippaerts et al., 2006; Vaeyens et al., 2006; Vandendriessche et al., 2012).

9.7 Talent Identification of Young Athletes

Currently, in most countries, sports federations organize young athletes by CA groups according to the calendar year of birth (Cumming et al., 2018). Thus, in the same competition and category, young athletes are observed to have CA difference of up to 12 months (Baxter-Jones et al., 2020; Sherar & Cumming, 2020; Vaeyens et al., 2008). As stated before, individual differences in maturation have influences on physical and morphological attributes. If the differences in CA at the same category are considered along maturity, notable differences in physical level and anthropometric characteristics of athletes competing together are evident. Consequently, early maturers born in the first part of the year would have a competitive "advantage" that would translate into higher yield potential than competitors with average or late maturation and born in the latter part of the year. This phenomenon has been called the "relative age effect" (RAE), and not only affects competition but also the selection of young talents (Cumming et al., 2018; Figueiredo et al., 2019; Lloyd et al., 2014; Musch & Grondin, 2001).

Traditionally, talent identification methods and programs have been based on the performances of athletes in the competitions (Cumming et al., 2018; Lloyd et al., 2014), as well as on physical growth and body size (Baxter-Jones et al., 2020; Cumming et al., 2021; Figueiredo et al., 2019; Teunissen et al., 2020). However, early maturers could create false expectations regarding the potential physical abilities they are able to develop as adults, since much of their evolution would have already occurred (Vaeyens et al., 2008). Conversely, the chances of being selected and standing out in competitions by less biologically mature athletes can imply a state of demotivation for the athlete, despite having a greater potential for developing their abilities (Baxter-Jones et al., 2020; Cumming et al., 2018, 2021; Rogol et al., 2018; Sherar et al., 2010).

Therefore, considerations of morphological, physical and maturational characteristics of adolescent athletes are advisable in the talent identification programs for youth to assure not only a system with more future prospects but also training programs appropriate to their CA and physical characteristics including BM (Baxter-Jones et al., 2020; Bennett et al., 2019; Cumming et al., 2018, 2021; Vaeyens et al., 2008).

Identification of young talents brings benefits to the organizations that implement an early search and selection program. Advantages include not only an early specialization in the skills and capacities but also the incorporation of those young players into a high-level group and long-term financial security, particularly in sports with smaller budgets, where it can be vital for the optimization of economic resources (Pion et al., 2015; Teunissen et al., 2020). Consequently, in the last decade, there has been an increasing interest in the creation of models for the talent identification among young athletes (Baxter-Jones et al., 2020; Bennett et al., 2019; Cumming et al., 2018, 2021; Fransen et al., 2018; Hertzog et al., 2018; Myburgh et al., 2016; Peña-González et al., 2018).

9.8 Bio-banding

Recently, experts have focused their efforts to deal with particular differences in BM in youth sports, labelling this strategy as "bio-banding" (Sherar et al., 2010). This strategy aims to band young athletes within a specific CA range, based on maturity status to reduce mismatches in strength, size and power, among others (Rogol et al., 2018).

A non-invasive assessment of maturity status is used in bio-banding to define categories of youths who are fairly similar in maturity status (MacMaster et al., 2021; Malina et al., 2019; Rogol et al., 2018; Towlson et al., 2021a). Compete or training with older and more physically advanced athletes might be discouraging for late maturers, whereas participating with individuals of similar characteristics might ensure a positive and safe experience (Cumming et al., 2018; Hill et al., 2020; Ludin et al., 2021; Malina et al., 2019; Rogol et al., 2018). Correspondingly, it is improvable that late maturing athletes who are thriving within their age group benefit from competing against peers who are younger but of similar maturity. Therefore, technical and psychological skills and attributes should also be taken into the consideration when grouping or matching athletes by size or maturation for the purpose of training and competition (Hill et al., 2020; Ludin et al., 2021; Malina et al., 2019; Rogol et al., 2018; Towlson et al., 2021b).

9.9 Conclusion

Individual differences in growth and maturation are paramount in the processes of talent identification and development, training design and implementation, and equity of competition among adolescent athletes. Coaches and practitioners should consider the processes of growth and maturation of young athletes, especially differences in maturation, comparing athletes' performance by age and maturity specific standards to better identify the strengths and weaknesses of individual athletes. Coaches might also consider athletes' performance when competing as one of the most or least mature within their cohort, ensuring that their success is simply not as a result of physical and functional advantages or disadvantages afforded by early or late maturation. Further research is required to understand the best ways to employ all different strategies, at what age they should be employed, and their broader benefits for early and late maturing athletes. The information on growth and maturation of adolescent athletes will complement the same from non-athletes and a comparative estimate between the two groups in general, will demonstrate a variation of biological characteristics of boys and girls in these age group that will consequently help researchers to find associations with other environmental factors like dietary habits, household psychosocial and economic status, etc.

References

Abbott, W., Williams, S., Brickley, G., & Smeeton, N. J. (2019). Effects of bio-banding upon physical and technical performance during soccer competition: A preliminary analysis. *Sports (Basel), 7*(8). https://doi.org/10.3390/sports7080193

Ackland, T. R., Ong, K. B., Kerr, D. A., & Ridge, B. (2003). Morphological characteristics of Olympic sprint canoe and kayak paddlers. *Journal of Science and Medicine in Sport, 6*(3), 285–294. https://doi.org/10.1016/s1440-2440(03)80022-1

Aicardi, G., Vignolo, M., Milani, S., Naselli, A., Magliano, P., & Garzia, P. (2000). Assessment of skeletal maturity of the hand-wrist and knee: A comparison among methods. *American Journal of Human Biology, 12*(5), 610–615. https://doi.org/10.1002/1520-6300(200009/10)12:5<610::AID-AJHB5>3.0.CO;2-D

Armstrong, N., Welsman, J. R., & Kirby, B. J. (1997). Performance on the Wingate anaerobic test and maturation. *Pediatric Exercise Science, 9*(3), 253–261.

Awais, M., Nadeem, N., Husen, Y., Rehman, A., Beg, M., & Khattak, Y. J. (2014). Comparison between Greulich-Pyle and Girdany-Golden methods for estimating skeletal age of children in Pakistan. *Journal of the College of Physicians and Surgeons–Pakistan, 24*(12), 889.

Bailey, D. A., Baxter-Jones, A. D., Mirwald, R. L., & Faulkner, R. A. (2003). Bone growth and exercise studies: The complications of maturation. *Journal of Musculoskeletal & Neuronal Interactions, 3*(4), 335–337. discussion 356.

Bar-Or, O. (1987). A commentary to children and fitness: A public health perspective. *Research Quarterly for Exercise and Sport, 58*(4), 304–307.

Baxter-Jones, A. D. (1995). Growth and development of young athletes. Should competition levels be age related? *Sports Medicine, 20*(2), 59–64.

Baxter-Jones, A. D., Thompson, A. M., & Malina, R. M. (2002). Growth and maturation in elite young female athletes. *Sports Medicine and Arthroscopy Review, 10*(1), 42–49.

Baxter-Jones, A. D. G., Barbour-Tuck, E. N., Dale, D., Sherar, L. B., Knight, C. J., Cumming, S. P., Ferguson, L. J., Kowalski, K. C., & Humbert, M. L. (2020). The role of growth and maturation during adolescence on team-selection and short-term sports participation. *Annals of Human Biology, 47*(4), 316–323. https://doi.org/10.1080/03014460.2019.1707870

Benedick, A., Knapik, D. M., Duren, D. L., Sanders, J. O., Cooperman, D. R., Lin, F.-C., & Liu, R. W. (2021). Systematic isolation of key parameters for estimating skeletal maturity on knee radiographs. *The Journal of Bone & Joint Surgery, 103*(9), 795–802. https://doi.org/10.2106/JBJS.20.00404

Bennett, K. J., Vaeyens, R., & Fransen, J. (2019). Creating a framework for talent identification and development in emerging football nations. *Science and Medicine in Football, 3*(1), 36–42. https://doi.org/10.1080/24733938.2018.1489141

Blom, A. A., Schats, R., Hoogland, M. L., & Waters-Rist, A. (2021). Coming of age in The Netherlands: An osteological assessment of puberty in a rural Dutch post-medieval community. *American Journal of Physical Anthropology, 174*(3), 463–478. https://doi.org/10.1002/ajpa.24161

Bull, R., Edwards, P., Kemp, P., Fry, S., & Hughes, I. (1999). Bone age assessment: A large scale comparison of the Greulich and Pyle, and Tanner and Whitehouse (TW2) methods. *Archives of Disease in Childhood, 81*(2), 172–173. https://doi.org/10.1136/adc.81.2.172

Cavallo, F., Mohn, A., Chiarelli, F., & Giannini, C. (2021). Evaluation of bone age in children: A mini-review. *Frontiers in Pediatrics, 9*, 21. https://doi.org/10.3389/fped.2021.580314

Cumming, S. P., Standage, M., Loney, T., Gammon, C., Neville, H., Sherar, L. B., & Malina, R. M. (2011). The mediating role of physical self-concept on relations between biological maturity status and physical activity in adolescent females. *Journal of Adolescence, 34*(3), 465–473.

Cumming, S. P., Sherar, L. B., Pindus, D. M., Coelho-e-Silva, M. J., Malina, R. M., & Jardine, P. R. (2012). A biocultural model of maturity-associated variance in adolescent physical activity. *International Review of Sport and Exercise Psychology, 5*(1), 23–43. https://doi.org/10.1080/1750984X.2011.630481

Cumming, S. P., Lloyd, R. S., Oliver, J. L., Eisenmann, J. C., & Malina, R. M. (2018). Bio-banding in sport: Applications to competition, talent identification, and strength and conditioning of youth athletes. *Strength & Conditioning Journal, 39*(2), 34–47. https://doi.org/10.1519/SSC.0000000000000281

Cumming, S. P., Patel, T. S., & Malina, R. M. (2021). The assessment and consideration of growth and maturation in youth athletes. *Nuevas tendencias en el desarrollo del talento deportivo, 33*.

Falk, B., & Bar-Or, O. (1993). Longitudinal changes in peak aerobic and anaerobic mechanical power of circumpubertal boys. *Pediatric Exercise Science, 5*(4), 318–331. https://doi.org/10.1123/pes.5.4.318

Figueiredo, A. J., Coelho, E. S. M. J., Cumming, S. P., & Malina, R. M. (2010). Size and maturity mismatch in youth soccer players 11- to 14-years-old. *Pediatric Exercise Science, 22*(4), 596–612. https://doi.org/10.1123/pes.22.4.596

Figueiredo, A. J., Coelho, E. S. M. J., Cumming, S. P., & Malina, R. M. (2019). Relative age effect: Characteristics of youth soccer players by birth quarter and subsequent playing status. *Journal of Sports Sciences, 37*(6), 677–684. https://doi.org/10.1080/02640414.2018.1522703

Fransen, J., Bush, S., Woodcock, S., Novak, A., Deprez, D., Baxter-Jones, A. D. G., Vaeyens, R., & Lenoir, M. (2018). Improving the prediction of maturity from anthropometric variables using a maturity ratio. *Pediatric Exercise Science, 30*(2), 296–307. https://doi.org/10.1123/pes.2017-0009

Furdock, R. J., Benedick, A. J., Nelson, G., Li, D., Cooperman, D. R., Sanders, J. O., & Liu, R. W. (2021). Systematic isolation of key parameters for estimating skeletal maturity on AP hip radiographs. *Journal of Pediatric Orthopaedics, 41*(8), 483–489. https://doi.org/10.1097/BPO.0000000000001876

Furdock, R. J., Huang, L. F., Sanders, J. O., Cooperman, D. R., & Liu, R. W. (2022). Systematic isolation of key parameters for estimating skeletal maturity on anteroposterior wrist radiographs. *The Journal of Bone & Joint Surgery, 104*(6), 530–536. https://doi.org/10.2106/JBJS.21.00819

Geithner, C. A., Woynarowska, B., & Malina, R. M. (1998). The adolescent spurt and sexual maturation in girls active and not active in sport. *Annals of Human Biology, 25*(5), 415–423. https://doi.org/10.1080/03014469800006662

Giudicelli, B. B., Luz, L. G. O., Sogut, M., Massart, A. G., Junior, A. C., & Figueiredo, A. J. (2020). Bio-banding in judo: The mediation role of anthropometric variables on the maturation effect. *International Journal of Environmental Research and Public Health, 17*(1), 361. https://doi.org/10.3390/ijerph17010361

Gordon, C., Halton, J., Atkinson, S., & Webber, C. (1991). The contributions of growth and puberty to peak bone mass. *Growth, Development, and Aging: GDA, 55*(4), 257–262.

Greulich, W. W., & Pyle, S. I. (1959). *Radiographic atlas of skeletal development of the hand and wrist*. Stanford University Press.

Hertzog, M., Paul, D. J., Nassis, G. P., & Silva, J. R. (2018). Does early recruitment predict greater physical performance in academy soccer players? *Sports, 6*(4), 108. https://doi.org/10.3390/sports6040108

Hill, M., Spencer, A., McGee, D., Scott, S., Frame, M., & Cumming, S. P. (2020). The psychology of bio-banding: A Vygotskian perspective. *Annals Humman Biology, 47*(4), 328–335. https://doi.org/10.1080/03014460.2020.1797163

Katzmarzyk, P., Malina, R., & Beunen, G. (1997). The contribution of biological maturation to the strength and motor fitness of children. *Annals of Human Biology, 24*(6), 493–505. https://doi.org/10.1080/03014469700005262

Khamis, H. J., & Roche, A. F. (1994). Predicting adult stature without using skeletal age: The Khamis-Roche method. *Pediatrics, 94*(4), 504–507.

Kim, J. R., Lee, Y. S., & Yu, J. (2015). Assessment of bone age in prepubertal healthy Korean children: Comparison among the Korean standard bone age chart, Greulich-Pyle method, and Tanner-Whitehouse method. *Korean Journal of Radiology, 16*(1), 201–205. https://doi.org/10.3348/kjr.2015.16.1.201

King, D., Steventon, D., O'sullivan, M., Cook, A., Hornsby, V., Jefferson, I., & King, P. (1994). Reproducibility of bone ages when performed by radiology registrars: An audit of Tanner and Whitehouse II versus Greulich and Pyle methods. *The British Journal of Radiology, 67*(801), 848–851. https://doi.org/10.1259/0007-1285-67-801-848

Knapik, D., Sanders, J., Gilmore, A., Weber, D., Cooperman, D., & Liu, R. (2018). A quantitative method for the radiological assessment of skeletal maturity using the distal femur. *Bone Joint Journal, 100*(8), 1106–1111. https://doi.org/10.1302/0301-620X.100B8.BJJ-2017-1489.R1

Koziel, S. M., & Malina, R. M. (2018). Modified maturity offset prediction equations: Validation in independent longitudinal samples of boys and girls. *Sports Medicine, 48*, 221–236. https://doi.org/10.1007/s40279-017-0750-y

Lee, B.-D., & Lee, M. S. (2021). Automated bone age assessment using artificial intelligence: The future of bone age assessment. *Korean Journal of Radiology, 22*(5), 792. https://doi.org/10.3348/kjr.2020.0941

Lloyd, R. S., & Oliver, J. L. (2012). The youth physical development model: A new approach to long-term athletic development. *Strength & Conditioning Journal, 34*(3), 61–72. https://doi.org/10.1519/SSC.0b013e31825760ea

Lloyd, R. S., Oliver, J. L., Faigenbaum, A. D., Myer, G. D., & Croix, M. B. D. S. (2014). Chronological age vs. biological maturation: Implications for exercise programming in youth. *The Journal of Strength & Conditioning Research, 28*(5), 1454–1464. https://doi.org/10.1519/JSC.0000000000000391

Loder, R. T., Estle, D. T., Morrison, K., Eggleston, D., Fish, D. N., Greenfield, M. L., & Guire, K. E. (1993). Applicability of the Greulich and Pyle skeletal age standards to black and white children of today. *American Journal of Diseases of Children, 147*(12), 1329–1333. https://doi.org/10.1001/archpedi.1993.02160360071022

Ludin, D., Donath, L., Cobley, S., & Romann, M. (2021). Effect of bio-banding on physiological and technical-tactical key performance indicators in youth elite soccer. *European Journal of Sport Science, 1–9*. https://doi.org/10.1080/17461391.2021.1974100

MacMaster, C., Portas, M., Parkin, G., Cumming, S., Wilcox, C., & Towlson, C. (2021). The effect of bio-banding on the anthropometric, physical fitness and functional movement characteristics of academy soccer players. *PLoS One, 16*(11), e0260136. https://doi.org/10.1371/journal.pone.0260136

Malina, R. M. (1994). Physical growth and biological maturation of young athletes. *Exercise and Sport Sciences Reviews, 22*(1), 280–284.

Malina, R. M. (2009). Children and adolescents in the sport culture: The overwhelming majority to the select few. *Journal of Exercise Science and Fitness, 7*(2), S1–S10. https://doi.org/10.1016/S1728-869X(09)60017-4

Malina, R. M. (2011). Skeletal age and age verification in youth sport. *Sports Medicine, 41*(11), 925–947. https://doi.org/10.2165/11590300-000000000-00000

Malina, R., Bouchard, C., & Bar-Or, O. (1991). *Physical activity as a factor in growth, maturation and performance. Growth, maturation, and physical activity* (Vol. 11, pp. 371–390). Human Kinetics.

Malina, R. M., Bouchard, C., & Bar-Or, O. (2004a). *Growth, maturation, and physical activity*. Human kinetics.

Malina, R. M., Eisenmann, J. C., Cumming, S. P., Ribeiro, B., & Aroso, J. (2004b). Maturity-associated variation in the growth and functional capacities of youth football (soccer) players 13-15 years. *European Journal of Appled Physiology, 91*(5–6), 555–562. https://doi.org/10.1007/s00421-003-0995-z

Malina, R. M., Cumming, S. P., Kontos, A. P., Eisenmann, J. C., Ribeiro, B., & Aroso, J. (2005). Maturity-associated variation in sport-specific skills of youth soccer players aged 13-15 years. *Journal of Sports Sciences, 23*(5), 515–522. https://doi.org/10.1080/02640410410001729928

Malina, R. M., Coelho ee Silva, M. J., Figueiredo, A. J., Carling, C., & Beunen, G. P. (2012). Interrelationships among invasive and non-invasive indicators of biological maturation in adolescent male soccer players. *Journal of Sports Sciences, 30*(15), 1705–1717. https://doi.org/10.1080/02640414.2011.639382

Malina, R. M., Baxter-Jones, A. D., Armstrong, N., Beunen, G. P., Caine, D., Daly, R. M., Lewis, R. D., Rogol, A. D., & Russell, K. (2013). Role of intensive training in the growth and maturation of artistic gymnasts. *Sports Medicine, 43*(9), 783–802. https://doi.org/10.1007/s40279-013-0058-5

Malina, R. M., Rogol, A. D., Cumming, S. P., Coelho e Silva, M. J., & Figueiredo, A. J. (2015). Biological maturation of youth athletes: Assessment and implications. *British Journal of Sports Medicine, 49*(13), 852–859. https://doi.org/10.1136/bjsports-2015-094623

Malina, R. M., Cumming, S. P., Rogol, A. D., Coelho, E. S. M. J., Figueiredo, A. J., Konarski, J. M., & Koziel, S. M. (2019). Bio-banding in youth sports: Background, concept, and application. *Sports Medicine, 49*(11), 1671–1685. https://doi.org/10.1007/s40279-019-01166-x

Malina, R. M., Kozieł, S. M., Králik, M., Chrzanowska, M., & Suder, A. (2020). Prediction of maturity offset and age at peak height velocity in a longitudinal series of boys and girls. *American Journal of Human Biology, 2020*, e23551. https://doi.org/10.1002/ajhb.23551

Malina, R. M., Coelho-e-Silva, M. J., Martinho, D. V., Sousa-e-Siva, P., Figueiredo, A. J., Cumming, S. P., et al. (2021). Observed and predicted ages at peak height velocity in soccer players. *PLoS One, 16*(7), e0254659. https://doi.org/10.1371/journal.pone.0254659

Mansourvar, M., Ismail, M. A., Raj, R. G., Kareem, S. A., Aik, S., Gunalan, R., & Antony, C. D. (2014). The applicability of Greulich and Pyle atlas to assess skeletal age for four ethnic groups. *Journal of Forensic and Legal Medicine, 22*, 26–29. https://doi.org/10.1016/j.jflm.2013.11.011

Michael, J. S., Smith, R., & Rooney, K. B. (2009). Determinants of kayak paddling performance. *Sports Biomechanics, 8*(2), 167–179. https://doi.org/10.1080/14763140902745019

Mirwald, R. L., Baxter-Jones, A. D., Bailey, D. A., & Beunen, G. P. (2002). An assessment of maturity from anthropometric measurements. *Medicine and Science in Sports and Exercise, 34*(4), 689–694. https://doi.org/10.1097/00005768-200204000-00020

Mughal, A. M., Hassan, N., & Ahmed, A. (2014). The applicability of the Greulich & Pyle Atlas for bone age assessment in primary school-going children of Karachi, Pakistan. *Pakistan Journal of Medical Sciences, 30*(2), 409.

Musch, J., & Grondin, S. (2001). Unequal competition as an impediment to personal development: A review of the relative age effect in sport. *Developmental Review, 21*(2), 147–167. https://doi.org/10.1006/drev.2000.0516

Myburgh, G. K., Cumming, S. P., Coelho, E. S. M., Cooke, K., & Malina, R. M. (2016). Growth and maturity status of elite British junior tennis players. *Journal of Sports Sciences, 34*(20), 1957–1964. https://doi.org/10.1080/02640414.2016.1149213

Ontell, F., Ivanovic, M., Ablin, D. S., & Barlow, T. (1996). Bone age in children of diverse ethnicity. *AJR American Journal of Roentgenology, 167*(6), 1395–1398. https://doi.org/10.2214/ajr.167.6.8956565

Pallavee, P., & Samal, R. (2018). Precocious puberty: A clinical review. *International Journal of Reproduction, Contraception, Obstetrics and Gynecology, 7*(3), 771–777. https://doi.org/10.18203/2320-1770.ijrcog20180853

Patil, S. T., Parchand, M., Meshram, M., & Kamdi, N. (2012). Applicability of Greulich and Pyle skeletal age standards to Indian children. *Forensic Science International, 216*(1–3), 200.e201–200.e204. https://doi.org/10.1016/j.forsciint.2011.09.022

Peña-González, I., Fernández-Fernández, J., Moya-Ramón, M., & Cervelló, E. (2018). Relative age effect, biological maturation, and coaches' efficacy expectations in young male soccer players. *Research Quarterly for Exercise and Sport, 89*(3), 373–379. https://doi.org/10.1080/02701367.2018.1486003

Philippaerts, R. M., Vaeyens, R., Janssens, M., Van Renterghem, B., Matthys, D., Craen, R., Bourgois, J., Vrijens, J., Beunen, G., & Malina, R. M. (2006). The relationship between peak height velocity and physical performance in youth soccer players. *Journal of Sports Sciences, 24*(3), 221–230. https://doi.org/10.1080/02640410500189371

Pinchi, V., De Luca, F., Ricciardi, F., Focardi, M., Piredda, V., Mazzeo, E., & Norelli, G.-A. (2014). Skeletal age estimation for forensic purposes: A comparison of GP, TW2 and TW3 methods on an Italian sample. *Forensic Science International, 238*, 83–90. https://doi.org/10.1016/j.forsciint.2014.02.030

Pion, J., Segers, V., Fransen, J., Debuyck, G., Deprez, D., Haerens, L., Vaeyens, R., Philippaerts, R., & Lenoir, M. (2015). Generic anthropometric and performance characteristics among elite adolescent boys in nine different sports. *European Journal of Sport Science, 15*(5), 357–366. https://doi.org/10.1080/17461391.2014.944875

Rash, C. L., Malinauskas, B. M., Duffrin, M. W., Barber-Heidal, K., & Overton, R. F. (2008). Nutrition-related knowledge, attitude, and dietary intake of college track athletes. *Sport Journal, 11*(1), 48–55.

Robinson, M. G., Holt, L. E., & Pelham, T. W. (2002). The technology of sprint racing canoe and kayak hull and paddle designs. *International Sports Journal, 6*, 68–85.

Rocha, F., Conceição, A., Mata, C., Narciso, J. M., Costa, A., Branco, M., & Louro, H. (2021). Reaction forces and bone maturation in taekwondo: Comparison with and without tatami. *Human Movement.* https://doi.org/10.5114/hm.2023.107246

Roche, A. F., Thissen, D., & Chumlea, W. (1988). *Assessing the skeletal maturity of the hand-wrist: Fels method*. Thomas.

Rogol, A. D., Cumming, S. P., & Malina, R. M. (2018). Biobanding: A new paradigm for youth sports and training. *Pediatrics, 142*(5). https://doi.org/10.1542/peds.2018-0423

Romann, M., Ludin, D., & Born, D. P. (2020). Bio-banding in junior soccer players: A pilot study. *BMC Research Notes, 13*(1), 240. https://doi.org/10.1186/s13104-020-05083-5

Saggese, G., Baroncelli, G. I., & Bertelloni, S. (2002). Puberty and bone development. *Best Practice & Research Clinical Endocrinology & Metabolism, 16*(1), 53–64. https://doi.org/10.1053/beem.2001.0180

Sherar, L. B., & Cumming, S. P. (2020). Human biology of physical activity in the growing child. *Annals of Human Biology, 47*(4), 313–315. https://doi.org/10.1080/03014460.2020.1816934

Sherar, L. B., Mirwald, R. L., Baxter-Jones, A. D. G., & Thomis, M. (2005). Prediction of adult height using maturity-based cumulative height velocity curves. *The Journal of Pediatrics, 147*(4), 508–514. https://doi.org/10.1016/j.jpeds.2005.04.041

Sherar, L. B., Cumming, S. P., Eisenmann, J. C., Baxter-Jones, A. D., & Malina, R. M. (2010). Adolescent biological maturity and physical activity: Biology meets behavior. *Pediatric Exercise Science, 22*(3), 332–349. https://doi.org/10.1123/pes.22.3.332

Smart, J. E., Cumming, S. P., Sherar, L. B., Standage, M., Neville, H., & Malina, R. M. (2012). Maturity associated variance in physical activity and health-related quality of life in adolescent females: A mediated effects model. *Journal of Physical Activity and Health, 9*(1), 86–95. https://doi.org/10.1123/jpah.9.1.86

Soegiharto, B. M., Cunningham, S. J., & Moles, D. R. (2008). Skeletal maturation in Indonesian and white children assessed with hand-wrist and cervical vertebrae methods. *American Journal of Orthodontics and Dentofacial Orthopedics, 134*(2), 217–226. https://doi.org/10.1016/j.ajodo.2006.07.037

Tanner, J. M. (1962). *Growth at adolescence*. Blackwell.

Tanner, J. M. (1983). *Assessement of skeletal maturity and predicting of adult height (TW2 method)* (Prediction of adult height) (pp. 22–37). Academic.

Tanner, J. M., Oshman, D., Lindgren, G., Grunbaum, J. A., Elsouki, R., & Labarthe, D. (1994). Reliability and validity of computer-assisted estimates of Tanner-Whitehouse skeletal maturity (CASAS): Comparison with the manual method. *Hormone Research, 42*(6), 288–294. https://doi.org/10.1159/000184211

Tanner, J., Oshman, D., Bahhage, F., & Healy, M. (1997). Tanner-Whitehouse bone age reference values for North American children. *The Journal of Pediatrics, 131*(1), 34–40. https://doi.org/10.1016/S0022-3476(97)90000-7

Teunissen, J. W. A., Rommers, N., Pion, J., Cumming, S. P., Rossler, R., D'Hondt, E., Lenoir, M., Savelsbergh, G. J. P., & Malina, R. M. (2020). Accuracy of maturity prediction equations in individual elite male football players. *Annals of Human Biology, 47*(4), 409–416. https://doi.org/10.1080/03014460.2020.1783360

Towlson, C., Abt, G., Barrett, S., Cumming, S., Hunter, F., Hamilton, A., Lowthorpe, A., Goncalves, B., Corsie, M., & Swinton, P. (2021a). The effect of bio-banding on academy soccer player passing networks: Implications of relative pitch size. *PLoS One, 16*(12), e0260867. https://doi.org/10.1371/journal.pone.0260867

Towlson, C., MacMaster, C., Goncalves, B., Sampaio, J., Toner, J., MacFarlane, N., Barrett, S., Hamilton, A., Jack, R., Hunter, F., & Others. (2021b). The effect of bio-banding on physical and psychological indicators of talent identification in academy soccer players. *Science and Medicine in Football, 5*(4), 280–292. https://doi.org/10.1371/journal.pone.0260136

Vaeyens, R., Malina, R. M., Janssens, M., Van Renterghem, B., Bourgois, J., Vrijens, J., & Philippaerts, R. M. (2006). A multidisciplinary selection model for youth soccer: The Ghent Youth Soccer Project. *British Journal of Sports Medicine, 40*(11), 928–934. https://doi.org/10.1136/bjsm.2006.029652

Vaeyens, R., Lenoir, M., Williams, A. M., & Philippaerts, R. M. (2008). Talent identification and development programmes in sport. *Sports Medicine, 38*(9), 703–714. https://doi.org/10.2165/00007256-200838090-00001

Vandendriessche, J. B., Vaeyens, R., Vandorpe, B., Lenoir, M., Lefevre, J., & Philippaerts, R. M. (2012). Biological maturation, morphology, fitness, and motor coordination as part of a selection strategy in the search for international youth soccer players (age 15–16 years). *Journal of Sports Sciences, 30*(15), 1695–1703. https://doi.org/10.1080/02640414.2011.652654

Wan, J., Zhao, Y., Feng, Q., Sun, Z., & Zhang, C. (2019). Potential value of conventional ultrasound in estimation of bone age in patients from birth to near adulthood. *Ultrasound in Medicine & Biology, 45*(11), 2878–2886. https://doi.org/10.1016/j.ultrasmedbio.2019.07.681

Welsman, J. R., & Armstrong, N. (2000). Statistical techniques for interpreting body size–related exercise performance during growth. *Pediatric Exercise Science, 12*(2), 112–127. https://doi.org/10.1123/pes.12.2.112

Part III
Biocultural Impacts on Child Growth and Nutrition in Latin American and Caribbean Countries

Chapter 10
Secular Trend in Growth and Nutritional Status in Argentina Over the Last Three Decades

Alicia B. Orden

10.1 Introduction

Auxologists have largely considered human growth as a phenomenon of biological plasticity that reflects individual's adaptive adjustments to environmental conditions during development. This conception, which relativizes the genetic contribution on phenotype, was endorsed by James Tanner (1986) and valued through the studies of Robert Fogel (1986) and his collaborators Rick Steckel (1995) and John Komlos (1994) among other scholars, who provided extensive empirical evidence by highlighting the importance of growth as a mirror of living standards, now redefined as an indicator of "biological well-being", in promoting or constraining economic development.

In auxology, one of the most conspicuous examples of the correlation between socioeconomic well-being and healthy growth of children is probably the secular trend, a phenomenon widely documented in Europe after the Second World War, where economic development and the improvement in the standard of living allowed a greater expression of the genetic potential of individuals leading to increased mean heights and advancement of maturation milestones such as menarche (Cole, 2003; Hauspie et al., 1997). In the long-term, such changes are the outcomes of a continuous interaction between genetic and environmental factors, while short-time changes (one or a few generations) involve variations in the environment in which child growth takes place. Given the secular trend had occurred very fast to be the result of genetic changes, such slowing down may indicate either an achievement of the growth genetic potential or that social conditions have not continued to improve. Such improvement probably accounts for the cessation or slowdown of secular

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S. Datta Banik (ed.), *Human Growth and Nutrition in Latin American and Caribbean Countries*, https://doi.org/10.1007/978-3-031-27848-8_10

trends in most of the Western European countries, while some eastern and southern European countries still showed positive changes in the twenty-first century (Bodzsár et al., 2016; Fudvoye & Parent, 2017; Woronkowicz et al., 2012).

In developing countries, secular changes can still be observed because of the current changes in living standards. Evidence of secular growth changes has been documented in several Latin American populations (Castilho & Lahr, 2001; Malina et al., 2018; Meisel-Roca & Granger, 2021; Núñez & Pérez, 2015). However, historical trajectories in Latin American countries are often marked by recurring political and economic crises. Therefore, despite global economic development, fundamental problems still persist in many countries in the region. Indeed, at the end of the twentieth century, Latin America had the highest poverty rates, given its per capita GDP, and was in fact the most unequal in comparison with other regions in the world (Salvatore et al., 2010; Subramanian et al., 2011). This implies that even when secular changes may progress in the population, not always attain the less favored social sectors, which remain aside of improvements in well-being and health. As a result, secular changes can be masked by social inequalities.

In the 1980s, the increase in body mass index (BMI), and the consequent obesity, marked the beginning of a new secular change at the global level. The emergence of obesity was the main output of changes in food consumption and physical activity patterns that defined the so-called nutrition transition. Popkin (2002) proposed five basic stages or patterns that were not restricted to the periods in which they first started to rise but described some geographical and socio-economic sub-populations: "collecting food", "fame", "receding fame", "nutrition-related non-communicable disease" (NR-NCD) and "behavioral change". Obesity emerged along with pattern fourth (NR-NCD) in most high-income societies and affluent people in developing countries. In the last stage of nutrition transition, the highest socioeconomic status (SES) people had the healthiest eating and living habits, while those with low-income, consequently with little access to healthy food and nutritional education, tended to be increasingly obese.

The association between standard of living and BMI (i.e., either undernutrition or obesity or coexistence of both) differs from that seen in linear growth or maturity milestones, as positive secular changes cannot be associated with well-being parameters. In fact, studies in the USA, Australia and several European countries described a stagnation or "leveling-off" in obesity rates (Ahluwalia et al., 2015; Ng et al., 2014; Olds et al., 2011; Rokholm et al., 2010) suggesting an inverse relationship between economic development and obesity (Ulijaszek et al., 2017). The transition from a predominantly underweight population to that overweight and obese has been particularly rapid in Latin America where the scenario seems to be more complex, with epidemiological and nutritional overlapping trends and a social distribution of changes substantially heterogeneous between and within countries (Frenk et al., 1991). In most of the countries, persists dual burden of malnutrition and non-communicable degenerative diseases (Popkin & Reardon, 2018; Rivera et al., 2014). The high prevalence of obesity is a common concern in many countries, including Argentina, as shown by the studies based on national surveys of the adult population (Christine et al., 2015; Fleischer et al., 2011). However, evidence for the sub-adult population is more limited, either because current national surveys are not probabilistic or because they are restricted to a narrow age range, which makes it impossible to assess temporal trends without sampling bias. Measuring secular change requires comparable data series, that are representative of the population under study and therefore, small-scale studies allow the change to be estimated with greater precision. This chapter discusses the secular variation of linear growth and nutritional status based on a series of cross-sectional studies carried out between 1990 and 2016 among children and adolescents from Santa Rosa, La Pampa (Argentina).

10.2 Data Sources

La Pampa is located in an area where production systems are developed in natural environments. In the mid-1990s, the province was integrated into the Patagonian region (Southern Argentina). Santa Rosa is the capital city and the main urban center of the province. According to the last national census conducted in 2010, it comprises a population of 103,241 inhabitants. Migration is mostly internal, being from small towns, rural areas, and neighboring provinces. From epidemiological point of view, the population shows a profile defined by a predominance of non-communicable diseases as the major causes of morbidity and mortality. Decreasing rates of mortality and births, as well increased life expectancy have been defining a progressive aging population during the period under study. Figures of some relevant indicators are summarized in Table 10.1.

Data for analyzing secular trend in anthropometric characteristics representing three cross-sectional studies conducted in public and private schools between 2005 and 2016 are:

Table 10.1 Evolution of socioeconomic and demographic indicators in La Pampa since 1990

Indicator	1990	2000	2010	2020
Santa Rosa (inhabitants)	78,022	94,758	103,241	118,669
Population under 15 years-old (%)	31.7	28.4	24.8	23.2
Population over 65 years-old (%)	7.6	8.7	10.2	14.0
Life expectancy at birth (both sexes, years)	71.6	74.8	76.2	76.2
Population with UBN[a] (%)	13.5	10.3	5.6	5.7
Crude death rate/1000 people	7.7	7.1	7.0	7.1
Crude birth rate/1000 people	23.3	18.1	16.2	13.5
Child mortality rate/1000 live births	22.2	12.4	7.9	9.2

[a]Unsatisfied basic needs (UBN) are referred to as direct measures of poverty (household conditions, access to sanitary services, education and economic capacity). Sources: National population and housing censuses (INDEC, 1991, 2001, and 2010) (Instituto Nacional de Estadística y Censos. https://www.indec.gob.ar). Data 2020 (census publication is pending) are projected by the INDEC, published by the Ministry of Health/Pan American Health Organization. (Indicadores Básicos, Argentina. https://iris.paho.org/handle/10665.2/53210)

- **Survey 2005/07**. This cross-sectional study collected data from 1755 boys and 1656 girls (n = 3411) aged 5–15 years (mean value of age was 10.3 ± 3.0 years), using a probabilistic two-stage cluster sampling design (included neighborhoods mapping and a random selection of the schools mapped on each neighborhood).
- **Survey 2009**. A cross-sectional study was carried out 4 years later in a sample of 12- to 18-year-old 911 boys and 1018 girls (n = 1929) (mean value of age was 15.1 ± 1.8 years), using the same procedures of sampling to select secondary schools.
- **Survey 2015/16**. The cross-sectional study recruited 542 boys and 608 girls (n = 1150) aged 6–12 years (mean value of age was 9.1 ± 1.8 years) who attended the same primary schools selected in the first survey.

Details on data collection and measurement techniques have been previously published (Orden et al., 2019; Orden & Apezteguía, 2016). Body mass index (BMI= weight in kg/height in m^2) categories, based on International Obesity Task Force (IOTF) cut-off values (Cole & Lobstein, 2012), were used as indicators of thinness, normal weight, overweight and obesity. Results derived from these surveys have been published in several research articles (Orden, 2012; Orden et al., 2009, 2013, 2019, 2021; Orden & Apezteguía, 2016) and will be summarized in the following sections.

10.3 Changes in Height

Height has been largely recognized as an indicator of welfare as well as other socio-demographic parameters of the standard of living, such as neonatal and infant mortality rates, which have shown a sustained declining trend in Latin America. Such figures, however, do not provide information on health of those children who survive, how they live and grow up (Lejarraga, 2007). In contrast to the morbidity and mortality indicators, height is a positive indicator of population health.

One of the strategies to evaluate population changes in height has been the construction and validation of growth references. In this sense, they constitute the "natural" baseline both for growth monitoring and secular trend studies. The Argentinian growth reference was built during two great periods: from 1960 to 1970 for children younger than 12 years of age and during 1985 for adolescents aged 12–19 years. In 2009, height-for-age percentiles were adjusted by the LMS method, including data from the WHO growth standard for children under 2 years old (Lejarraga et al., 2009). Two studies aimed to evaluate the validity of the Argentinian growth reference data that were conducted between 1998 and 2001 among children aged 0–5 years (del Pino et al., 2003) and adolescents aged 10–19 years (del Pino et al., 2005). Both studies described a trend of higher mean height in boys and girls aged 4–5 years and also in older children and adolescents, with a progressive decrease up to age 18. The same pattern was found by Orden and Apezteguía (2016) in boys and girls aged 5–18 years measured between 2005 and 2009. These studies reached almost identical results, showing a minimal increase in the final height achieved in boys (1.6–1.8 cm) and girls (<0.33 cm), which, regarding units per decade, signifies a stagnation of height (Fig. 10.1).

On the other hand, differences mediated by SES accounted for approximately 2 cm above the mean value of the school population and 3 to 4 cm above the national reference (Fig. 10.2). Unlike what has been described in various European populations, in which the secular trend affected the height distribution as a whole (Hermanussen & Bogin, 2014), these data suggest a non-uniform trend showing a stronger impact on the more affluent sectors (Fig. 10.2). High SES boys and girls were significantly taller than that compared with the estimated values from general population and reached similar values of WHO (de Onis et al., 2007), Italian (Cacciari et al., 2002) and Spanish (Carrascosa et al., 2010) growth references.

Secular changes occur either by changes in the adult size and/or in the child growth rates. Data from the army (which for many years was the greatest preservatory of probabilistic samples of 18-year-old boys) recorded height of 174 cm in recruits born in 1975, measured almost the same height of those aged-matched boys born in 1991 (Orden, 2012). Despite this stagnation of adult height, clear differences appeared among the pre-adolescents whose values are well above the data representing national level. This evidence suggests a possible secular acceleration of growth or secular trend in tempo of growth. This means that children are taller during childhood and adolescence than their counterparts of some decades ago, but this increased growth rate does not affect final size (Cole, 2003; Hauspie & Vercauteren, 2004). Since the Argentinian reference was constructed from cross-sectional samples, it does not have data of peak height velocity or other maturity indicators. The percentage of adult height reached at each age may be an alternative measure of growth timing. Higher the percentage, the more accelerated the tempo of growth. In our population, percentage of adult height gain in preadolescents was noticeable; higher in boys and girls sampled in 2005/07 and 2009 compared to their

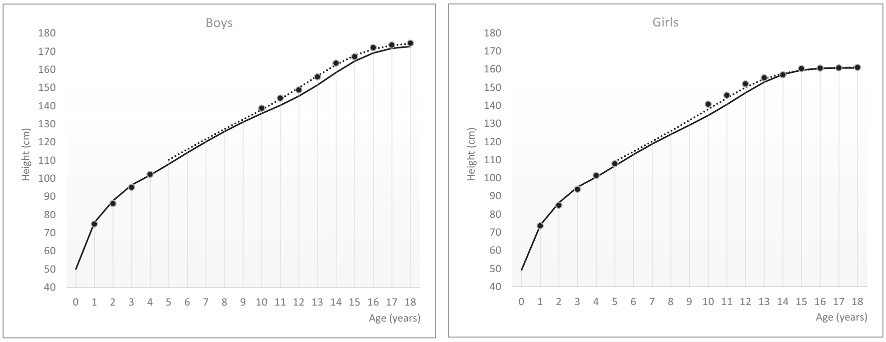

Fig. 10.1 Linear height growth in Argentinian children and adolescents. Solid line: 50th centile of the Argentinian growth reference (Lejarraga et al., 2009). Black circles: children and adolescents aged 0–5 years and 10–18 years sampled during 1998–2001 (del Pino et al., 2003, 2005). Dotted line: children and adolescents aged 0–18 years surveyed during 2005–2009. (Orden & Apezteguia, 2016)

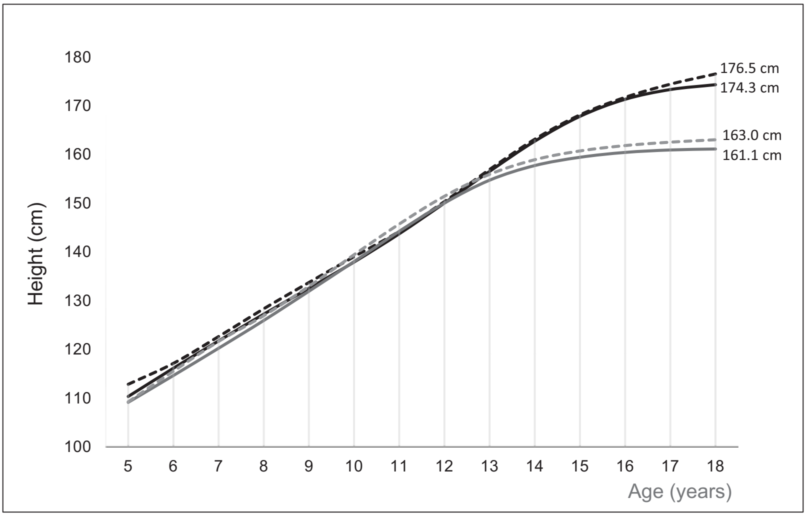

Fig. 10.2 Height in children and adolescents from Santa Rosa, La Pampa. Solid line: 50th centile in boys (black) and girls (grey). Dashed line: 50th centile in boys and girls who attended private schools. (unpublished data)

national reference of peers (Fig. 10.3). Differences in maturational timing could suggest age-cohort effects, such that younger children would have experienced better conditions than older ones. This effect, however, must be ruled out since the two cohorts separately showed the same acceleration patterns (Orden, 2012; Orden et al., 2009).

The secular changes towards an earlier growth spurt and tempo have been observed in several populations, so that boys and girls were taller at earlier ages (Khadilkar et al., 2009; Kulaga et al., 2010; Zong & Li, 2013), and also in multiethnic societies, where children of migrants appeared to be comparatively tall and heavy at late puberty but remained shorter in height after puberty (Redlefsen et al., 2007).

Socio-political conditions are closely linked to the well-being of the population and therefore, it is expected that they are expressed in indicators such as height (Hermanussen et al., 2019). In this perspective, Gomula et al. (2020) found both a secular trend toward increased body height and an accelerated developmental tempo over nearly 50 years, when Poland has undergone considerable socioeconomic and political changes. In Argentina, the political situation has been stabilized since the return of democracy in 1983, but economic stability that allows a sustained improvement in the living conditions for the entire population has not been achieved yet. Further studies will be necessary to assess this effect in other settlements throughout the country, as well as in migrant populations, with increasing demographic growth in the last 30 years.

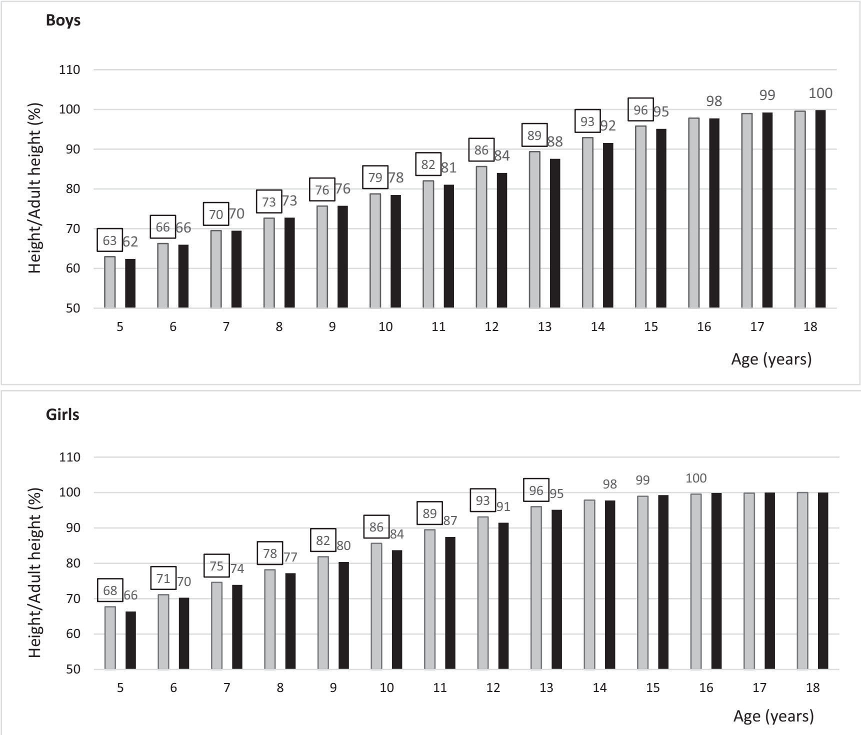

Fig. 10.3 Secular acceleration in Argentinian boys and girls. Bars represent the percentage of adult height attained at each age in the Argentinian growth reference (black) and children and adolescents surveyed in 2005/07 and 2009 (grey), whose values (in squares) indicates an advanced tempo of growth in girls (5–13 years) and boys (10–16 years)

The secular trend of earlier pubertal timing has been partially associated with increasing childhood body mass index (Ohlsson et al., 2019). The changes in nutritional status indicators between 1990 and 2016 are described below.

10.4 Trends in Nutritional Status

Baseline data to analyze the secular change in anthropometric indicators of nutritional status were collected in 1990 by the staff of the School Health Office (Ministry of Culture and Education of La Pampa) in all public and private schools of the province. Baseline data corresponding to Santa Rosa were compared with the aforementioned surveys conducted in 2005/07 (Orden et al., 2013) and 2015/16 (Orden et al., 2019). Comparisons with the baseline data of 1990 show a sustained increase in BMI. As it had been widely documented, obesity epidemic results from changes in BMI distribution (i.e. a positive skewing) with stronger effects on the upper centiles while the percentiles below the median hardly change (Fig. 10.4).

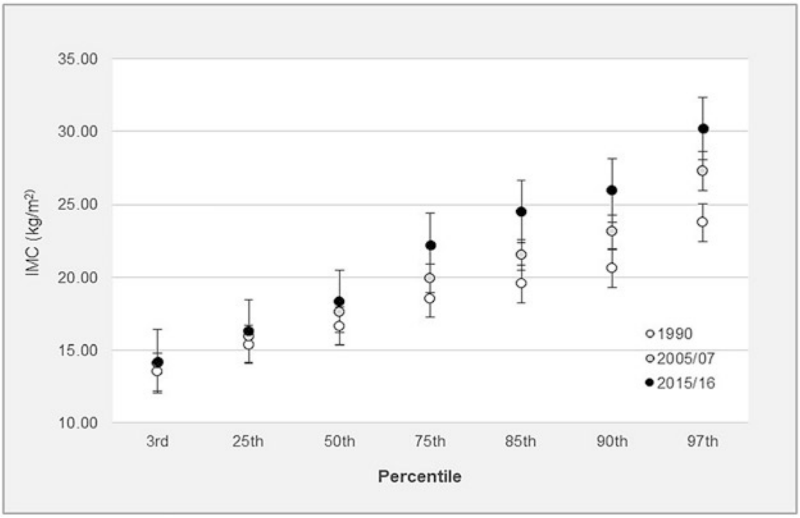

Fig. 10.4 Temporal trends in BMI distribution. Each point correspond to selected percentiles (non- adjusted values) from three surveys in Santa Rosa. The greatest differences occur from the 50th percentile onwards

This temporal trend in body mass changed the nutritional status of school-age population: less than 5% of children remained underweight, almost 15% of those who had normal weight have been moving into the ranks of overweight (~20%) and obesity (~12%). This continuous increase in childhood overweight is similar to that described in other Latin American countries under rapid nutrition transition (Corvalán et al., 2017; Hernández-Cordero et al., 2017; Rivera et al., 2014). Although the trend in both BMI categories is significant throughout the study period, there was a change in velocity between the surveys: overweight increased from around 13–20% and obesity progressed from around 2–12%. However, while the increase in overweight slowed from 0.28 to 0.23% per year, the obesity rate accelerated from 0.31 to 0.50% per year for the periods 1990–2005/07 and 2005/07–2015/16, respectively (Fig. 10.5).

Usually, temporal trends are not linear. Since the mid-2000s, a number of studies in developed countries have described a "levelling off" or even a slowing down in obesity rates (Aeberli et al., 2010; de Wilde et al., 2014; Hardy et al., 2017; Lazzeri et al., 2015; Ogden et al., 2014; Olds et al., 2010; Stamatakis et al., 2010). In contrast, an increasing trend has been observed in some Eastern European countries (Ahluwalia et al., 2015; Sigmund et al., 2018). Such disparities point out the difficulty of delineating global trends given regional, socioeconomic, or ethnic differences, among other factors (Rokholm et al., 2010). Therefore, along with the need to understand the global patterns of the obesity epidemic, studies began to analyze the temporal trends of obesity and associated factors. One of these factors is the SES measured through family income, occupation and/or parental education as well as

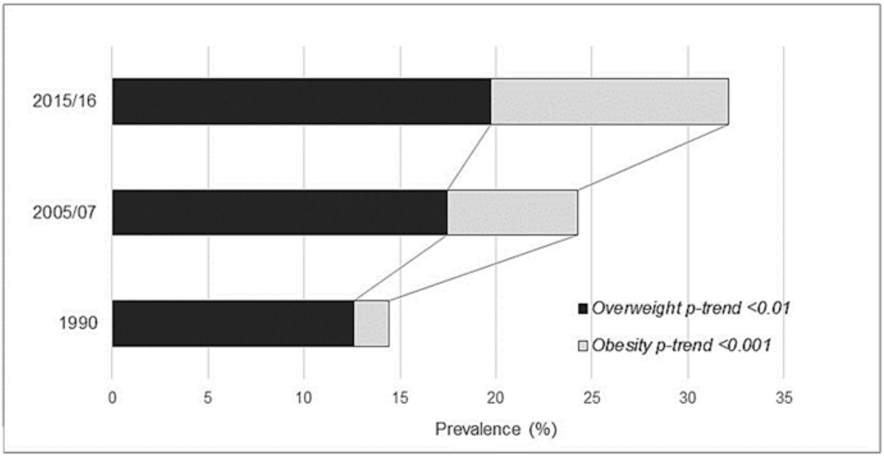

Fig. 10.5 Trends in overweight and obesity in schoolchildren from Santa Rosa (Argentina) through the periods 1990–2005/07 and 2005/07–2015/16. During the last period rate in overweight slow down while obesity rate accelerated

other welfare indexes (appliances, goods, services, etc.). In some cases, aggregate or multilevel measures have been considered, incorporating the schools, neighborhoods and census data (Hardy et al., 2017; Sundblom et al., 2008), in addition to individual or household characteristics (Miqueleiz et al., 2014).

Since the 1990s, the Argentinian educational system has been progressively decentralized, becoming an element of social differentiation, where children from the most affluent sectors attended private schools, while a large part of the middle and lower SES population had the only option to educate their children in public schools. Hence, the type of school can be used as an aggregate measure or proxy for community SES (Gasparini et al., 2011; Krüger & Formichella, 2012). When analyzing the trends of overweight and obesity according to the school, it is observed that all changes had occurred only in children who attended public schools (Orden et al., 2021). Such differential trend between public and private schools probably started during the last decade since it was not present in the previous surveys (Table 10.2).

Likewise, parental education was an inversely associated factor in childhood obesity, which confirms what it was reported in the adolescent population (EMSE, 2012). As it is illustrated in Fig. 10.6, both father's and mother's education levels had similar effects on BMI status in children, showing a strong association between overweight/obesity and SES: overweight and obesity increased significantly in the population of children whose parents had low or middle education level. In contrast, a leveling off was observed in children whose parents had higher education (Orden et al., 2019). Boys always showed a more accelerated increase in obesity and have higher rates of obesity than girls. However, no specific trends have been observed in relation to sex as they have been observed in other studies probably because sex

Table 10.2 Trend in overweight and obesity according to SES measured by type of school

	Survey year				Increase / decade (%)	
Nutritional status	1990	2005/07	2015/16	*p-trend*[a]	1990–2005/07	2005/07–2015/16
Overweight						
Public schools	13.0	17.4	20.4	<0.01	2.5	3.3
Private schools	13.1	17.3	16.7	n.s.	2.5	−0.1
p-value[b]	0.968	0.567	0.946			
Obesity						
Public schools	1.9	7.5	14.1	<0.001	3.4	7.4
Private schools	1.5	3.0	2.8	n.s.	2.4	−0.1
p-value[b]	0.787	0.156	<0.0001			

Source: Orden et al. (2021)
ns non-significant
[a]Comparison among the three surveys
[b]Comparison between schools by survey year

patterns are associated with fashions, body image and cultural perceptions, particularly among adolescents (Sigmund et al., 2018; Sundblom et al., 2008).

Several studies have described a change in the relationship between SES and obesity as well a widening of the social gap in child obesity (Stamatakis et al., 2010; Bamann et al., 2013; Miqueleiz et al., 2014; Hardy et al., 2017; Bann et al., 2018). A similar process may occur in Argentina in which increase in obesity prevalence has occurred together with an increase in income disparities, and therefore, there is differential access to healthy foods (Viego et al., 2017). Accordingly, stabilization of obesity in low-income children would not be expected until SES disparities decrease.

10.5 Some Conclusions and Perspectives

While in the early 1980s, Argentina returned to democracy, the 1990s were marked by major economic reforms. At the beginning of the 1990s, Argentina embraced a comprehensive economic reform. In addition to "dollarization", it included a massive privatization of public utilities, deep trade and financial expansion and deregulation of domestic markets (Frenkel, 2002). Despite stop-and-go cycles, the economic course during the 1990s opened to foreign capital influx and new markets for consumer goods and services became accessible to a large proportion of the population. Thus, living conditions changed as well as lifestyle and consumption patterns. Since then, several wealth indicators improved, and transformed the demographic and epidemiological characteristics of the country. Advances in political freedoms and the conquest of social rights have been increasingly important, but successive economic crisis after 2001 have progressively deteriorated the living standards of the population. Consequently, almost 40 years of democracy have not brought substantial improvements in biological indicators for the entire population.

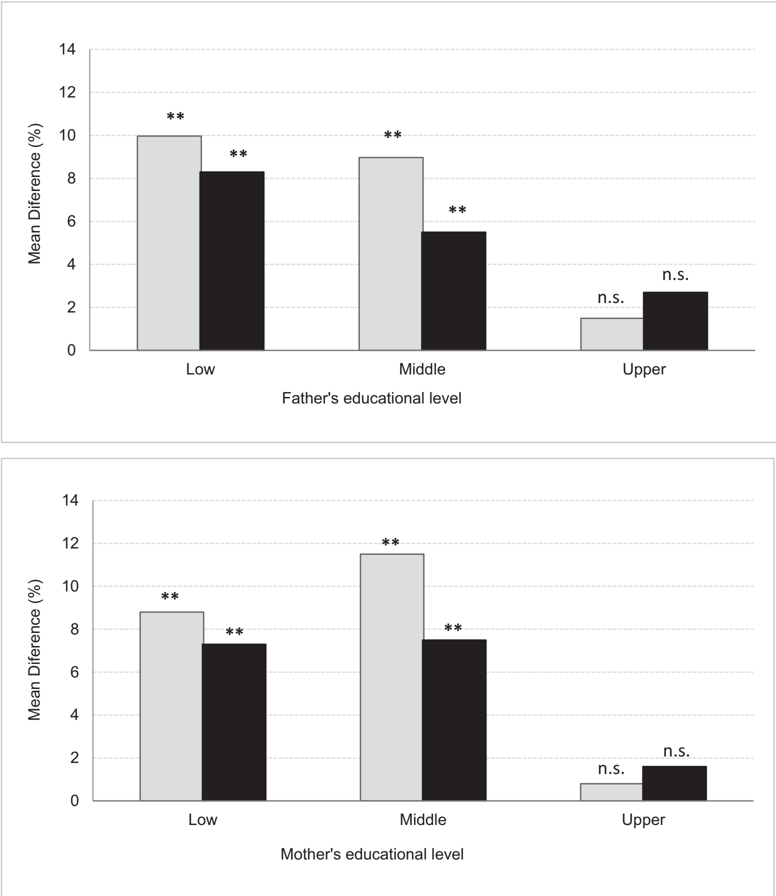

Fig. 10.6 Trend in overweight and obesity by SES defined by parental educational level. Bars represent mean differences (2015/16–2005/07) in overweight (grey) and obesity (black). Data of parental education are no available for 1990. $**p < 0.01$; n.s.: non-significant

This is clearly reflected in the child growth patterns, whose secular trend has been almost null in the period, despite height of children of wealthy families was like Spanish and Italian age-peers and reaches the values of the US child growth reference.

Although changes in final height are negligible, there has been a secular acceleration in pre-pubertal ages in both boys and girls. This acceleration explains that prior to puberty, these children reach a higher percentage of adult height than their age-peers of the Argentinian growth reference, born in the 60s. There is no data on sexual maturation milestones to suggest an earlier puberty. On the other hand, the secular acceleration of growth is likely associated with increasing childhood obesity. Argentina, like other countries in the region, has suffered a rapid transitional process and a current socioeconomic distribution, which emulates that observed in developed countries.

The association between SES and obesity also confirms the findings obtained in Argentinian adults (De Maio et al., 2009; Fleischer et al., 2011; Christine et al., 2014). All these studies coincide on the importance of formal schooling as a predictor of obesity and chronic non-communicable diseases, even after controlling for other independent variables. In addition to the transversal associations, the results presented show an evolution of this association, in which childhood overweigh and obesity are still increasing in Argentinian low SES children and level off in high SES children. The stagnation of obesity trends in high SES children during the last decade allows us to speculate that socioeconomic gap began by the mid-2000s. Thus, the stage of healthy behavior in the nutritional transition model seems to be reached only by a part of the population whose access to better living standards is probably mediated by their higher educational level. These findings suggest that measures of educational attainment may offer the most appropriate means to investigate social inequalities in health in Latin American countries, even more in Argentina (Jiwani et al., 2019; Mazariegos et al., 2021).

Trends in BMI have harmed health, given the increase in obesity in the schoolchildren. The emergence of the SARS-CoV-2 pandemic has caused countless social, economic, and psychological changes, which significantly altered work and social life, and daily routines. Indeed, recent studies have shown that the confinement of children and adolescents is harmful to health, negatively affecting eating habits and physical activity (Nagata et al., 2020; Ruíz-Roso et al., 2020). Therefore, potential health-related impacts should be considered in the post-pandemic period. It is not known with certainly if all these aforementioned effects will modify the obesity trends currently observed, but the serious economic consequences will surely have impacts that should be evaluated in future.

Acknowledgements This chapter and the research behind it would not have been possible without the support of parents, who accepted their children participate of every research project. The author is grateful to the authorities of the Ministry of Culture and Education of La Pampa and school authorities who authorized the activities at the schools, and especially to the teachers who facilitated the fieldwork. A special thanks to Maria E. Prieto Flores for her critical and constructive reading and to Sebastián Consoli for the final English edition.

References

Aeberli, I., Henschen, I., Molinari, L., & Zimmermann, M. B. (2010). Stabilization of the prevalence of childhood obesity in Switzerland. *Swiss Medical Weekly, 140*, w13046. https://doi.org/10.4414/smw.2010.13046

Ahluwalia, N., Dalmasso, P., Rasmussen, M., et al. (2015). Trends in overweight prevalence among 11-, 13- and 15-year-olds in 25 countries in Europe, Canada and USA from 2002 to 2010. *European Journal of Public Health, 25*, 28–32. https://doi.org/10.1093/eurpub/ckv016

Bammann, K., Gwozdz, W., Lanfer, A., et al. (2013). Socioeconomic factors and childhood overweight in Europe: Results from the multicentre IDEFICS study. *Pediatric Obesity, 8*, 1–12. https://doi.org/10.1111/j.2047-6310.2012.00075.x

Bann, D., Johnson, W., Li, L., Kuh, D., & Hardy, R. (2018). Socioeconomic inequalities in childhood and adolescent body-mass index, weight, and height from 1953 to 2015: An analysis of four longitudinal, observational, British birth cohort studies. *The Lancet Public Health, 3*, e194–e203. https://doi.org/10.1016/S2468-2667(18)30045-8

Bodzsár, É. B., Zsákai, A., & Mascie Taylor, N. (2016). Secular growth and maturation changes in Hungary in relation to socioeconomic and demographic changes. *Journal of Biosocial Science, 48*, 158–173. https://doi.org/10.1017/S0021932015000061

Cacciari, E., Milani, S., Balsamo, A., et al. (2002). Italian cross-sectional growth charts for height, weight and BMI (6–20 y). *European Journal of Clinical Nutrition, 56*, 171–180. https://doi.org/10.1038/sj.ejcn.1601314

Carrascosa A, Fernández JM, Fernández M, López-Siguero JP, López D, Sánchez E, y Grupo Colaborador. *Estudios españoles de crecimiento 2010*. Available at: http://www.aeped.es/noticias/estudios-espanoles-crecimiento-2010. Retrieved on 20 August 2021

Castilho, L. V., & Lahr, M. M. (2001). Secular trends in growth among urban Brazilian children of European descent. *Annals of Human Biology, 28*, 564–574. https://doi.org/10.1080/03014460110045146

Christine, P. J., Diez Roux, A. V., Wing, J. J., Alazraqui, M., & Spinelli, H. (2015). Temporal trends in BMI in Argentina by socio-economic position and province-level economic development. *Public Health Nutrition, 18*, 817–826. https://doi.org/10.1017/S1368980014001694

Cole, T. J. (2003). The secular trend in human physical growth: A biological view. *Economics and Human Biology, 1*, 161–168. https://doi.org/10.1016/S1570-677X(02)00033-3

Cole, T. J., & Lobstein, T. (2012). Extended international (IOTF) body mass index cut-offs for thinness, overweight and obesity. *Pediatric Obesity, 7*, 284–294. https://doi.org/10.1111/j.2047-6310.2012.00064.x

Corvalán, C., Garmendia, M. L., Jones-Smith, J., et al. (2017). Nutrition status of children in Latin America. *Obesity Reviews, 18*(Suppl 2), 7–18. https://doi.org/10.1111/obr.12571

De Maio, F. G., Linetzky, B., & Virgolini, M. (2009). An average/deprivation/inequality (ADI) analysis of chronic disease outcomes and risk factors in Argentina. *Population Health Metrics, 7*, 8. https://doi.org/10.1186/1478-7954-7-8

de Onis, M., Onyango, A. W., Borghi, E., Siyam, A., Nishida, C., & Siekmann, J. (2007). Development of a WHO growth reference for school-aged children and adolescents. *Bulletin of the World Health Organization, 85*, 660–667. https://doi.org/10.2471/blt.07.043497

de Wilde, J. A., Verkerk, P. H., & Middelkoop, B. J. (2014). Declining and stabilizing trends in prevalence of overweight and obesity in Dutch, Turkish, Moroccan and South Asian children 3–16 years of age between 1999 and 2011 in The Netherlands. *Archives of Disease in Childhood, 99*, 46–51. https://doi.org/10.1136/archdischild-2013-304222

del Pino, M., Bay, L., Lejarraga, H., Kovalkys, I., Berner, E., & Rausch Herscovici, C. (2005). Peso y estatura de una muestra nacional de 1971 adolescentes de 10 a 19 años: Las referencias argentinas continúan vigentes. *Archivos Argentinos de Pediatría, 103*, 323–330.

del Pino, M., de Olivera, N., & Lejarraga, H. (2003). Vigencia de los estándares nacionales de peso y estatura de 0 a 5 años. *Archivos Argentinos de Pediatría, 101*, 351–356.

EMSE. (2012). *Argentina*. Ministerio de Salud de la Nación. Organización Mundial de la Salud (OPS/OMS). Available at: http://www.msal.gob.ar/ent/images/stories/vigilancia/pdf/2014-09_informe-EMSE-2012.pdf. Retrieved on 28 July, 2021

Fleischer, N. L., Diez Roux, A. V., Alazraqui, M., Spinelli, H., & De Maio, F. (2011). Socioeconomic gradients in chronic disease risk factors in middle-income countries: Evidence of effect modification by urbanicity in Argentina. *American Journal of Public Health, 101*, 294–301. https://doi.org/10.2105/AJPH.2009.190165

Fogel, R. W. (1986). Physical growth as a measure of economic well-being of populations: The eighteen and nineteenth centuries. In F. Faulkner & J. M. Tanner (Eds.), *Human growth* (pp. 263–281). Plenum Press.

Frenk, J., Frejka, T., Bobadilla, J. L., et al. (1991). La transición epidemiológica en América Latina. *Boletín de la Oficina Sanitaria Panamericana, 111*, 485–496.

Frenkel, R. (2002). Capital market liberalization and economic performance in Latin America. In J. Eatwell & L. Taylor (Eds.), *International capital markets. Systems in transition* (pp. 255–276). Oxford University Press.

Fudvoye, J., & Parent, A. S. (2017). Secular trends in growth. *Annales d'Endocrinologie, 78*, 88–91. https://doi.org/10.1016/j.ando.2017.04.003

Gasparini, L., Jaume, D., Serio, M., & Vazquez, E. (2011). La segregación entre escuelas públicas y privadas en Argentina. Reconstruyendo la evidencia. *Desarrollo Económico, 51*, 189–219.

Gomula, A., Nowak-Szczepanska, N., Hermanussen, M., Scheffler, C., & Koziel, S. (2020). Trends in growth and developmental tempo in boys aged 7 to 18 years between 1966 and 2012 in Poland. *American Journal of Human Biology, 2021, 33*(6), e23548. https://doi.org/10.1002/ajhb.23548

Hardy, L. L., Mihrshahi, S., Gale, J., Drayton, B. A., Bauman, A., & Mitchell, J. (2017). 30-year trends in overweight, obesity and waist-to-height ratio by socioeconomic status in Australian children, 1985 to 2015. *International Journal of Obesity, 41*, 76–82. https://doi.org/10.1038/ijo.2016.204

Hauspie, R., & Vercauteren, M. (2004). Secular trend. In I. Nicoletti, L. Benso, & G. Gilli (Eds.), *Physiological and pathological auxology* (pp. 543–552). Firenze.

Hauspie, R. C., Vercauteren, M., & Susanne, C. (1997). Secular changes in growth and maturation: An update. *Acta Paediatrica, 86*(S423), 20–27. https://doi.org/10.1111/j.1651-2227.1997.tb18364.x

Hermanussen, M., & Bogin, B. (2014). Auxology -an editorial. *Italian Journal of Pediatrics, 40*, 8. https://doi.org/10.1186/1824-7288-40-8

Hermanussen, M., Bogin, B., & Scheffler, C. (2019). The impact of social identity and social dominance on the regulation of human growth: A viewpoint. *Acta Paediatrica, 108*, 2132–2134. https://doi.org/10.1111/apa.14970

Hernández-Cordero, S., Cuevas-Nasu, L., Morales-Ruán, M. C., et al. (2017). Overweight and obesity in Mexican children and adolescents during the last 25 years. *Nutrition & Diabetes, 7*, e247. https://doi.org/10.1038/nutd.2016.52

Jiwani, S. S., Carrillo-Larco, R. M., Hernández-Vásquez, A., et al. (2019). The shift of obesity burden by socioeconomic status between 1998 and 2017 in Latin America and the Caribbean: A cross-sectional series study. *The Lancet Global Health, 7*, e1644–e1654. https://doi.org/10.1016/S2214-109X(19)30421-8

Khadilkar, V. V., Khadilkar, A. V., Cole, J. T., & Sayyad, M. G. (2009). Cross-sectional growth curves for height, weight and body mass index for affluent Indian children, 2007. *Indian Pediatrics, 46*, 477–489.

Komlos, J. (1994). *Stature, living standard, and economic development. Essays in anthropometric history*. The University of Chicago Press.

Krüger, N., & Formichella, M. M. (2012). Escuela pública y privada en Argentina: Una comparación de las condiciones de escolarización en el nivel medio. *Perspectivas, 6*, 113–144.

Kulaga, Z., Litwin, M., Tkaczyk, M., et al. (2010). The height-, weight-, and BMI-for-age of Polish school-aged children and adolescents relative to international and local growth references. *BMC Public Health, 10*, 109. https://doi.org/10.1186/1471-2458-10-109

Lazzeri, G., Panatto, D., Pammolli, A., et al. (2015). Trends in overweight and obesity prevalence in Tuscan schoolchildren (2002–2012). *Public Health Nutrition, 18*, 3078–3085. https://doi.org/10.1017/S1368980015001676

Lejarraga, H. (2007). Consideraciones sobre el uso de tablas de crecimiento en la Argentina. *Archivos Argentinos de Pediatría, 105*, 545–551.

Lejarraga, H., del Pino, M., Fano, V., Caino, S., & Cole, T. J. (2009). Referencias de peso y estatura desde el nacimiento hasta la madurez para niñas y niños argentinos. Incorporación de datos de la OMS de 0 a 2 años, recálculo de percentilos para obtención de valores LMS. *Archivos Argentinos de Pediatría, 107*, 126–133. https://doi.org/10.1590/S0325-00752009000200006

Malina, R. M., Little, B. B., & Peña Reyes, M. E. (2018). Secular trends are associated with the demographic and epidemiologic transitions in an indigenous community in Oaxaca, Southern Mexico. *American Journal of Physical Anthropology, 165*, 47–64. https://doi.org/10.1002/ajpa.23326

Mazariegos, M., Auchincloss, A. H., Braverman-Bronstein, A., et al. (2021). Educational inequalities in obesity: A multilevel analysis of survey data from cities in Latin America. *Public Health Nutrition, 25*, 1–9. https://doi.org/10.1017/S1368980021002457

Meisel-Roca, A., & Granger, A. (2021). The height of children and adolescents in Colombia. A review of more than sixty years of anthropometric studies, 1957–2020. *International Journal of Environmental Research and Public Health, 18*, 8868. https://doi.org/10.3390/ijerph18168868

Miqueleiz, E., Lostao, L., Ortega, P., Santos, J. M., Astasio, P., & Regidor, E. (2014). Trends in the prevalence of childhood overweight and obesity according to socioeconomic status: Spain, 1987–2007. *European Journal of Clinical Nutrition, 68*, 209–214. https://doi.org/10.1038/ejcn.2013.255

Nagata, J. M., Abdel Magid, H. S., & Pettee Gabriel, K. (2020). Screen time for children and adolescents during the coronavirus disease 2019 pandemic. *Obesity, 28*, 1582–1583. https://doi.org/10.1002/oby.22917

Ng, M., Fleming, T., Robinson, M., et al. (2014). Global, regional, and national prevalence of overweight and obesity in children and adults during 1980–2013: A systematic analysis for the global burden of disease study 2013. *Lancet, 384*, 766–781. https://doi.org/10.1016/S0140-6736(14)60460-8

Núñez, J., & Pérez, G. (2015). Trends in physical stature across socioeconomic groups of Chilean boys, 1880–1997. *Economics and Human Biology, 16*, 100–114. https://doi.org/10.1016/j.ehb.2013.12.008

Ogden, C. L., Carroll, M. D., Kit, B. K., & Flegal, K. M. (2014). Prevalence of childhood and adult obesity in the United States, 2011–2012. *JAMA, 311*, 806–814. https://doi.org/10.1001/jama.2014.732

Ohlsson, C., Bygdell, M., Celind, J., Sondén, A., Tidblad, A., Sävendahl, L., & Kindblom, J. M. (2019). Secular trends in pubertal growth acceleration in Swedish boys born from 1947 to 1996. *JAMA Pediatrics, 173*, 860–865. https://doi.org/10.1001/jamapediatrics.2019.2315

Olds, T., Maher, C., Zumin, S., et al. (2011). Evidence that the prevalence of childhood overweight is plateauing: Data from nine countries. *International Journal of Pediatric Obesity, 6*, 342–360. https://doi.org/10.3109/17477166.2011.605895

Olds, T. S., Tomkinson, G. R., Ferrar, K. E., & Maher, C. A. (2010). Trends in the prevalence of childhood overweight and obesity in Australia between 1985 and 2008. *International Journal of Obesity, 34*, 57–66. https://doi.org/10.1038/ijo.2009.211

Orden, A. B. (2012). Evaluación del crecimiento físico en adolescentes de Argentina: Instrumentos y reflexiones. In D. Turbón, L. Fañanas, C. Rissech, & A. Rosa (Eds.), *Biodiversidad Humana y Evolución* (pp. 83–87). Universitat Autónoma de Barcelona.

Orden, A. B., & Apezteguía, M. C. (2016). Weight and height centiles of *Argentinian* children and adolescents: A comparison with WHO and national growth references. *Annals of Human Biology, 43*, 9–17. https://doi.org/10.3109/03014460.2014.970576

Orden, A. B., Apezteguía, M. C., & Mayer, M. A. (2021). Aceleración y estabilización: Disparidad en la tendencia de obesidad en escolares de La Pampa entre 1990 y 2016. *Revista Argentina de Antropología Biológica, 23*, 1–10. https://doi.org/10.24215/18536387e028

Orden, A. B., Bucci, P. J., & Petrone, S. (2013). Trends in weight, height, BMI and obesity in schoolchildren from Santa Rosa (Argentina), 1990–2005/07. *Annals of Human Biology, 40*, 348–354. https://doi.org/10.3109/03014460.2013.778329

Orden, A. B., Lamarque, M. S., & Apezteguía, M. C. (2019). Trend in childhood obesity reflects socioeconomic status in Argentina. *Annals of Human Biology, 46*, 531–536. https://doi.org/10.1080/03014460.2019.1694070

Orden, A. B., Torres, M. F., Castro, L., et al. (2009). Physical growth in schoolchildren from Argentina: Comparison with Argentinean and CDC/NCHs growth references. *American Journal of Human Biology, 21*, 312–318. https://doi.org/10.1002/ajhb.20861

Popkin, B. M. (2002). An overview on the nutrition transition and its health implications: The Bellagio meeting. *Public Health Nutrition, 5*, 93–103. https://doi.org/10.1079/phn2001280

Popkin, B. M., & Reardon, T. (2018). Obesity and the food system transformation in Latin America. *Obesity Reviews, 19*, 1028–1064. https://doi.org/10.1111/obr.12694

Redlefsen, T., Commentz, J., Meigen, C., & Hermanussen, M. (2007). Reference values for height, weight and body mass index of German born Turkish children. *Anthropologischer Anzeiger, 65*, 263–274.

Rivera, J. A., de Cossío, T. G., Pedraza, L. S., Aburto, T. C., Sánchez, T. G., & Martorell, R. (2014). Childhood and adolescent overweight and obesity in Latin America: A systematic review. *The Lancet Diabetes and Endocrinology, 2*, 321–332. https://doi.org/10.1016/S2213-8587(13)70173-6

Rokholm, B., Baker, J. L., & Sorensen, T. I. (2010). The levelling off of the obesity epidemic since the year 1999—A review of evidence and perspectives. *Obesity Reviews, 11*, 835–846. https://doi.org/10.1111/j.1467-789X.2010.00810.x

Ruíz-Roso, M. B., de Carvalho, P. P., Matilla-Escalante, D. C., et al. (2020). Changes of physical activity and ultra-processed food consumption in adolescents from different countries during Covid-19 pandemic: An observational study. *Nutrients, 12*, 2289. https://doi.org/10.3390/nu12082289

Salvatore, R., Coatsworth, J., & Challu, A. (2010). Introduction. In R. D. Salvatore, J. H. Coatsworth, & A. E. Challu (Eds.), *Living standards in Latin American history. Heights, welfare, and development, 1750–2000* (pp. 1–21). Harvard University Press.

Sigmund, E., Badura, P., Sigmundová, D., et al. (2018). Trends and correlates of overweight/obesity in Czech adolescents in relation to family socioeconomic status over a 12-year study period (2002–2014). *BMC Public Health, 18*, 122. https://doi.org/10.1186/s12889-017-5013-1

Stamatakis, E., Wardle, J., & Cole, T. J. (2010). Childhood obesity and overweight prevalence trends in England: Evidence for growing socioeconomic disparities. *International Journal of Obesity, 34*, 41–47. https://doi.org/10.1038/ijo.2009.217

Steckel, R. (1995). The stature and the standard of living. *Journal of Economic Literature, 33*, 1903–1940.

Subramanian, S. V., Özaltin, E., & Finlay, J. E. (2011). Height of nations: A socioeconomic analysis of cohort differences and patterns among women in 54 low to middle-income countries. *PLoS One, 6*, e18962. https://doi.org/10.1371/journal.pone.0018962

Sundblom, E., Petzold, M., Rasmussen, F., Callmer, E., & Lissner, L. (2008). Childhood overweight and obesity prevalences levelling off in Stockholm but socioeconomic differences persist. *International Journal of Obesity, 32*, 1525–1530. https://doi.org/10.1038/ijo.2008.104

Tanner, J. M. (1986). Growth as a mirror of the condition of society; secular trends, and class distinctions. In M. B. Dubuc & A. Demirdjian (Eds.), *Human growth: A multidisciplinary review* (pp. 3–34). Taylor and Francis.

Ulijaszek, S. J., Pentecost, M., Marcus, C., Karpe, F., Frühbeck, G., & Nowicka, P. (2017). Inequality and childhood overweight and obesity: A commentary. *Pediatric Obesity, 12*, 195–202. https://doi.org/10.1111/ijpo.12128

Viego, V., Temporelli, K., Cattáneo, C.A., Merino, C., & Miotto, C. (2017). Costs of healthy and unhealthy food in Argentina: 2002–2015. *Applied Food Science Journal, 1*, 4–5.

Woronkowicz, A., Cichocka, B. A., Kowal, M., Kryst, L., & Sobiecki, J. (2012). Physical development of girls from Krakow in the aspect of socioeconomical changes in Poland (1938–2010). *American Journal of Human Biology, 24*, 626–632. https://doi.org/10.1002/ajhb.22283

Zong, X. N., & Li, H. (2013). Construction of a new growth references for China based on urban Chinese children: Comparison with the WHO growth standards. *PLoS One, 8*, e59569. https://doi.org/10.1371/journal.pone.0059569

Chapter 11
Changes on Nutritional Status and Urbanization in a Northeastern Patagonian City. A Brief Secular Trend Story of the School Children from Puerto Madryn in Chubut, Argentina

Bárbara Navazo and Silvia Lucrecia Dahinten

11.1 Introduction

> Growth is a mirror of the condition of society…. (Tanner, 1987)

Biological anthropology studies all the processes that contribute to human population variation as product of the dynamic-systemic interaction between their intrinsic variability and environmental conditions (Pucciarelli, 1989). One of the topics addressed in this discipline is human growth, which constitutes a dynamic and continuous process, determined by heredity, and modulated by the environment, during which an individual increases in size, and modifies their body proportions and composition (Hernández Rodríguez, 2007). Adverse environmental conditions prolonged in time may have negative impacts on physical growth and development, particularly in early childhood. Among the factors that condition these processes, nutritional ones stand out for their importance. This is due to the fact that a healthy diet encourages the proper balance between incorporation of nutrients, and their use by the organism (Pellegrini & Battistini, 2015). On the contrary, when there is an imbalance between energy intake and expenditure, growth and nutritional status may be altered. The term malnutrition is used to refer both deficit (stunting or low

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S. Datta Banik (ed.), *Human Growth and Nutrition in Latin American and Caribbean Countries*, https://doi.org/10.1007/978-3-031-27848-8_11

height-for-age, wasting or low weight-for-height, underweight or low weight-for-age), and excess (overweight and obesity) (WHO, 2020). Both types of malnutrition affect individual's health and can be irreversible when they occur during the growth and development of individuals. Thereby, child malnutrition constitutes an important determinant of human potential, since it compromises aspects of cognitive and psycho-emotional development, with an effect on educational and work trajectories that have long-term negative impacts on economic productivity and human capital of a country (Longhi et al., 2022; Swinburn et al., 2019). Despite both extremes of malnutrition were analyzed separately, studies such as those by Doak et al. (2005) and Wells et al. (2020) showed their co-existence within communities, families, and even individuals, such as those who are both stunted and overweight. This scenario, which is more frequently found in low- and middle-income countries, represents a nutrition paradox known as the double burden of malnutrition, since it refers to the coexistence of undernutrition and excess weight as mentioned above (Borda Pérez, 2007; Popkin et al., 2020). In relation to this and according to the latest report on food and nutritional security in Latin America and the Caribbean, between 1990 and 2018 stunting in girls and boys under 5 years of age decreased by 13.8% in the region. On the other hand, overweight increased by 1.3% during this period, such that 4 million children in the region presented this condition (FAO et al., 2019).

The simultaneous manifestation of nutritional problems of a different nature is associated with the nutrition transition, characterized by diets with a higher consumption of sugars, fats and/or sodium, abundant in ultra-processed and hypercaloric foods (FAO et al., 2019). The general concept of nutrition transition is that in each region of the world (not only countries but subregions within countries), a transformation in the way that people eat, drink, and move at work, at home, in transport, and spend leisure time have affected the body composition characteristics and created nutritional and health-related problems (Popkin, 2002; Popkin et al., 2012). The transition has produced remarkable shifts in physical activity and diets in low- and middle-income countries and a rapid increase in overweight, obesity, and nutrition-related non communicable diseases (Ng et al., 2012; Ng & Popkin, 2012).

At this point, it should be mentioned that people's nutritional status is closely linked to a process known as a secular trend. This is understood as a change in the average size or in the shape of the individuals of a population from one generation to the next (Bogin, 2021). Therefore, while food restrictions delay individual's growth and maturation, an adequate diet allows their maximum genetic expression (Marrodán Serrano, 2000). In this regard, there is evidence about the influence that the consumption of animal protein has had on secular change. An example is the study carried out by Takahashi (1984) in Japan, in which he suggested that a reduction in rice intake and an increase of meat and milk consumption, occurred between the 1950s and 1960s, could have contributed to the increase in children's height. Likewise, other studies have provided evidence about morphological variations occurred over time in adult human populations. Research carried out in the south of Argentina such as those of Cobos et al. (2014) and Millán et al. (2013) contributed to the characterization of the resident groups from the Patagonia region. Also, in relation to the secular trend described above, the studies made by Dahinten et al. (2009, 2013), based on historical records, showed height variation among males born between 1909 and 1949 enrolled in the Military District of Chubut. According to the authors, during the time period considered, male height registered a secular increase of 4.1 cm, mainly caused by better quality of life.

11.2 A Brief Story of the Human Growth Studies in Puerto Madryn

Despite the existence of studies on different anthropometric characteristics in adults from Patagonia, by the end of the 1990s, little was known about the child and youth populations of the area. Because of this paucity of information, since the beginning of twenty-first century, biological anthropology team of the *Instituto de Diversidad y Evolución Austral* (IDEAus CENPAT-CONICET) have been studying themes like growth pattern, nutritional status, and body composition characteristics of the inhabitants of the northeast of Chubut. Between 2001 and 2006, studies were carried out in the department of Biedma through the PROBIEDMA project. Anthropometric surveys were done among school children, and the most important data set was collected in Puerto Madryn (Botterón et al., 2003; Dahinten et al., 2005; Peralta, 2002).

The studies reported the presence of stunting and overweight in the child and youth populations, possibly related to the fact that since 2009, a decline in economic well-being was observed in Puerto Madryn due to the deterioration of the level of industrialization achieved in previous decades (Donato, 2011). This cyclical variation in the economic development of the city could have repercussions on the well-being of its inhabitants and even more so on children, promoting secular changes. The lack of information referring to the biological variations associated with these processes and in particular about the secular trend, motivated the team to undertake new surveys. Therefore, the IDEAus team started to co-work with the *Laboratorio de Investigaciones en Ontogenia y Adaptación* (LINOA UNLP, CONICET), comparing the results obtained in Puerto Madryn with others from different parts of Argentina (Dahinten et al., 2011; Oyhenart et al., 2008, 2017). Also, both teams carried out projects supported by the *Agencia Nacional de Promoción Científica y Tecnológica* (ANPCyT) (PICT N°1145) and the *Consejo Nacional de Investigaciones Científicas y Técnicas* (CONICET) (PIP N° 0106). Within the framework of the aforementioned projects, Navazo's doctoral thesis (2019) was carried out.

The fact of having different anthropometric data sets of school children residing in Puerto Madryn, where most of the population of the northeast of Chubut is concentrated, allowed to evaluate the changes in nutritional status of children after the first decade of the XXI century.

11.3 Subjects and Methods

Study Area: Regional Scale, the Patagonia

The name "Patagonia" traditionally alluded to the southernmost lands of the Argentine territory, characterized by the dominance of landscapes in which natural elements prevailed over those built by human groups (Kloster, 2008). Starting in the sixteenth century, Patagonia was considered a strategic maritime transit zone and the southernmost point where to replenish supplies before the passage to the Pacific Ocean (Navarro Floria, 1999). Since middle of the nineteenth century, different groups of European settlers dedicated to cattle farming, arrived in a large part of the Patagonian territory (Bandieri, 2005). In relation to this, one of the most significant undertakings for the region was the project to build a railway line in the Lower Valley of the Chubut River, which began to take shape in the 1880s (Schlüter, 1996). It represented the consolidation of Argentine dominance in the area because the railways acted as a social and economic catalyst for all the population centres that it crossed (Navarro Floria, 1999).

Among the peculiarities of the Patagonian region, it can be mentioned that human populations are concentrated mainly along the Atlantic coast and the Andes. In addition, the provinces that comprise it present a constant and significant population increase. According to Kloster (2001), while in Argentina the average annual growth rate was decelerating from 1947 until the beginning of the twenty-first century, in Patagonia the growth rates were above the national average. Thus, since the 1950s, the main urban centres of the Patagonian region recorded a significant population increase, for having Puerto Madryn, in the department of Biedma, province of Chubut, one of the best-known cases.

Study Area: Local Scale, the City of Puerto Madryn

The city of Puerto Madryn is located in the northeast of the Patagonian region, on the Golfo Nuevo's south-western coast where climate is semi-arid steppe, with little precipitation distributed regularly throughout the year, and annual average temperatures do not exceed 15 °C (Frumento & Contrera de Davies, 2017). Its foundation in 1865 was linked to the arrival to the gulf of the first contingent of migrants from Wales, United Kingdom. With the beginning of the construction of railways that connected the Welsh colony with the gulf in 1886, the first more or less stable population settlement emerged in the current location of the city. Almost a century later, it began a transformation process fostered by the installation of the Aluar aluminum production plant (*Aluminio Argentino S.A.*). Thus, since 1970, large numbers of people came to the area attracted by the new economic conditions and the prospects for personal improvement.

According to Kaminker and Velásquez (2015), between the end of that decade and the beginning of the next one, the construction of an industrial port made it possible to attract large number of fishing companies. Also, the porphyry and construction industry increased the labour demand. Tourism was also important, because the activity was institutionalized as an international attraction after the Declaration of *Peninsula de Valdés* as a Natural Heritage of Humanity by UNESCO in 1999.

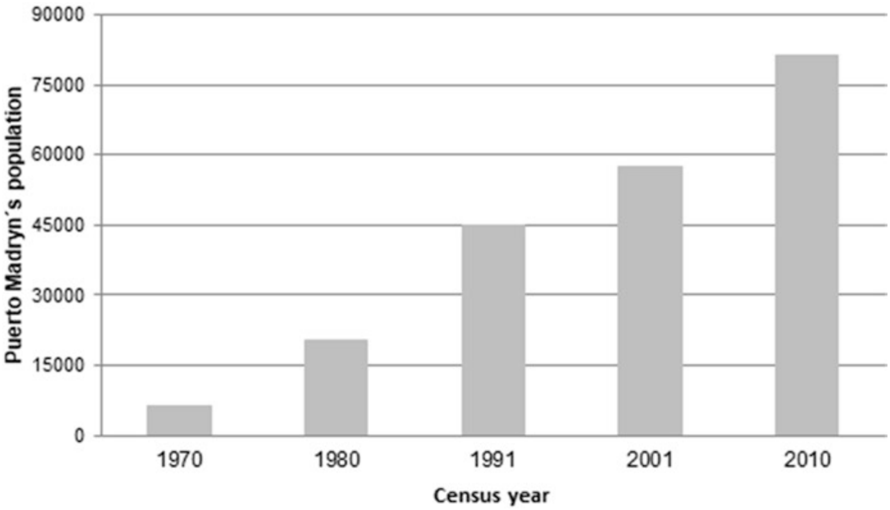

Fig. 11.1 Demographic evolution of Puerto Madryn (1970–2010)

Regarding the demographic changes of Puerto Madryn, according to the results of the national census surveys carried out between 1970 and 2010, the number of inhabitants increased thirteen times, from six thousand people to around eighty-two thousand, consolidating as one of the most important urban centres in the province of Chubut and the Patagonian region (Kaminker & Ortiz-Camargo, 2016) (Fig. 11.1).

Sample

To evaluate changes in nutritional status of school children during a decade, two groups (G) of 6- to 14-year-old boys and girls were selected. The studies were cross-sectional in nature and were carried out in thirteen educational establishments, distributed in 11 neighbourhoods of Puerto Madryn (Table 11.1).

Prior authorization was obtained from the Ministry of Education of the province of Chubut, Puerto Madryn's *Subsecretaría de Educación* and the directors of each institution. The objectives of the study were explained clearly. The G1 surveyed in 2001–2006 included 3114 individuals (girls: 48.6%; boys: 51.4%); and G2 carried out in 2014–2016 recruited 2799 school children (girls: 51.2%; boys: 48.8%) (Fig. 11.2).

Anthropometric measurements were weight (kg) and height (cm). Body mass index (BMI) was calculated according to the formula: BMI = [(weight (kg)/height (m)^2]. Internationally standardized protocol was followed, and innocuous anthropometric techniques did not affect physical, mental and moral integrity of the school children (Lohman et al., 1988). Voluntary participation of minors required the written informed consent of one of their parents / guardians (Article 5 of the Regulatory Decree of National Law No. 25,326) before the commencement of the survey. Participants having chronic or acute diseases and/or taking medication at the time of the survey (according to evidence in institutional records), as well as the students

Table 11.1 Neighbourhoods where surveyed schools were located

Neighbourhoods	Location	School
Don Bosco	Northeast	Provincial n° 736
Julio Roca	Northeast	Provincial n° 49
Agustín Pujol I	Northwest	Municipal n° 1
Agustín Pujol II	Northwest	Provincial n° 219
Parry Madryn	Central east	Provinciales n° 84 and 710
Colonos Galeses	Central east	Mutualista
Conquistadores del Desierto	Central west	FAPE
Villa Padilla	Central west	Politécnico n° 703
Del Desembarco	Southeast	Provinciales n° 158 and 728
Gobernador Fontana	Southwest	Provincial n° 213
San Miguel	Southwest	Municipal n° 3

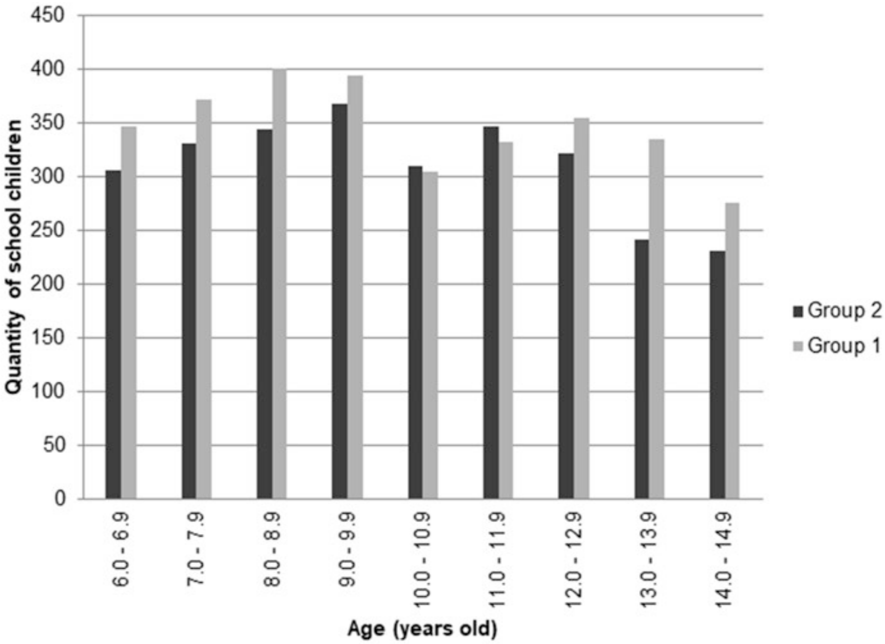

Fig. 11.2 Samples by age

who did not have written authorization from their parents/guardians (Article 5 of the Regulatory Decree of Law 25,326) and those who still had it but expressed their denial to participate, were excluded from the study.

Nutritional Status

Considering the age of each student, their weight, height and BMI, nutritional status was evaluated based on the National Health and Nutrition Examination Survey

Table 11.2 Cut-off points considered to determine nutritional status, according to NHANES III

Nutritional status	Cut-off points
Undernourished	< percentil 5
Overweight	≥ percentil 85; < percentil 95
Obesity	≥ percentil 95

(NHANES III) cut-off points (Frisancho, 2008). Table 11.2 shows the criteria to evaluate undernutrition (underweight, wasting and stunting), overweight, and obesity. Those school children who did not belong to any of these categories were classified as well-nourished.

Urbanization

National census data from 2001 to 2010 allowed describing the urbanization and changes that occurred in Puerto Madryn. This source of public secondary data allowed describing the number of inhabitants, variables referring to access to public services, employment situation of the adult population, illiteracy rate, health coverage, and critical crowding (INDEC, 2001, 2010).

Statistical Analysis

To understand the association of malnutrition with age, sex and group (G1, G2), binary logistic regression models were used. The prevalence for each indicator of nutritional status was calculated by group and compared by chi-square test (χ^2). For both statistical tests, the p-value used was set at $p \leq 0.05$. Data were analyzed using SPSS statistical program, version 20.0.

Ethical Considerations

The study was evaluated and approved by both the *Universidad Nacional de la Patagonia San Juan Bosco* and the *Universidad Nacional de La Plata*, as well as by the *Comité de Bioética de la Escuela Latinoamericana de Bioética*, based on the regulations established in the Helsinki Declaration, issued and updated by the World Medical Association (2013). In addition, the personal data of all participants were protected, in accordance with current bioethical regulations and regulations, strictly complying with Argentine National Law 25,326.

11.4 Results

The analysis of census data showed changes in the demography and the urbanization of Puerto Madryn. Between 2001 and 2010, population increased to 24,206 inhabitants. Also, the percentage of people employed registered an increment (near to 20%); the quantity of houses with septic tank (18% approximately), the pavement (17.5%), the illiteracy (almost 5%) and crowding (0.8%). Other parameters showed a decline, for example: waste collection and access to health insurance (Table 11.3).

Table 11.3 Socioeconomic characteristics of Puerto Madryn according to the last two censuses

Variable	2001 Census	2010 Census
Number of inhabitants	58,677	82,883
Work:		
Employed	48.00%	67.00%
Unemployed	17.00%	5.00%
Retired / pensioned	35.00%	28.00%
Illiteracy	2.06%	7.26%
Access to health insurance	39.31%	27.29%
Acceptable housing quality	89.00%	91.08%
Critical crowding = 3 or more people / bedroom	5.24%	6.00%
Street lighting	97.12%	94.59%
Pavement	53.12%	70.61%
Waste collection	97.92%	96.81%
Fuel (cooking/heating):		
Gas (piped)	93.07%	90.92%
Bottled gas (cylinder)	6.29%	8.63%
Electricity	No data	0.15%
Firewood	0.63%	0.30%
Drinking water (main source):		
Piped water system	98.70%	99.38%
Drilling well	0.09%	0.05%
Protected well	1.21%	0.58%
Wastewater disposal:		
Sewage system	69.30%	87.28%
Septic tank	30.70%	12.72%

Source: Own elaboration according to census data published by INDEC (2001, 2010)

Prevalence of nutritional status of school children showed that 70.6% of G1 and 60.1% in G2 were well-nourished. The difference found was statistically significant ($\chi^2 = 71.67$; $p < 0.001$). In the case of undernourished, prevalence in G1 was 6.4%, whereas in G2 was 5.2% ($\chi^2 = 3.70$; $p = 0.05$). On the other hand, ponderal excess passed from 23.0% in G1 to 34.7% in G2, being the difference was statistically significant ($\chi^2 = 98.92$; $p < 0.001$) (Fig. 11.3).

The comparison of nutritional status between groups indicated that the highest prevalence of wasting and stunting corresponded to G1. For its part, G2 presented higher values of underweight, overweight and obesity. Only in the last two mentioned were found statistically significant differences (overweight $\chi^2 = 8.70$; $p < 0.001$ and obesity $\chi^2 = 99.28$; $p < 0.001$) (Fig. 11.3).

Due to the significant differences found by age and sex, Figs. 11.4a and 11.4b show the differences of undernourished, stunting, ponderal excess, overweight and obesity in girls and boys of G1 and G2 by age. Both undernourished and stunting showed greatest differences between groups in boys at 9, 10 and 11 years, in the first two cases being G2 > G1 and in the remaining G1 > G2. Among girls, G2 was

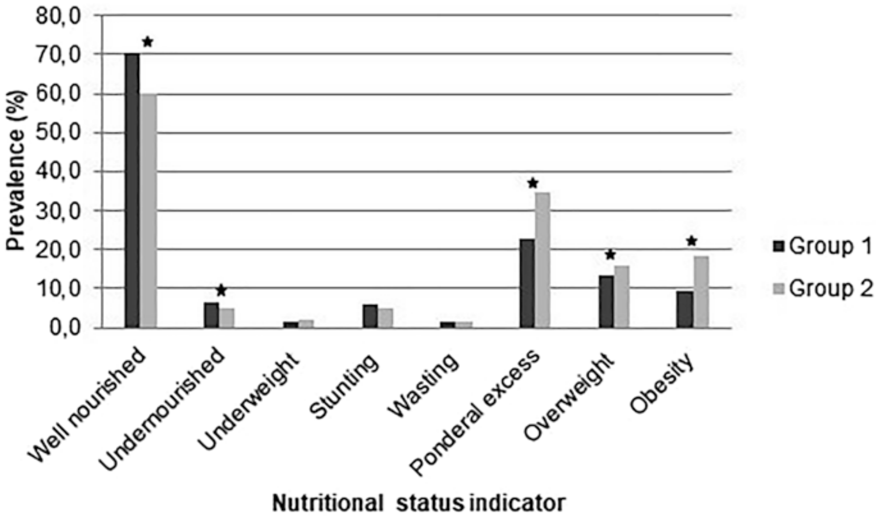

Fig. 11.3 Prevalence of nutritional status. Comparison between groups. Stars were placed where the comparison of nutritional status between groups showed statistically significant differences

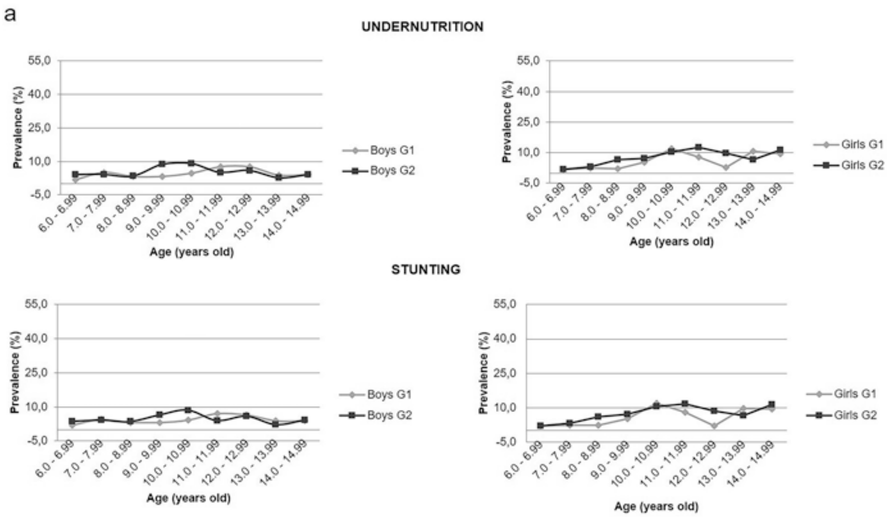

Fig. 11.4a Average prevalence of malnutrition by sex and age (malnutrition by deficiency)

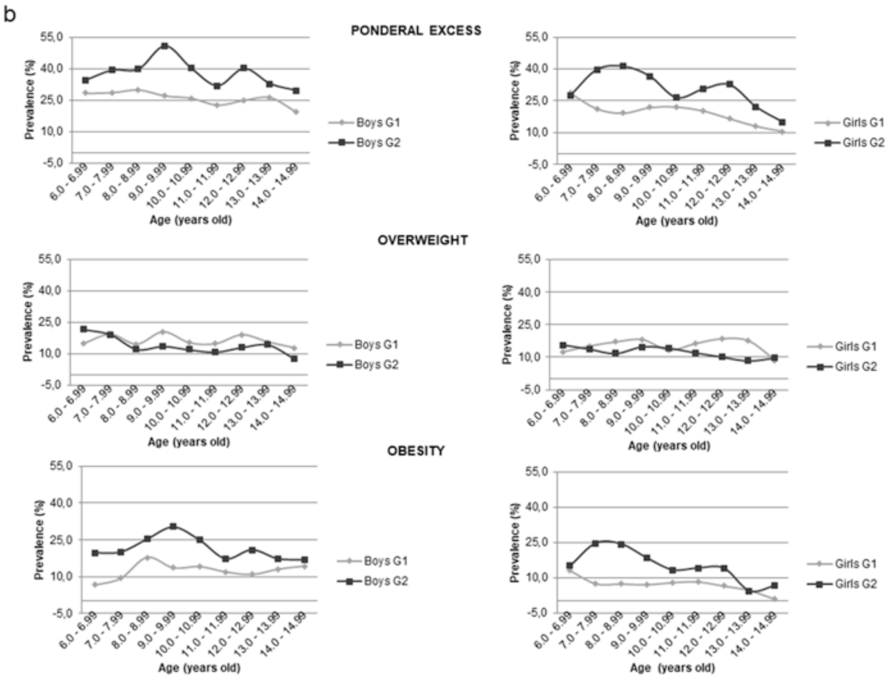

Fig. 11.4b Average prevalence of malnutrition by sex and age (malnutrition by excess)

visibly greater than G1 at the ages of 8, 11 and 12 years, while at 13 years, it was G1 which surpassed G2. As can be seen in Fig. 11.4b, in both sexes, the prevalence of excess weight of G2 was higher than that of G1 at all ages. On the other hand, in overweight, the highest prevalence was registered mainly in G1. Thus, among boys, the differences between groups were found at the ages of 6 (where G2 > G1), 9–12 and 14 years (where G1 > G2). Among girls, G1 surpassed G2 at the ages of 8, 9, 11–13 years. Finally, in the case of obesity, the situation registered was the opposite, being G2 the group that presented visibly higher prevalence. Among boys, differences were found between 6 and 13 years old, while in girls those were found between 7 and 12 years, as well as at 14 years.

The logistic regression model showed association of age, sex and groups (G1, G2) with nutritional status: undernourished, stunting, ponderal excess, overweight and obesity (Table 11.4).

11.5 Discussion

A distinctive feature of Argentina is its vast territorial extension. In this sense, the country occupies eighth place in the world ranking of the States with the largest surface area and the second position in Latin American countries, after Brazil

Table 11.4 Logistic regression model for malnutrition by age, sex, and group

Response variable	Predictors	Beta	Standard error	Wald coefficient	*p* values
Undernourished	Age	0.101	0.022	20.388	<0.0001
	Sex	0.333	0.112	8.803	0.003
	Group	0.216	0.113	3.694	0.055
Underweight	Age	0.070	0.062	1.279	0.258
	Sex	−0.285	0.313	0.830	0.362
	Group	−0.213	0.310	0.475	0.491
Stunting	Age	0.101	0.023	19.215	<0.0001
	Sex	0.399	0.116	11.804	0.001
	Group	0.191	0.116	2.737	0.098
Wasting	Age	0.098	0.087	1.270	0.260
	Sex	−0.469	0.450	1.085	0.298
	Group	0.365	0.450	0.657	0.418
Ponderal excess	Age	−0.067	0.012	33.163	<0.0001
	Sex	−0.335	0.059	32.662	<0.0001
	Group	−0.589	0.059	100.941	<0.0001
Overweight	Age	−0.048	0.015	10.683	0.001
	Sex	−0.111	0.074	2.289	0.130
	Group	−0.218	0.074	8.778	0.003
Obesity	Age	−0.064	0.015	17.423	<0.0001
	Sex	−0.453	0.077	34.587	<0.0001
	Group	−0.779	0.078	99.599	<0.0001

Source: Navazo (2019)

(argentina.gob.ar, 2021). Taking this particularity into account, Oyhenart et al. (2008) evaluated nutritional status of the child and youth populations residing in six Argentine provinces, located in four of the five health regions of the country (Northwest: Jujuy and Catamarca; center: Buenos Aires; Cuyo: Mendoza; South: La Pampa and Chubut), applying a uniform methodology that allowed to have diagnostic elements for contrasting the results. Thus, the authors recorded a clinal variation in the prevalence of malnutrition; while rates of undernutrition decreased from north to south, overweight and obesity showed an inverse trend (Oyhenart et al., 2008).

The presence of both extremes of malnutrition registered in the aforementioned study agrees with what was reported at the national level more recently by Tumas et al. (2019). According to their research, between 2003 and 2015 Argentina was facing different nutritional transition processes, where sociodemographic factors played a major role in shaping diverse profiles. One of those was double burden of malnutrition, characterized by highly urbanized scenarios in which prevalence of stunting in children was moderate and prevalence of obesity in adults and children was high. One of the provinces that authors included in this profile was Chubut, where Puerto Madryn is located (Tumas et al., 2019).

Coinciding with the reported literature, the bioanthropological research conducted since the first decade of the twenty-first century in the northeast of Patagonia, evidenced the existence of the nutrition paradox in child and youth populations. The results showed in G2 a decrease of the prevalence of well-nourished children (almost 10%, compared to those found in G1). This reduction was due to an increase of malnourished (undernutrition and excess weight) in the current group (G2). Looking for the reason of that change, it was found that both extremes of malnutrition showed an opposite trend: while undernourished decreased by 1.2%, ponderal excess raised by 11.7%. In the case of undernutrition, in both groups stunting prevailed over underweight and wasting and presented small negative trend (−0.9%; 2.0) between G1 (5.9%) and G2 (5.0%). Regarding ponderal excess, while in G1 the prevalence of overweight was greater than that of obesity (13.3% vs. 9.7%, respectively), then in G2 this trend was reversed (overweight: 16.0% vs. obesity: 18.6%) (Navazo, 2019; Navazo et al., 2018).

Studies carried out in other regions of Argentina have revealed similar trends in the nutritional status of the child and youth populations. A study by Guimarey et al. (2014) compared two samples of school children aged 4 to12 years, residing in La Plata (province of Buenos Aires). The authors recorded that over the course of 35 years, both overweight and obesity prevalence increased by 2.6% and 3.0%, respectively. As a possible explanation for the changes described, the researchers suggested that La Plata's population experienced deterioration in living conditions and important changes in their lifestyle, such as an increased consumption of energy-dense foods and sedentary habits (Guimarey et al., 2014). Another example was the study carried out in Santa Rosa (province of La Pampa) by Orden et al. (2021), who compared data from three surveys (1990, 2005–2007 and 2015–2016) in school children of both sexes, between 6 and 12 years of age. The study found that over the 25-years, overweight increased by 6.6%, while obesity showed an increase of 10.6%. According to the authors, positive trend found would have occurred together with the increase in income disparities, which would determine the differential access to healthy foods (Orden et al., 2021).

Likewise, Bustamante et al. (2021) reported that in the period 1996–2015, school children between 4 and 7 years of age, residing in the department of Doctor Manuel Belgrano (province of Jujuy), there was an increase in overweight (3.0%) and obesity (5.7%), and a decrease of thinness prevalence (1.6%). The authors observed that, during the two decades, percentage of change in obesity prevalence was very high in all areas and in both sexes.

Considering the proposal by Ulijaszek and Komlos (2010) that anthropometric indicators cannot be substituted but are complementary to the conventional measures of living standards, expanding the power of historical-economic analysis; it can be said that trends in nutritional status prevalence registered in Puerto Madryn's school children had a correlation with modifications in socio-environmental conditions of the city. This came from the comparison of national census surveys, where it was observed that between 2000 and 2010, the families of Puerto Madryn had a detriment in their living conditions, although the population residing in the city increased by 29% and the number of people with different occupations raised, also increased critical crowding and illiteracy, and simultaneously decrease the access to public services (INDEC, 2001, 2010).

In relation to the population growth described, different authors reported that urbanization was expanding towards the areas of Puerto Madryn that were not totally suitable for habitations, mainly due to the action of geomorphological processes such as water erosion and mass removal (Ferrari, 2017). For this reason, the emergence of precarious and unplanned settlements in the peripheries became a problem for the city, because in recent years they have expanded rapidly (Ferrari & Bozzano, 2016), both in the northwest and southwest sectors, evidencing the conflict of access and ownership of the land (Ferrari, 2017).

Faced with these events, the state services did not follow a planned logic, but rather one of spontaneity and urgency (Ferrari et al., 2021). However, since 2005, the state plan called PROMEBA (acronym translated as Neighborhood Improvement Program) was developed in different neighborhoods of the city, which was aimed at consolidating precarious settlements. Among the main actions carried out within the framework of the program, can be mentioned community infrastructure works, environmental sanitation, provision and access to the public services, relocation of families living in a situation of environmental risk, and property regularization in the neighborhoods of the northwest and central-west of the city (Kaminker & Velásquez, 2015). These works, together with the existence of social networks that contributed to the containment and settlement of the families recently arrived in the city, could have led to the negative trend of stunting recorded (Navazo et al., 2018).

On the other hand, in relation to the positive trend in overweight and obesity registered in this research, there are other studies that provide similar evidence. Corvalán et al. (2017) reported that in Latin America, rapid urbanization combined with greater penetration of the retail food has promoted diets that rely on energy-dense and nutrient-poor foods. At the same time, sedentary behaviors have become the habit among children and adults. For their part, Zapata et al. (2016) reported changes in eating habits that occurred in Argentine population in recent years. Thus, between 1996 and 2013 authors observed changes in dietary pattern, consumption of beef decreased at the expense of an increased consumption of chicken, pork, and semi-processed meat products. In the case of wheat, changes were observed in the forms of consumption pattern; purchase of fresh bread and flour decreased, intake of noodles, cookies, pastry mixes and pie dough, *empanadas* and pizza increased (Zapata et al., 2016).

As Tacoli (2019) pointed out, over the last two decades there has been a shift in policy debates on a predominant concern for food production to increased attention to food consumption and a focus on access, affordability, and utilization of resources. The latter are especially relevant to most of the world's population now living in urban areas who rely primarily on food purchases. In this regard, it is worth mentioning that in the city of Puerto Madryn, the supply of products such as vegetables, beef, lamb, and pork meats are provided by the farmers of the Lower Valley of the Chubut River (Albertoli et al., 2016; Hughes & Owen, 2002). However, this regional supply can vary according to the seasonality of the products and the competition of others from the north of the country. As a result of this situation, commercially processed and ultra-processed foods correspond to a major part of the food consumed (Dahinten et al., 2011).

Considering the particularities described about the food supply in Puerto Madryn, it is important to remember the words said by Aguirre (2000): low-income people know what they should eat, but they do not eat what they want, they eat what they can.

11.6 Conclusion

This brief story highlights the need for evaluation of nutritional status of children and youth in the background of socioeconomic environment where they live. This could be a first step to understand how changes due to urbanization could be related to phenotypic variability within a population and secular trend of nutritional status. In this sense, during the time period considered, the increase of almost 30% of Puerto Madryn population would have led to the expansion of informal settlements with health and socioeconomic vulnerabilities and an increase in malnourished school children, both due to the increase in ponderal excess, as well as a reduction in undernutrition. Secular trend observed in Puerto Madryn child and youth populations corresponds to nutrition paradox, characteristic of an advanced stage of nutrition transition.

Despite the evidence presented, more studies are required to be able to describe secular trend of nutritional status of a human population in a holistic approach. In this sense, other aspects such as eating habits and physical activity should be included in future research. The real challenge that has to be faced by the biological anthropologists is to identify and account how phenotypic plasticity is expressed in different socioeconomic and cultural contexts over time.

Acknowledgements Authors wish to thank the teaching staff of Puerto Madryn educational institutions where research projects were carried out, as well as the school children and their families for participating in the studies. In addition, collaboration of Lorena Peralta and Vanesa Botterón (*Universidad Nacional de la Patagonia* San Juan Bosco, Sede Puerto Madryn), and of Marcelo Gavirati and Delfina Palleres (IDEAus, CENPAT-CONICET) in the fieldwork, and Guido Tolosa Timbaldi in the translation of the manuscript. This chapter is dedicated to Dra. Evelia Oyhenart, who worked side by side with the authors, sharing her passion and knowledge for biological anthropology.

Conflict of Interest The authors declare that they have no conflicts of interest.

References

Aguirre, P. (2000). Aspectos socioantropológicos de la obesidad en la pobreza. In M. Peña & J. Bacallao (Eds.), *La obesidad en la pobreza: un nuevo reto para la salud pública* (pp. 13–25). Organización Panamericana de la Salud.

Albertoli, S., Perez Cavenago, D., & Pecorari, N. (2016). *Investigación de la potencialidad económica y agroalimentaria del Valle Inferior del Río Chubut*. Instituto Nacional de Tecnología Agropecuaria, INTA.

argentina.gob.ar. (2021). From https://www.argentina.gob.ar/pais/territorio/extension. Retrieved November 5, 2021

Bandieri, S. (2005). *Historia de la Patagonia*. Sudamericana.

Bogin, B. (2021). *Patterns of human growth*. Cambridge University Press. https://doi.org/10.1017/9781108379977

Borda Pérez, M. (2007). La paradoja de la malnutrición. *Salud Uninorte, 23*(2), 276–291.

Botterón, T. V., Zavatti, J. R., Giménez, D., Gallastegui, M. S., & Dahinten, S. L. (2003). Influencia del nivel socioeconómico sobre el dimorfismo sexual de escolares patagónicos. *Revista Argentina de Antropología Biológica, 5*(1), 119.

Bustamante, M. J., Alfaro, E. L., Dipierri, J. E., & Román, M. D. (2021). Excess weight and thinness over two decades (1996–2015) and spatial distribution in children from Jujuy, Argentina. *BMC Public Health, 21*(1), 1–10. https://doi.org/10.1186/s12889-021-10239-4

Cobos, V. A., Favier Dubois, C. M., & Perez, S. I. (2014). Dieta y variación morfológica craneofacial en poblaciones humanas del golfo San Matías (Patagonia, Argentina). *Magallania, 42*(2), 125–139. https://doi.org/10.4067/S0718-22442014000200007

Corvalán, C., Garmendia, M. L., Jones-Smith, J., Lutter, C. K., Miranda, J. J., Pedraza, L. S., Popkin, B. M., Ramirez-Zea, M., Salvo, D., & Stein, A. D. (2017). Nutrition status of children in Latin America. *Obesity Reviews, 18*(Supplement 2), 7–18. https://doi.org/10.1111/obr.12571

Dahinten, S. L., Zavatti, J. R., & Botterón, T. V. (2005). Variación regional del crecimiento y estado nutricional: Chubut. *Revista Argentina de Antropología Biológica, 7*(1), 93.

Dahinten, S., Gavirati, M., & Castro, L. (2009). *Nuevos aportes sobre la evolución de la talla en varones adultos del Chubut (clases 1909–1949)* (p. 86). Novenas Jornadas Nacionales de Antropología Biológica. Puerto Madryn.

Dahinten, S. L., Castro, L. E., Zavatti, J. R., Forte, L. M., & Oyhenart, E. E. (2011). Growth of school children in different urban environments in Argentina. *Annals of Human Biology, 38*(2), 219–227. https://doi.org/10.3109/03014460.2010.515949

Dahinten, S., Gavirati, M., & Castro, L. (2013). La evolución de la talla de los varones enrolados en el Chubut (clases 1909.1949), como fuente de la historia económica y social de la región. Un enfoque interdisciplinario desde la historia y la antropología biológica. *X Congreso de Historia Social y Política de la Patagonia Argentino Chilena. Poblaciones y procesos de poblamiento en Patagonia*. Trevelin Chubut. p. 1–7

Doak, C. M., Adair, L. S., Bentley, M., Monteiro, C., & Popkin, B. M. (2005). The dual burden household and the nutrition transition paradox. *International Journal of Obesity, 29*, 129–136. https://doi.org/10.1038/sj.ijo.0802824

Donato, V. (2011). *Industria manufacturera año 2010: Observatorio PyME Regional Provincia del Chubut*. Fundación Observatorio Pyme. Bononiae Libris. GECSEA Patagonia-Universidad Nacional de la Patagonia San Juan Bosco.

FAO, OPS, WFP, UNICEF. (2019). *Panorama de la seguridad alimentaria y nutricional en América Latina y el Caribe 2019*. Santiago. 135. Licencia: CC BY-NC-SA 3.0 IGO. From https://iris.paho.org/bitstream/handle/10665.2/51685/9789251319581FAO_spa.pdf?s. Retrieved October 20, 2021

Ferrari, M. P. (2017). Configuraciones del riesgo y percepción social. Los asentamientos La Lomita y Alta Tensión, Puerto Madryn, Chubut. *Geograficando, 13*(2), e024. https://doi.org/10.24215/2346898Xe024

Ferrari, M. P., & Bozzano, H. (2016). Aplicación del método Territorii en dos asentamientos espontáneos de Puerto Madryn, Argentina. *Papeles de Geografía, 62*, 137–151. https://doi.org/10.6018/geografia/2016/260061

Ferrari, M.P., Kaminker, S.A., Velasquez, R.Y., Pacho, C., & Santos Valencia, A. (2021). Discusión y aporte teórico-metodológico sobre movilidad y experiencia de desigualdad en una ciudad turística patagónica. *VII Congreso Nacional de Geografía de Universidades Públicas y XXI*

Jornadas de Geografía de la UNLP From http://jornadasgeografia.fahce.unlp.edu.ar/front-page/actas/ponencias/Ferrari2.pdf. Retrieved October 20, 2021

Frisancho, A. R. (2008). Anthropometric standards. In *An interactive nutritional reference of body size and body composition for children and adults*. University of Michigan Press.

Frumento, O. A., & Contrera de Davies, E. (2017). *Reportes climáticos 2017*. Estación Metereológica Automática-Laboratorio de Climatología-CENPAT-CONICET. From http://www.repositorio.cenpat-conicet.gob.ar/123456789/351. Retrieved November 12, 2021

Guimarey, L. M., Castro, L. E., Torres, M. F., Cesani, M. F., Luis, M. A., Quintero, F. A., & Oyhenart, E. E. (2014). Secular changes in body size and body composition in schoolchildren from La Plata City (Argentina). *Anthropologischer Anzeiger, 71*(3), 287–301. https://doi.org/10.1127/0003-5548/2014/0364

Hernández Rodríguez, M. (2007). Fisiología y valoración del crecimiento y la pubertad. *Pediatría Integral, 11*(6), 471–484.

Hughes, J.C., & Owen, O.M. (2002). Trabajadores migrantes bolivianos en la horticultura Argentina: transformación del paisaje rural en el valle inferior. Scripta Nova*, Revista Electrónica de Geografía y Ciencias Sociales*. From http://www.ub.edu/geocrit/sn/sn119125.htm. Retrieved November 24, 2021

INDEC. (2001). Censo Nacional de Población, Hogares y Viviendas. In *Instituto Nacional de Estadística y Censos*. *Ministerio de Economía y Finanzas Públicas de la Nación*. From http://www.indec.gov.ar. Retrieved October 16, 2021

INDEC. (2010). *Censo Nacional de Población, Hogares y Viviendas. Instituto Nacional de Estadística y Censos*. Ministerio de Economía y Finanzas Públicas de la Nación. From https://www.indec.gob.ar/ftp/cuadros/poblacion/censo2010_tomo2.pdf. Retrieved October 16, 2021

Kaminker, S. A., & Velásquez, R. Y. (2015). Programa de mejoramiento de barrios en la patagonia central: Regularización de la informalidad urbana en Puerto Madryn, Chubut. *Cuaderno Urbano, 18*(18), 89–109.

Kaminker, S. A., & Ortiz-Camargo, D. P. (2016). Puerto Madryn, de pueblo a ciudad intermedia. La dinámica poblacional local a través de cinco retratos censales (1970-2010). *Papeles de Población, 22*(89), 223–254.

Kloster, E. E. (2001). Región Patagónica. In G. Á. Velázquez (Ed.), *Geografía, calidad de vida y fragmentación en la Argentina de los 90’* (pp. 144–156). *Análisis regional y departamental utilizando SIG’s*, CIG-FCH-UNCPBA.

Kloster, E. E. (2008). La calidad de vida en la región patagónica, período 1991–2001. In G. Á. Velázquez (Ed.), *Geografía y bienestar. Situación local, regional y global de la Argentina luego del censo 2001* (pp. 385–404). EUDEBA.

Lohman, T. G., Roche, A. F., & Martorell, R. (1988). *Anthropometric standardization reference manual*. Human Kinetics Books.

Longhi, F., Cordero, M. L., & Cesani, M. F. (2022). Malnutrición infantil en Rio Chico (Tucumán, Argentina). Evolución y manifestaciones actuales en el contexto de la transición nutricional. *Revista Universitaria de Geografía, 31*(1), 13–37. https://doi.org/10.52292/j.rug.2022.31.1.0033

Marrodán Serrano, M. D. (2000). La alimentación en el contexto de la evolución biocultural de los grupos humanos. *Zainak Cuadernos de Antropología-Etnografía, 20*, 109–121.

Millán, A. G., Gómez Otero, J., & Dahinten, S. L. V. (2013). Tendencia secular de la estatura en poblaciones humanas del valle inferior del Río Chubut y de la costa centro-septentrional (Patagonia Argentina) durante el Holoceno Tardío. *Relaciones, 38*(2), 421–440.

Ng, S. W., & Popkin, B. M. (2012). Time use and physical activity: A shift away from movement across the globe. *Obesity Reviews, 13*, 659–680. https://doi.org/10.1111/j.1467-789X.2011.00982.x

Ng, S. W., Norton, E. C., Guilkey, D. K., & Popkin, B. M. (2012). Estimation of a dynamic model of weight. *Empirical Economics, 42*, 413–443. https://doi.org/10.1007/s00181-012-0547-7

Navarro Floria, P. (1999). *Historia de la Patagonia*. Ciudad Argentina.

Navazo, B. (2019). Crecimiento, estado nutricional y composición corporal como expresión de la calidad de vida. *Un estudio transversal, prospectivo y retrospectivo, de la población* *infanto-juvenil de Puerto Madryn* (Chubut, Argentina). [Doctoral thesis]. La Plata, Buenos Aires: Universidad Nacional de la Plata. From http://sedici.unlp.edu.ar/handle/10915/72893. Retrieved October 30, 2021

Navazo, B., Dahinten, S. L., & Oyhenart, E. E. (2018). Malnutrición y pobreza estructural. Comparación de dos cohortes de escolares de Puerto Madryn, Argentina. *Revista de Salud Pública, 20*(1), 60–66. https://doi.org/10.15446/rsap.v20n1.68576

Orden, A. B., Apezteguía, M. C., & Mayer, M. A. (2021). Aceleración y estabilización: disparidad en la tendencia de obesidad en escolares de la provincia de La Pampa (Argentina) entre 1990 y 2016. *Revista Argentina de Antropología Biológica, 23*(1), 1–10. https://doi.org/10.24215/18536387e028

Oyhenart, E. E., Dahinten, S. L., Alba, J. A., Alfaro, E. L., Bejarano, I. F., Cabrera, G. E., Cesani, M. F., Dipierri, J. E., Forte, L. M., Lomaglio, D. B., Luis, M. A., Luna, M. E., Morradán, M. D., Moreno Romero, S., Orden, A. B., Quintero, F. A., Sicre, M. L., Torres, M. F., Verón, J. A., & Zavatti, J. R. (2008). Estado nutricional infanto juvenil en seis provincias de Argentina: Variación regional. *Revista Argentina de Antropología Biológica, 10*(1), 1–62.

Oyhenart, E. E., Dahinten, S. L., Forte, L. M., & Navazo, B. (2017). Composición corporal en relación al sobrepeso ya la obesidad. Un estudio en niños residentes en diferentes áreas geográficas de Argentina. *Revista Nutrición Clínica y Dietética Hospitalaria, 37*(2), 114–124. https://doi.org/10.12873/372oyhenart

Pellegrini, M., & Battistini, N. C. (2015). Nutritional status evaluation: body composition and energy balance. In A. Lenzi, S. Migliaccio, & L. M. Donini (Eds.), *Multidisciplinary approach to obesity: from assessment to treatment* (pp. 171–192). Springer International Publishing. https://doi.org/10.1007/978-3-319-09045-0

Peralta, L. (2002). *Variación ambiental en el crecimiento y desarrollo en niños de Puerto Madryn*. [Bachelor in Biological Sciences Seminar] Universidad Nacional de la Patagonia San Juan Bosco.

Popkin, B. M. (2002). The shift in stages of the nutrition transition in the developing world differs from past experiences! *Public Health Nutrition, 5*, 205–214. https://doi.org/10.1079/PHN2001295

Popkin, B. M., Adair, L. S., & Ng, S. W. (2012). Global nutrition transition and the pandemic of obesity in developing countries. *Nutrition Reviews, 70*, 3–21. https://doi.org/10.1111/j.1753-4887.2011.00456.x

Popkin, B. M., Corvalán, C., & Grummer-Strawn, L. M. (2020). Dynamics of the double burden of malnutrition and the changing nutrition reality. *Lancet, 395*(10217), 65–74. https://doi.org/10.1016/S0140-6736(19)32497-3

Pucciarelli, H. M. (1989). Contribución al concepto de Antropología Biológica. *Revista de Antropologia, 7*, 27–31.

Schlüter, R. (1996). *Chubut. Turismo, hábitat y cultura*. Facultad de Ciencias Económicas. Universidad Nacional de la Patagonia San Juan Bosco.

Swinburn, B. A., Kraak, V. I., Allender, S., Atkins, V. J., Baker, P. I., Bogard, J. R., et al. (2019). The global syndemic of obesity, undernutrition, and climate change: the lancet commission report. *Lancet, 393*(10173), 791–846. https://doi.org/10.1016/S0140-6736(18)32822-8

Tacoli, C. (2019). The urbanization of food insecurity and malnutrition. *Environment and Urbanization, 31*(2), 371–374. https://doi.org/10.1177/0956247819867255

Takahashi, E. (1984). Secular trend in milk consumption and growth in Japan. *Human Biology, 56*(3), 427–437.

Tanner, J. M. (1987). Growth as a mirror of the condition of society: Secular trends and class distinctions. *Acta Paediatrica Japonica, 29*(1), 96–103. https://doi.org/10.1177/0956247819867255

Tumas, N., Junyent, C. R., Aballay, L. R., Scruzzi, G. F., & Pou, S. A. (2019). Nutrition transition profiles and obesity burden in Argentina. *Public Health Nutrition, 22*(12), 2237–2247. https://doi.org/10.1017/S1368980019000429

Ulijaszek, S. J., & Komlos, J. (2010). From a history of anthropometry to anthropometric history. In C. G. N. Mascie-Taylor, A. Yasukouchi, & S. J. Ulijaszek (Eds.), *Human variation, from laboratory to the field* (pp. 183–197). CRC Press.

Wells, J. C., Sawaya, A. L., Wibaek, R., Mwangome, M., Poullas, M. S., Yajnik, C. S., & Demaio, A. (2020). The double burden of malnutrition: aetiological pathways and consequences for health. *Lancet, 395*(10217), 75–88. https://doi.org/10.1016/S0140-6736(19)32472-9

World Medical Association. (2013). *Declaración de Helsinki de la asociación Médica Mundial*. Principios éticos para las investigaciones médicas en seres humanos. From https://www.wma.net/es/. Retrieved November 1, 2021

WHO. (2020). *Obesity and overweight*. From https://www.who.int/es/news-room/fact-sheets/detail/obesity-and-overweight. Retrieved October 13, 2021

Zapata, M. E., Rovirosa, A., & Carmuega, E. (2016). Cambios en el patrón de consumo de alimentos y bebidas en Argentina, 1996–2013. *Salud Colectiva, 12*, 473–486. https://doi.org/10.18294/sc.2016.936

Chapter 12
Inequalities in Malnutrition and Living Conditions of Children from Native and Migrant Families Residing in the Productive Belt of La Plata City in Buenos Aires, Argentina

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12.1 Introduction

From an anthropological approach, food is viewed from the point of view of biology, culture, and adaptive response to the environment (Contreras, 2007). It also links biological and socio-cultural attributes in an indissoluble way since humans do not only consume nutrients but also "perceive" (Fischler, 1995). In the words of Aguirre (2010a, b; p. 14), "eating for humans is not only ingesting nutrients to sustain life: it is a complex process that transcends the eater, situates him/her in a time, a

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S. Datta Banik (ed.), *Human Growth and Nutrition in Latin American and Caribbean Countries*, https://doi.org/10.1007/978-3-031-27848-8_12

geography and a history, with others, sharing, transforming and transmitting -real or symbolically- that which he/she calls food and the why, which makes him/her eat it". In turn, these meanings depend on multiple factors, such as the position of groups in the social structure, ethnic-national affiliation, gender, age, health, housing, sanitation, employment, access to goods and services, among others.

García Canclini (1995) stated that classes and social groups are differentiated by their unequal appropriation of material and symbolic goods in production, distribution and consumption, which is the basis for the concept of food insecurity. According to the Food and Agriculture Organization FAO, food security exists when all people, always have physical and economic access to sufficient, safe and nutritious food to meet their dietary needs and food preferences for an active and healthy life (FAO, 2011).

In this way, knowing the data of dietary habits of the people of a society allow us to understand the social organization and structure, since consumption reflects the place occupied by the individuals in a given society (Durán Monfort, 2006). In this sense, we understand that food as an eloquent indicator of the living conditions of families and, growth and nutritional status of children, as empirical references of them (Bergel Sanchís, 2014; Ortale, 2003).

Nutritional status is defined as the balance between caloric gain and loss. Therefore, malnutrition occurs when this balance is altered, either by deficit (undernutrition) or excess (overweight and obesity). Both types have direct consequences on health, being even more serious when they occur during the early stages of growth (WHO, 2008).

In general terms, current food consumption patterns in Argentina are characterized by an abundant intake of fat, sugar and sodium, and deficient intake of essential nutrients such as calcium, iron, zinc or vitamins C and A and fiber (Durán et al., 2009). According to Piaggio et al. (2011), the problems indicated in the quality and quantity of food that children receive have consequences on their health: (1) micronutrient deficiencies are associated with short stature (chronic malnutrition), greater susceptibility to infections and learning difficulties; (2) excessive consumption of sugars has an impact on the high prevalence of dental problems (caries and loss of teeth); (3) excessive consumption of fat and sugar, combined with increasing sedentary behavior, contribute to become overweight and obesity, which are correlated with the development of chronic noncommunicable diseases in adulthood.

On the other hand, it is well known that migration is a phenomenon of great social, economic, and political relevance, to the point that cosmopolitanism characterizes today's urban societies. It is often stated, moreover, that migratory processes

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entail transformations that modify, among other aspects, food consumption practices (Koc & Welsh, 2014).

The movement of populations from neighboring countries to Argentina has a long history; Balán (1985) has defined the existence of a "Southern Cone migratory system" in which our country has been a regular destination (Magliano & Mallimaci Barral, 2015). Specifically, since 1970, there has been an intense and constant flow of Bolivian immigrants to Argentina (Cerrutti, 2010).

According to García (2015), a characteristic of this process was the settlement of immigrant families in peripheral areas of the main cities, as we observed in the present study. Our sample was made up of people who settled in the productive belt of La Plata, capital city of the province of Buenos Aires, which is located around 60 kilometers away from the Autonomous City of Buenos Aires (CABA in Spanish acronym), the capital of Argentina. This territory is conceived, regionally, as a rural-peri-urban or intermediate rural area and is characterized by its rural identity – underlined by a predominance of horticultural activity, together with a partial provision of public services. In general, it has a low population density and a large presence of family farmers, many of whom are immigrants from neighboring countries, mostly Bolivia (Barsky, 2015).

Like other groups, due to their migrant status and low labor qualifications, Bolivians are frequently employed at the lowest and most precarious levels of the occupational structure, which results in a lack of social security (Cerrutti, 2010). In such conditions, these families must adapt to the characteristics of the new environment and the cultural peculiarities of its inhabitants, including types of consumption, possibilities of access to food and change or modify their eating habits (Salva, 2000). As expressed by Koc and Welsh (2014), such adaptations usually require transformations that combine actions aimed at reproducing preparations from the place of origin with culinary substitutions, incorporations and/or suppressions in the absence or inaccessibility of traditional ingredients. Thus, the difficulty in accessing a nutritionally and culturally adequate diet, usually involves changes in the quality of the diet, with an impact on nutritional status and population health (Hun & Urzúa, 2019; Zhou et al., 2018).

In this sense, the present study seeks to address the nutrition-feeding processes to obtain quantifiable data to achieve a deeper understanding of the expression of the body as a result of the interaction of particular socio-cultural co-determinants (Peña Sánchez, 2012).

Therefore, the objectives of this study were: (1) to characterize nutritional status of children living in the productive belt of the city of La Plata, together with household socio-economic, ethnic composition, and environmental indicators that allowed us to understand the living conditions of these populations; and (2) to explore the existence of possible inequalities, by means of comparative analysis between native and immigrant families.

12.2 The Productive Belt of La Plata City as a Study Area

In recent decades, the territories surrounding the CABA, capital of Argentina (Fig. 12.1), have undergone intense socio-spatial and socio-productive transformations. The so-called "Third crown" of the city has emerged as the geographic scenario where active peri-urbanization processes are taking place (Fig. 12.2). The region known as the "*Cinturón Verde Bonaerense*" (Buenos Aires' Green Belt) comprises a 50-kilometer radius around CABA and is made up of 13 districts, with an area of approximately 18,000 hectares. Within this region, La Plata is the district with the largest horticultural production, occupying 26.7% of total area and producing more than 75,000 tons of agricultural products, annually (CHFBA, 2005).

Fig. 12.1 Province of Buenos Aires in the context of Argentina and Latin America. (Self-elaboration)

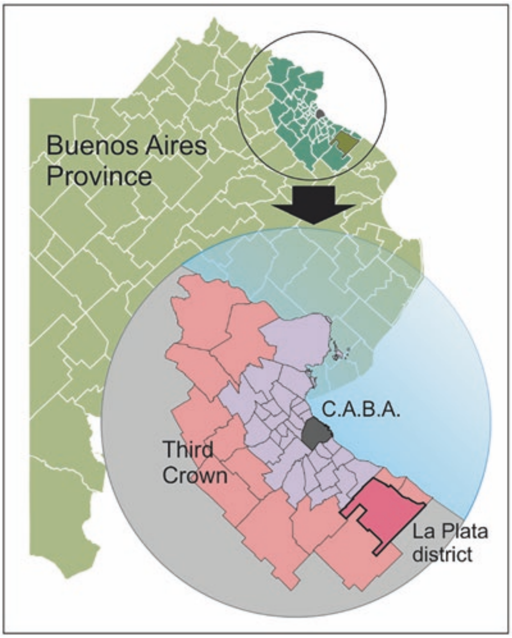

Fig. 12.2 Location of the third crown of the CABA, Buenos Aires green belt and La Plata district. (Self-elaboration)

The productive belt of La Plata is a heterogeneous territory, both physically and socially (Quintero et al., 2021). Diverse activities are carried out in this region, such as primary food production, urbanization and industrial development, and other issues that generate coexistence of conflicts and cohesion among people (Feito, 2018). Its current development responds to the changes occurred both in the economic modality of horticultural farms and in the ethnic composition of the workers. Since the end of the nineteenth century, production in the farms of that region was traditionally carried out first by the Italian and Spanish immigrants and then by the Portuguese. From the second half of the twentieth century onwards, there was a socio-demographic change observed with the arrival of Bolivian immigrants, who shaped their cultural patterns both in the production practices and in the distribution and marketing modalities (Barsky, 2015).

12.3 Population and Sample

The present study was carried out in 7 state schools in 5 community centers (CC) located in the productive peri-urban areas of La Plata: Arana, Arturo Seguí, Ángel Etcheverry, Los Hornos and Lisandro Olmos (Fig. 12.3). The survey was carried out based on convenience sampling. Access to the schools was arranged with the authorities of the *Dirección General de Cultura y Educación* of the province of Buenos Aires.

Fig. 12.3 La Plata district. Location of the community centers where field work was carried out. (Self-elaboration)

Table 12.1 Sample composition by family origin, sex and age

Age (years)	Total			Natives		Immigrants	
	Total	Boys	Girls	Boys	Girls	Boys	Girls
	n (%)	n (%)	n (%)	n (%)	n (%)	n (%)	n (%)
3	58 (12.5)	28 (6.0)	30 (6.5)	21 (4.5)	20 (4.3)	7 (1.5)	10 (2.2)
4	174 (37.4)	93 (20.0)	81 (17.4)	63 (13.5)	54 (11.6)	30 (6.5)	27 (5.8)
5	190 (40.9)	114 (24.5)	76 (16.3)	66 (14.2)	42 (9.0)	48 (10.3)	34 (7.3)
6	43 (9.3)	26 (5.6)	17 (3.7)	20 (4.3)	13 (2.8)	6 (1.3)	4 (0.9)
Total n (%)	465 (100)	261 (56.1)	204 (43.9)	170 (36.6)	129 (27.7)	91 (19.6)	75 (16.1)

The cross-sectional study included 465 participants (boys: 56.1%; girls: 43.9%) between 3.0 and 6.9 years of age (Table 12.1). Schoolchildren with a pathological history and who expressed their refusal to participate and/or did not have a signed authorization from mother/father/guardian were excluded from the survey.

Of these 465 children, 299 (64.3%) were considered “natives”, as they had parents from Argentina, and 166 (35.7%) were considered “immigrants”, as at least one of their parents had a foreign nationality. Regarding the place of origin of the latter group, 71% were from Bolivia, 26% from Paraguay and the remaining (3%) from other countries in the region.

12.3.1 Anthropometric Measurements

Anthropometric measurements were recorded following standard protocols (Lohman et al., 1988): (a) body weight in kilograms using a portable digital scale (100 g of precision) that was calibrated at the beginning of each session, and (b) height in centimeters using a vertical anthropometer (1 mm of precision). Body weight and height data were used to calculate the Body Mass Index (BMI = body weight (kg)/height (m^2)), z-score values were calculated according to the WHO reference (WHO, 2006).

Malnutrition, in all its forms were estimated: underweight (low weight-for-age, UW); stunting (low height-for-age, S); wasting (low weight for height, W) by taking $<-2z$ values as cut-off point, while overweight (Ov) and obesity (Ob) by taking into consideration BMI values between $> +1z$ and $\leq +2z$ and $> +2z$, respectively. Thus, three groups were defined based on nutritional status: undernourished (UW, S, W); excess weight (Ov plus Ob) and normal (children who were not included in other categories). The assessment of nutritional status was based on the z-score values calculated using WHO Anthroplus v1.0.3 program.

12.3.2 Household Socio-economic and Environmental Study

A structured questionnaire filled out by the parents was applied to record household socio-economic characteristics and thereby estimating the status (Oyhenart et al., 2008). Therefore, data of the household environment (critical overcrowding following the INDEC (2018) definition, and characteristics of the dwelling place) and of the peri-domiciliary environment (availability of public services: pavement, running water, electricity, waste collection, sewage, natural gas, etc.) were collected. Regarding household socio-economic status, the following aspects were considered: nationality, level of education and occupation of mother/father/guardian, tenancy regime of the dwelling, health coverage, orchard practices in the family garden, animal husbandry and access to the material and consumer goods, and to social plans, referring to national or local programs (from government agencies, NGO's, or other entities) that benefit poor families by supplementing their food budget (nutritional support) and/or by providing cash relief to the heads of households (monetary support). According to the information of the nationality of fathers and mothers, each participant was assigned to one of the following groups: (1) "native", when both father and mother reported being Argentinean; and (2) "immigrants", when the father or mother reported to be a foreigner.

12.3.3 Statistical Analysis

Prevalence (%) of nutritional status indicators and frequencies for the socioeconomic and environmental variables were calculated. The comparative analysis was performed by applying Chi-square test. All data analysis was performed using the SPSS v21 statistical package.

12.3.4 Ethical Considerations

This research was conducted in accordance with the principles proclaimed in the Universal Declaration of Human Rights (1948), the ethical standards instituted by the Nuremberg Code (1947), the Declaration of Helsinki (1964) and its subsequent amendments and clarifications, and the national law 25,326 (Law 26,343/08) and its amendments N° 1558/01, regulations and rules for the protection of personal data. In addition, the research protocol was approved by the Bioethics Committee of the Latin American School of Bioethics CELABE and had the permissions of the *Dirección General de Cultura y Educación de la provincia de Buenos Aires* and by the authorities of each educational establishments where the research was carried out.

Complementarily, the study objectives and procedures were explained to the mother/father/guardian of the schoolchildren through meetings carried out in each school and an informed consent form was signed by them. In addition, children's verbal assent was obtained and only those who agreed were included in the guaranteed, emphasizing voluntary participation.

12.4 Results

The results of anthropometric evaluation showed that 46.5% of children (n = 216) were not suffering from malnutrition, while 53.5% (n = 249) had either undernutrition or excess weight: 6.2% and 48.9%, respectively; 1.6% had both types (stunting and excess weight). Separate estimates showed 5.2% had S, 1.3% UW and 1.3% W, 32.3% Ov and 16.6% Ob (Table 12.2). The comparative analysis of nutritional status by sex and age showed no significant differences.

The results of household socio-economic and environmental survey are presented in Table 12.3. Four out of ten households did not own house and a quarter of these (25%) lived in overcrowded conditions. In terms of house building quality, 57% of the families had houses with firebrick walls and 44% had wooden walls or other types. Only 31% had concrete floor and most were made of cement (67%). Only 30% houses were located beside paved roads, 20% had sewage service, 12% had piped gas system, 79% households had electricity, 67% had piped water system, and

Table 12.2 Nutritional status: comparison between native and migrant children

Nutritional Status	Total (n = 465)	Natives (n = 299)	Immigrants (n = 166)	Chi²	p-value
Undernourished	6.2	5.7	7.2	0.43	0.510
Stunting (low height-for-age)	5.2	4.3	6.6	1.13	0.287
Underweight (low weight-for-age)	1.3	1.3	1.2	0.01	0.903
Wasting (low weight-for-height)	1.3	1.7	0.6	0.96	0.327
Excess weight	48.9	44.8	56.0	5.37	0.021
Overweight	32.3	30.4	35.5	1.27	0.259
Obesity	16.6	14.4	20.5	2.87	0.060

Table 12.3 Frequency of household socio-economic and environmental characteristics in total sample and among native and immigrant families

Socioeconomic status variables	Total (n = 465)	No data	Native (n = 299)	Immigrants (n = 166)	Chi²	p-values
Lodging status						
Own house	59.0	1.9	70.9	37.8	47.52	<0.0001
Lease holder	20.8	1.9	11.3	37.8	44.73	<0.0001
Rented or borrowed house	20.2	1.9	17.8	24.4	2.82	0.093
Crowding						
Critical crowding	24.9	0.0	24.1	26.5	0.33	0.562
Public assistance						
Monetary support	22.7	0.4	21.5	24.8	0.69	0.407
Nutritional support (foods)	9.5	0.2	13.1	3.0	12.61	<0.0001
Health insurance						
Public hospital	77.1	0.4	67.3	94.6	44.75	<0.0001
Social work	21.8	0.4	32.7	2.4	57.13	<0.0001
Prepaid coverage	1.3	0.4	2.0	0.0	3.39	0.065
Others						
Internet	19.2	2.4	27.5	3.8	37.41	<0.0001
Cable television	68.9	2.4	73.9	59.7	9.66	0.002
Air conditioning	5.7	2.4	8.1	1.3	9.05	0.003
Car	37.0	2.4	40.0	31.4	3.24	0.072
Father's occupation						
Formal employment	34.2	27.7	44.8	13.3	33.20	<0.0001
Self-employed worker	26.5	27.7	23.3	32.7	3.42	0.064
Unemployed	6.8	27.7	5.8	8.8	1.07	0.300
Informal worker	35.8	27.7	28.7	49.6	14.37	<0.0001
Retired/pensioned	2.4	27.7	3.1	0.9	1.64	0.200

(continued)

Table 12.3 (continued)

Socioeconomic status variables	Total (n = 465)	No data	Native (n = 299)	Immigrants (n = 166)	Chi^2	p-values
Mother's occupation						
Formal employment	16.9	9.7	22.7	6.1	18.71	<0.0001
Self-employed worker	9.0	9.7	7.7	11.6	1.83	0.176
Unemployed	10.0	9.7	12.0	6.2	3.66	0.380
Informal worker	9.5	9.7	6.2	15.8	10.08	0.001
Retired/pensioned	5.5	9.7	5.8	4.8	0.20	0.654
Housewife	61.2	9.7	58.0	67.1	3.32	0.043
Father's education		26.2				
None	0.6		0.0	1.7	10.08	0.039
Elementary incomplete	25.4		22.5	30.6		
Elementary complete	46.4		45.9	47.1		
High school complete	23.6		26.1	19.0		
Tertiary/Universitary	4.1		5.4	1.7		
Mother's education		5.8				
None	0.2		0.3	0.0	45.80	<0.0001
Elementary incomplete	18.0		12.5	28.7		
Elementary complete	39.7		34.7	49.3		
High school complete	36.5		44.1	22.0		
Tertiary/Universitary	5.5		8.3	0.0		
Farming practice						
Orchard (agriculture)	12.6	0.6	4.7	26.5	45.94	<0.0001
Animal husbandry	3.9	0.2	2.7	6.0	3.19	0.074
Building materials						
Fired brick	56.4	0.4	70.5	30.9	67.58	0.000
Metal sheet	7.8	0.4	7.0	9.1	0.62	0.432
Wood	45.4	0.4	34.6	64.8	39.30	<0.0001
Dirt floor	3.3	1.7	2.4	4.9	2.17	0.141
Cement floor	67.4	1.7	58.6	83.3	29.01	<0.0001
Coated floor (ceramic)	31.5	1.7	42.0	12.3	42.71	<0.0001
Services						
Pavement	32.6	2.4	43.3	12.6	44.64	<0.0001
Sewage system	20.7	2.4	26.8	9.4	18.93	<0.0001
Septic tank	69.8	2.4	66.1	76.7	5.54	0.019
Gas (piped system)	13.2	2.4	15.9	8.2	5.42	0.020
Bottled gas (cylinder)	83.5	2.4	81.7	86.8	1.95	0.163
Firewood	10.4	2.4	3.7	22.6	39.82	<0.0001
Electricity	83.0	2.4	85.4	78.6	3.40	0.065
Waste collection	57.5	2.4	73.2	28.3	85.30	<0.0001
Piped water system	68.1	2.4	81.0	44.0	65.04	<0.0001
Protected well	20.3	2.4	11.2	37.1	42.96	<0.0001

55% had waste collection. Ten percent used firewood for heating and/or cooking. Also, 18% had Internet access, 5% had air conditioning, and approximately 32% did not have cable television. Twenty-two percent of the families received state monetary aid, 9% received food aid, and the majority received care in public hospitals (77%). In addition, 13% consumed food from their own orchard and 4% raised animals for the same purpose.

Regarding father's and mothers' occupation, it was observed that approximately 24% and 14% were "employed"; 18% and 8% were "self-employed"; 27% and 9% were "temporary" (intermittent and informal work) and 5% and 9% were "unemployed", respectively. On the other hand, 61% of the mothers described themselves as "housewives" or home makers. About the maximum level of education reached by fathers and mothers, the most prevalent category was "completed elementary school" with 33% and 37%, respectively. Approximately 20% said they had not completed this level and only 18% of fathers and 34% of mothers said they had completed high school. Completion of tertiary/university level did not exceed 5% in any case.

12.4.1 Comparative Study Between Native and Immigrant Families

The comparative analysis of nutritional status of schoolchildren representing native and immigrant families showed non-significant differences except for the combined prevalence of overweight and obesity ($p = 0.021$), with a higher rate among the immigrant group (56.0% vs. 44.8%) (Table 12.2).

In contrast, analysis of household socio-economic and environmental status showed statistically significant differences between the two groups in most of the variables considered (Table 12.3). For example, majority of native families owned their houses (71%), while immigrants lived either in rented or borrowed ones (62%). In addition, the most prevalent construction material in native dwellings was firebrick (71%), while wood appeared in first place among immigrant families (65%). Forty-five percent of the native fathers and twenty-three percent of the native mothers were employed, while thirteen percent and six percent, respectively, of the immigrant population were employed. Likewise, approximately half of the fathers and sixteen percent of the immigrant mothers reported themselves as "*changarines*" (temporary job) vs. twenty-nine and six percent of the natives, respectively. Regarding educational level, twenty-six and forty-four percent of native fathers and mothers completed secondary school, respectively, while nineteen and twenty-two percent of immigrant fathers and mothers completed high school, respectively. In terms of health coverage, 33% of native families had social security coverage vs. two percent of immigrant families. Finally, among other variables, 28% of native families had internet access, while only four percent of immigrant families had access to this service (Table 12.3).

12.5 Discussion

The results obtained in this study showed that the nutritional status of children aged 3 to 6 years living in the productive belt of La Plata is compromised since half of the schoolchildren showed some type of malnutrition. While undernutrition presented prevalence rate close to 6% (mainly chronic type), excess weight reached 49% of the sample. According to Atalah et al. (2014), in the context of poverty, it is common to find coexistence of undernutrition and excess weight in the same region, social stratum, family environment and even in the same child (as occurred with 1.6% in the sample of present study), because of the micronutrient deficiency that accompanies excess weight. Other reports by Raj Patel (2008) and Miryam K. de Gorban (2014), explained undernutrition and overweight as "two sides of the same coin", pointing to the food industry as one of the main causes of both extremes of malnutrition.

In this sense, although the prevalence of undernutrition in our country continues to decline, the increase in excess weight in the last three decades is a fact reported in previous studies (Bustamante et al., 2021; Guimarey et al., 2014; Navazo et al., 2018; Oyhenart et al., 2021).

As in other regions of our country and of the continent, the low prevalence of undernutrition together with high prevalence of overweight illustrate an advanced process of nutrition transition (Bergel et al., 2016, 2017; Cordero & Cesani, 2019; Garraza & Oyhenart, 2020; Navazo et al., 2019). In this regard, Rosique Gracia et al. (2012) stated, while the coexistence of undernutrition and obesity characterizes the societies in nutrition transition, the prevalence of overweight and obesity, as the main epidemiological problem of malnutrition, characterizes societies that have completed their transition.

Therefore, what at first seemed to be a situation characteristic of the more affluent social sectors, that become evident with an increasing trend and at an accelerated rate in less favored populations, since, in the background of limited economic resources, one of the most common family consumption strategies is to invest in volume and not in nutritional quality. That is why, in the contexts of poverty, it is common that the intake of flours, sugars and fats predominates, which are cheaper and produce greater satiety, but are conducive to an increase in overweight and obesity (Cordero & Cesani, 2018). As stated by the WHO, poverty amplifies the risk of malnutrition. People who are poor are more likely to be affected by different forms of malnutrition. Also, malnutrition increases health care costs, reduces productivity, and slows down economic growth, which can perpetuate a cycle of poverty and ill-health (WHO, 2021).

Our data obtained from the primary sources, showed that families living in the productive belt of La Plata are in a situation of socio-economic deprivation and environmental vulnerability: a quarter of the children lived in overcrowded household, only two out of ten had health coverage through social security, most of them lived in houses with cement floors, beside unpaved street, did not have piped gas system or piped water system, nor even internet connection. In addition, four out of ten households did not receive waste collection service. Furthermore, most of the parents of these children had barely completed elementary school and did not have formal and stable occupation. In this context, the difficulty in accessing a balanced diet could explain the high prevalence of overweight and obesity.

Going deeper, the poverty-excess weight interrelationship is reaffirmed upon further analysis. While differentiating and comparing nutritional status of children and household living conditions between native and immigrant families, it was observed that the latter presented the worst conditions for both indicators. Among immigrant families, health coverage through social security decreased to the point of being practically insignificant, as did households with connectivity; houses with concrete floors and walls are markedly reduced in relation to native families (12% vs. 42%), and most of them are made of sheet metal or wood (while in the houses of native families, bricks predominated). Educational levels and the formal job of fathers and mothers also decrease notably among the immigrants, to mention just a few indicators. On the other hand, children of this immigrant population reached 56% of excess weight, more than 11% above their native peers.

A similar scenario has been reported in a study conducted in more than 50,000 multicultural preschoolers in Hannover (Germany), where the close interrelationship between excess weight and ethnic and social inequalities has been confirmed (Zhou et al., 2018). In national territory, Navazo et al. (2019) also reported higher prevalence of excess weight among children of foreign origins, living in the northwest of Puerto Madryn city (Chubut, Argentina), where socio-environmental conditions are deficient compared to those found in the rest of the city.

A plausible explanation of this situation can be taken from Ambort (2019) and Fernández (2018) who reported that, despite the fact that these immigrant families can achieve some social ascent (from the development of own productive ventures through the lease or purchase of land that turns them into small-scale producers with the contribution of their own and their family's labor force), do not manage to reverse the conditions of exploitation, precariousness and informality that characterize this labor market, keeping many families in a situation of poverty and marginalization, that have negative impacts on child health and nutritional status.

According to the literature, in a globalized world such as the present, migration plays a central role in the processes of social reproduction. More specifically, migration is intimately linked to the processes of demographic changes, economic development and socio-economic stratification. In relation to demographic changes, migration plays a central role in "the complementarity of the population dynamics of the regions of origin with the dynamics in the countries of destination" (Canales, 2016, p. 22). In relation to the reproduction of capital, it has a double effect: as a process of transferring labor force and human capital between the contexts of origin and destination, and by originating flows of resources, especially remittances, often essential for the social reproduction of families, by definition, transnational and their communities of origin. Finally, migration is an important factor in the reproduction of social differences and inequalities in the countries of origin and destination. In the former case, there is a dependence on the labor and economic dynamics of the contexts of arrival. In the latter case, the work of immigrants is usually concentrated in activities linked to the social and daily reproduction of the native population, for example, through domestic and care work, as is generally the case of Paraguayan and Peruvian women, or in activities linked to rural work, as is the case of Bolivian families (CEPAL, 2018; Courtis & Pacecca, 2010).

Food consumption belongs to the habitual practices in private and daily sphere of all human beings, it is also an unmistakable feature of economic, social, and cultural position. Inevitably, during the migratory process, children‘s food habits are transformed as a way of cultural and economic adaptation to the new environment. Given that food is a faithful reflection of the social roles and cultural customs of a community, it is to be expected that the nutritional status and/or physical activity are also differentiated in the population (Pavez-Soto et al., 2017). In this sense, it seems that post-migration food practices are often associated with a detriment in nutritional status, quality of life and health status, as reported by Zhou et al. (2018): “the problem that migrants must face is not the availability of food, specific to their place of origin, but rather access, by virtue of the income they have and the costs, distances and time to acquire the products”.

Indeed, in a system where food is a consumer good and consequently access to it is strongly dependent on income and on the cost of food (Aguirre, 2004, 2005) “acceptable, sufficient and adequate”, the basis of food security, is restricted for these sectors, promoting high prevalence of child malnutrition as we observed in the present study. Likewise, the results obtained showed the unequal distribution is even more accentuated in the case of immigrant families, who arrive in the country in search of better living conditions and find themselves in precarious situations that end up affecting children‘s growth, health, and nutrition, since food has a direct impact on the development of chronic undernutrition, obesity and other chronic non-communicable diseases at the present and/or in a future life. Household socio-economic environment and diet of children are the important determinants of child health. Recent studies also reported that it is not only the nutrition, rather social-economic-political-emotional (SEPE) inequalities and insecurities are the important factors that determine physical growth and nutrition of children (Bogin & Varea, 2020; Schffler et al., 2019).

Therefore, to achieve food security, the State must guarantee, in addition to availability, access to food for these immigrant communities. Equal access and basic citizenship rights are the public obligations with respect to food security. In addition, having access to nutritionally sufficient and culturally appropriate food is a fundamental part of “feeling at home”, as food “is central to our sense of identity” (Fischler, 1988; Koc & Welsh, 2014).

12.6 Final Considerations

Based on the data analyzed, we are able to affirm that the population residing in the productive belt of La Plata city is defined as heterogeneous one, in terms of ethnic, cultural, social, and economic opportunities and quality of life. Native/migrant status appears as a differentiating variable that places the migrant group at a higher levels of socioeconomic and environmental vulnerability, with impacts on child health. In this context, excess weight -possibly due to an inadequate and monotonous diet of low nutritive values- together with social-economic-political-emotional inequalities and insecurities are of concerns. In addition, undernutrition, although to a lesser degree, is still present in this population, indicating a nutrition transition process. Therefore, it is essential to implement joint actions by different public sectors for intervention programs to improve the living conditions also to mitigate child malnutrition in this population, paying special attention to the needs of immigrant families.

Acknowledgments The authors are especially grateful to the school authorities, parents, mothers, and students of the localities of Arana, Arturo Seguí, Ángel Etcheverry, Los Hornos, Lisandro Olmos and for their disinterested participation. We would also like to thank María Cristina Muñe for her careful reading and contributions to the manuscript. This work was funded by the *Consejo Nacional de Investigaciones Científicas y Técnicas* (CONICET: PIP 0106); by the *Agencia Nacional de Promoción Científica y Tecnológica* (ANPCyT: PICT 01145 and PICT 2049); and by the *Universidad Nacional de La Plata* (UNLP: 11 N/808).

Conflict of Interest The authors declare no conflicts of interest associated with the study.

References

Aguirre, P. (2004). *Ricos Flacos, Gordos Pobres. La Alimentación en Crisis*. Colección Claves para Todos. Capital Intelectual.

Aguirre, P. (2005). *Estrategias de Consumo ¿Qué Comen los Argentinos que Comen?* Miño y Dávila-CIEPP.

Aguirre, P. (2010a). An anthropological view of the impact of poverty and globalization on the emerging epidemic of obesity. In A. Tsatsoulis, J. Wyckoff, & F. Brown (Eds.), *Diabetes in women. Pathophysiology and therapy* (pp. 105–125). Springer/Humana Press. https://doi.org/10.1007/978-1-60327-250-6. ISBN 978-1-60327-249-0, e-ISBN 978-1-60327-250-6.

Aguirre, P. (2010b). La construcción social del gusto en el comensal moderno. In P. Aguirre, M. Katz, & M. Bruera (Eds.), *Comer. Una Palabra con Múltiples Sentidos*. Libros del Zorzal. ISBN 10: 9875991546, ISBN 13: 9789875991545.

Ambort, M. E. (2019). Género, migración y trabajo en la agricultura familiar: Trayectorias laborales y migratorias de horticultoras bolivianas en el cinturón hortícola del gran La Plata (Argentina), 2018. *Revista Latinoamericana de Antropología del Trabajo, 3*(6), 1–31. From http://www.memoria.fahce.unlp.edu.ar/art_revistas/pr.11843/pr.11843.pdf. Last access: 14 Nov 2022.

Atalah, E., Amigo, H., & Bustos, P. (2014). Does Chile's nutritional situation constitute a double burden? *American Journal of Clinical Nutrition, 100*(6), 1623S–1627S. https://doi.org/10.3945/ajcn.114.083790. Last access: 14 Nov 2022.

Balán, J. (1985). *Las Migraciones Internacionales en el Cono Sur*. CIM. From http://repositorio.cedes.org/handle/123456789/3984. Last access: 14 Nov 2022

Barsky, A. (2015). Las producciones familiares bolivianas y el rol del Estado: Análisis de las políticas públicas para el sostenimiento de la agricultura periurbana en la Región Metropolitana de Buenos Aires (2000–2015). *Revista de Ciencias Sociales, Segunda Época*, *28,* 33–47. From http://ridaa.unq.edu.ar/handle/20.500.11807/1631. Last access: 14 Nov 2022.

Bergel Sanchís, M. L. (2014). *Malnutrición, Condiciones Socio-ambientales y Alimentación Familiar. Un Estudio Bio-socio-antropológico en Población Escolar de Villaguay (Provincia de Entre Ríos, Argentina).* [Doctoral thesis]. Facultad de Ciencias Naturales y Museo. Universidad Nacional de La Plata. https://doi.org/10.35537/10915/43346. Last access: 14 Nov 2022.

Bergel Sanchís, M. L., Cesani, M. F., & Oyhenart, E. E. (2017). Contexts of occurrence of child malnutrition in the district of Villaguay, Entre Ríos, Argentina. A multivariate analysis. *PLoS ONE, 12*(4), e0176346. https://doi.org/10.1371/journal.pone.0176346. Last access: 14 Nov 2022.

Bergel Sanchís, M. L., Quintero, F. A., Navazo, B., Cesani, M. F., Garraza, M., Torres, M. F., Luna, M. E., Luis, M. A., Castro, L. E., & Oyhenart, E. E. (2016). Caracterización del estado nutricional en relación con factores socio-ambientales de la población escolar del partido de Punta Indio (provincia de Buenos Aires, Argentina). *Revista Argentina de Antropología Biológica, 18*(2), 1–13. https://doi.org/10.17139/raab.2016.0018.02.09

Bogin, B., & Varea, C. (2020). COVID-19, crisis, and emotional stress: A biocultural perspective of their impact on growth and development for the next generation. *American Journal of Human Biology, 32*(5), e23474. https://doi.org/10.1002/ajhb.23474

Bustamante, M. J., Alfaro, E. L., Dipierri, J. E., & Román, M. D. (2021). Excess weight and thinness over two decades (1996-2015) and spatial distribution in children from Jujuy, Argentina. *BMC Public Health, 21*, 196. https://doi.org/10.1186/s12889-021-10239-4

Canales, A. I. (2016). La migración en la reproducción de la sociedad. Elementos para una teoría de las migraciones. In: Canales A (coordinador). *Debates Contemporáneos sobre Migración Internacional. Una Mirada desde América Latina* (pp. 21–63). Universidad de Guadalajara-Miguel Angel Porrúa Editor.

CEPAL. (2018). Estudio Económico de América Latina y el Caribe. Evolución de la Inversión en América Latina y el Caribe: Hechos Estilizados, Determinantes y Desafíos de Política. In *Comisión Económica para América Latina y el Caribe (CEPAL)*. ISBN 978-92-1-121996-8 (Printed).

Cerrutti, M. (2010). *Salud y Migración Internacional: Mujeres Bolivianas en la Argentina*. Fondo de Población de las Naciones Unidas (UNFPA)-Centro de Estudios de Población (CENEP).

CHFBA (2005). *Censo Hortiflorícola. Provincia de Buenos Aires 2005*. Gobierno de la Provincia de Buenos Aires. Ministerio de Economía, Dirección Provincial de Estadística. Ministerio de Asuntos Agrarios, Dirección Provincial de Economía Rural, Buenos Aires, Argentina.

Contreras, J. (2007). Alimentación y Religión. *Humanitas, Humanidades Médicas, 16*, 1–31. ISSN-e 1886-1601.

Cordero, M. L., & Cesani, M. F. (2018). Sobrepeso, obesidad y salud percibida en contextos de pobreza de Tucumán, Argentina. *Salud Colectiva, 14*(3), 563–578. https://doi.org/10.18294/sc.2018.1309. Last access: 14 Nov 2022.

Cordero, M. L., & Cesani, M. F. (2019). Nutritional transition in schoolchildren from Tucumán, Argentina: A cross-sectional analysis of nutritional status and body composition. *American Journal of Human Biology, 31*, e23257. https://doi.org/10.1002/ajhb.23257

Courtis, C., & Pacecca, M. I. (2010). Género y trayectoria migratoria: Mujeres migrantes y trabajo doméstico en el Área Metropolitana de Buenos Aires. *Papeles de Población, 16*(63), 155–185. ISSN-e 2448-7147.

Durán, P., Mangialavori, G., Biglieri, A., Kogan, L., & Abeyá Gilardon, E. (2009). Estudio descriptivo de la situación nutricional en niños de 6–72 meses de la República Argentina. Resultados de la Encuesta Nacional de Nutrición y Salud (ENNyS). *Archivos Argentinos de Pediatría, 107*(5), 397–404. From https://www.sap.org.ar/docs/publicaciones/archivosarg/2009/v107n5a06.pdf. Last access: 14 Nov 2022

Durán Monfort, P. D. (2006). ¿Estamos ante un nuevo orden alimentario en Túnez? La obtención y el consumo de carne como indicador de globalización. *Contra/Relatos desde el Sur. Apuntes sobre África y Medio Oriente, 3*, 45–66. ISSN 1669-953X.

FAO. (2011). *El Estado de la Inseguridad Alimentaria en el Mundo ¿Cómo Afecta la Volatilidad de los Precios Internacionales a las Economías Nacionales y la Seguridad Alimentaria?* FAO. ISBN 978-92-5-306927-9.

Feito, M. C. (2018). Problemas y desafíos del periurbano de Buenos Aires. Estudios Socioterritoriales. *Revista de Geografía, 24*, e002. From http://hdl.handle.net/11336/97356. Last access: 14 Nov 2022

Fernández, L. (2018). La exclusión social de los agricultores familiares de La Plata. Un análisis del período 2005-2018. *Revista Pilquen – Sección Ciencias Sociales, 21*(2), 109–128. From https://www.redalyc.org/articulo.oa?id=347558973009. Last access: 14 Nov 2022.

Fischler, C. (1988). Food, self and identity. *Social Science Information, 27*(2), 275–292. https://doi.org/10.1177/053901888027002005. Last access: 14 Nov 2022.

Fischler, C. (1995). *El (h)omnívoro. El Gusto, la Cocina y el Cuerpo*. Editorial Anagrama.

García, M. (2015). Horticultura de La Plata (Buenos Aires). Modelo productivo irracionalmente exitoso. *Revista de la Facultad de Agronomía, 114*(Núm. Esp. 1), 190–201.

García Canclini, N. (1995). *Consumidores y Ciudadanos. Conflictos Multiculturales de la Globalización*. Grijalbo.

Garraza, M., & Oyhenart, E. E. (2020). Doble carga de malnutrición, composición y proporción corporal en escolares del periurbano de Guaymallén, Mendoza. *Nutrición Clínica y Dietética Hospitalaria, 40*(4), 99–107. https://doi.org/10.12873/404garraza

de Gorban, M. K (2014) La crisis mundial y la problemática alimentaria. In: de Gorban MK, Carballo C, Paiva M, Abajo V, Filardi M, Giai M, Veronesi G, Graciano A, Risso Patrón V, Broccoli AM, Gilardi R Seguridad y Soberanía Alimentaria. : Akadia. p 97–112.

Guimarey, L. M., Castro, L. E., Torres, M. F., Cesani, M. F., Luis, M. A., Quintero, F. A., & Oyhenart, E. E. (2014). Secular changes in body size and body composition in schoolchildren from La Plata City (Argentina). *Anthropologischer Anzeiger, 71*(3), 287–301. https://doi.org/10.1127/0003-5548/2014/0364

Hun, N., & Urzúa, A. (2019). Comportamiento alimentario en inmigrantes, aportes desde la evidencia. *Revista Chilena de Nutrición, 46*(2), 190–196. https://doi.org/10.4067/S0717-75182019000200190. Last access: 14 Nov 2022.

Instituto Nacional de Estadística y Censos (INDEC). (2018). *Indicadores de condiciones de vida de los hogares en 31 aglomerados urbanos. Primer semestre de 2018.* Condiciones de vida. Vol. 2, N° 1. Ministerio de Hacienda. Presidencia de la Nación. ISSN 2545-6660. From http://www.indec.gob.ar/uploads/informesdeprensa/eph_indicadores_hogares_01_18.pdf. Last access: 14 Nov 2022.

Koc, M., & Welsh, J. (2014). Alimentos, prácticas alimentarias y experiencia de la inmigración. In L. R. Piaggio & A. M. Solans (Eds.), *Enfoques Socioculturales de la Alimentación* (pp. 212–229). Librería Akadia Editorial. ISBN 978-987-570-239-4.

Lohman, T. G., Roche, A. F., & Martorell, R. (1988). *Anthropometric standardization reference manual*. Human Kinetics Books.

Magliano, M. J., & Mallimaci Barral, A. I. (2015). Las edades de la migración boliviana en Argentina: Córdoba y Ushuaia como destino. Si Somos Americanos. *Revista de Estudios Transfronterizos, XV(1)*, 141–167. https://doi.org/10.4067/S0719-09482015000100006. Last access: 14 Nov 2022.

Navazo, B., Dahinten, S. L., & Oyhenart, E. E. (2018). Malnutrición y pobreza estructural. Comparación de dos cohortes de escolares de Puerto Madryn, Argentina. *Revista de Salud Pública, 20*(1), 60–66.

Navazo, B., Oyhenart, E. E., & Dahinten, S. L. (2019). Doble carga de malnutrición y nivel de bienestar socio-ambiental de escolares de la Patagonia Argentina (Puerto Madryn, Chubut). *Nutrición Clínica y Dietética Hospitalaria, 39*(2), 111–119. https://doi.org/10.12873/392navazo

Ortale, M. S. (2003). *Prácticas y Representaciones sobre Desnutrición Infantil de Causa Primaria en Familias Pobres Urbanas del Gran La Plata* [Doctoral thesis]. Facultad de Ciencias Naturales y Museo. Universidad Nacional de La Plata. https://doi.org/10.35537/10915/4585. Last access: 14 Nov 2022.

Oyhenart, E. E., Castro, L. E., Forte, L. M., Sicre, M. L., Quintero, F. A., Luis, M. A., Torres, M. F., Luna, M. E., Cesani, M. F., & Orden, A. B. (2008). Socioenvironmental conditions and nutritional status in urban and rural schoolchildren. *American Journal of Human Biology, 20*(4), 399–405. https://doi.org/10.1002/ajhb.20738. Last access: 14 Nov 2022.

Oyhenart, E. E., Luis, M. A., Torres, M. F., Forte, L. M., Garraza, M., Quintero, F. A., Bergel Sanchís, M. L., Navazo, B., Luna, M. E., & Cesani, M. F. (2021). El periurbano productivo de la ciudad de La Plata (Buenos Aires, Argentina). Un espacio propicio para la malnutrición infanto-juvenil. *Revista Argentina de Antropología Biológica, 23*(1), 1–14. https://doi.org/10.24215/18536387e026

Patel, R. (2008). *Obesos y Famélicos. El Impacto de la Globalización en el Sistema Alimentario Mundial*. Marea Editorial. ISBN 978-987-1307-18-0.

Pavez-Soto, I., Durán-Agüero, S., & Valladares, M. (2017). Infancia migrante y alimentación: Desafíos culturales y sanitarios. *Revista Médica de Chile, 145*(1), 135–136. https://doi.org/10.4067/S0034-98872017000100019. Last access: 14 Nov 2022.

Peña Sánchez, E. Y. (2012). *Enfoque Biocultural en Antropología. Alimentación-Nutrición y Salud-Enfermedad en Santiago de Anaya, Hidalgo*. Instituto Nacional de Antropología e Historia, México, D.F. ISBN 978-607-484-258-6.

Piaggio, L., Concilio, C., Rolón, M., Macedra, G., & Dupraz, S. (2011). Alimentación infantil en el ámbito escolar: Entre patios, aulas y comedores. *Salud Colectiva, 7*(2), 199–213.

Quintero, F. A., Cesani, M. F., Luis, M. A., Torres, M. F., Garraza, M., Navazo, B., Luna, M. E., Forte, L. M., & Oyhenart, E. E. (2021). Distribución geográfica de la presión arterial elevada en relación al exceso ponderal en niños y niñas que viven en el cinturón productivo de La Plata (Buenos Aires, Argentina). *Revista Argentina de Antropología Biológica, 23*(2), 1–15. https://doi.org/10.24215/18536387e039

Rosique Gracia, J., García, A. F., & Villada Gómez, B. A. (2012). Estado nutricional, patrón alimentario y transición nutricional en escolares de Donmatías (Antioquia). *Revista Colombiana de Antropología, 48*(1), 97–124. ISSN 0486–6525.

Scheffler, C., Hermanussen, M., Bogin, B., Liana, D. S., Taolin, F., Cempaka, P. M. V. P., Irawan, M., Ibbibah, L. F., Mappapa, N. K., Payong, M. K. E., Homalessy, A. V., Takalapeta, A., Apriyanti, S., Manoeroe, M. G., Dupe, F. R., Ratri, R. R. K., Touw, S. Y., K, P. V., Murtani, B. J., Nunuhitu, R., Puspitasari, R., Riandra, I. K., Liwan, A. S., Amandari, P., Permatasari, A. A. I., Julia, M., Batubara, J., & Pulungan, A. (2019). Stunting is not a synonym of malnutrition. *European Journal of Clinical Nutrition, 74*(3), 377–386. https://doi.org/10.1038/s41430-019-0439-4

Salva, M. C. (2000). Cotidianeidad en la horticultura: Cuerpo, trabajo y salud. In R. Ringuelet (Compilador), *Espacio Tecnológico, Población y Reproducción Social en el Sector Hortícola de La Plata* (vol. 39, pp. 103–114). Facultad de Humanidades y Ciencias de la Educación. UNLP.

WHO. (2006). *Multicentre growth reference study group. WHO child growth standards: Length/height-for-age, weight-for-age, weight-for-length, weight-for-height and body mass index-for-age: Methods and development*. World Health Organization. ISBN 924154693X.

WHO. (2008). *Obesity and overweight*. World Health Organization.

WHO. (2021). *Malnutrition*. World Health Organization. From https://www.who.int/news-room/fact-sheets/detail/malnutrition. Last access: 14 Nov 2022.

Zhou, Y., von Lengerke, T., Walter, U., & Dreier, M. (2018). Migration background and childhood overweight in the Hannover Region in 2010–2014: A population-based secondary data analysis of school entry examinations. *European Journal of Pediatrics, 177*, 753–763. https://doi.org/10.1007/s00431-018-3118-x. Last access: 14 Nov 2022.

Chapter 13
Growth and Nutrition Indicators in Brazil: Some Perspectives and Changes from 1975 to 2019

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13.1 Introduction

Brazil is a multicultural country, with a population matrix composed by indigenous populations, and descendants of European, African and Asian populations. In the American continent, Brazil occupies the third largest geographical area, population, and economy size as measured by the GINI Index of the World Bank. Brazil also holds high figures in inequality indicators: stays among the 20 countries with highest values for GINI index; the 10% poorest share only 1.6% of the national income;

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S. Datta Banik (ed.), *Human Growth and Nutrition in Latin American and Caribbean Countries*, https://doi.org/10.1007/978-3-031-27848-8_13

in 2019, the annualized average growth rate in per capita mean consumption or income dropped 1.4% for the bottom 40% of population while it grew 20.4% for the population mean (World Bank, 2022).

Nutritional status is influenced by factors such as social and political policies, access to health services, food market, and cultural practices. These factors rearrange in different ways and with different weigh to determine obesity or growth deficit, or to explain nutritional status in adults and children (Monteiro et al., 2010; Bogin, 2021).

In the last decades, the country has experienced a fast nutrition and epidemiologic transition. Among children under 5 years of age, prevalence of stunting – an insufficient growth to a given age (low height-for-age) has decreased over the last five decades concurrently with the reduction of social inequalities (Monteiro et al., 2009). That achievement is attributable mostly to a mix of health and social policies adopted in Brazil in those decades (Victora et al., 2011).

Among adults, obesity has been increasing and it is extensively associated with increased risk of morbidity and mortality, cardiovascular diseases, some types of cancer, chronic musculoskeletal problems etc. Overall, in Brazil, data from available regional and national surveys suggest that, in general, nutritional status trends go in line with global trends. In 2013, Brazil ranked third with the highest absolute number of obese men (11.9 million) (Gomes et al., 2019). Among women, there was a flat trend interval for obesity from 1989 to 2003, soon reversed to an increasing trend in the next period from 2003 to 2009 (Gomes et al., 2019). In public health perspective, a drop by 5% of mean body mass index (BMI) across the population could save US$273 billion over 40 years in the country (Rtveladze et al., 2013).

Globally, deficiency of energy intake resulting in undernutrition is associated with poverty and affects mostly children (Monteiro, 2003). Undernutrition was a severe burden for Brazilian people for many decades, but in recent years it has been decreasing compared to the increase in obesity rates (Coutinho et al., 2008). Between 1975 and 1997 the proportion of underweight to obese women changed from 2:1 to 1:2 (Coutinho et al., 2008; Monteiro et al., 2004).

Within the Brazil's diverse ethnic/ancestral matrix, growth and health trajectory of some populations, such as the native American populations and the Quilombola (afroderived) groups deserve special attention as these have been subject to greater impacts of the social determinants of health and are the most affected by the socio-ecological changes taking place in the last decades, especially in the Amazon region (Silva et al., 2016). The objectives of this chapter are to describe the overall secular trend of anthropometric indicators in Brazil, to analyze the evolution of anthropometric growth indicators in the country, and to discuss some growth and health aspects of traditional Amazonian Quilombola groups as an example of the diversity and the complexity involved in analyzing growth, nutrition and development trends in the Brazilian population.

13.2 Methods

The information used in this study is organized in two blocks. The first comes from data of nine Brazilian national surveys presented in chronological order as follows: National Study on Family Expenditures (*Estudo Nacional da Despesa Familiar* [ENDEF]), carried out in 1974–1975 (IBGE, 1978); National Health and Nutrition Survey (*Pesquisa Nacional sobre Saúde e Nutrição* [PNSN]) performed in 1989 (IBGE, 1990); Demographic and Health Surveys (*Pesquisa Nacional de Demografia e Saúde* [PNDS]) in 2 editions, the first in 1996 (IBGE, 1997) and the second in 2006 (Brasil & Centro Brasileiro de Análise e Planejamento, 2009); the Family Budget Surveys (*Pesquisa de Orçamentos Familiares* [POF]) in 2 editions, the first conducted in 2002–2003 (IBGE, 2004), and the second in 2008–2009 (IBGE, 2010); the National Adolescent School-based Health Survey (*Pesquisa Nacional de Saúde dos Escolares* [PeNSE]) performed in 2015 (IBGE, 2016), and finally, the National Health Survey (*Pesquisa Nacional de Saúde*) in 2 editions, the first one in 2013 (IBGE, 2015) and the second in 2019 (IBGE, 2020). All surveys were designed to sample household complexes that were representative of the Brazilian population. The surveys conducted before the 2000s did not sample the rural areas in the northern region of Brazil. The one conducted in 2002–2003 sampled some of these areas.

Samples drawn in the surveys were calculated to be representative of the Brazilian population and allow direct comparisons at national level as well as large stratification across the period analyzed. Complete information about sampling schemes, variables, and data collection procedures are described in the respective survey reports. All surveys were carried out under request of the Brazilian Health Ministry. Eight of them were conducted by the Brazilian National Agency of Geography and Statistics (IBGE in Portuguese). The survey PNDS 2006 was conducted by the Brazilian Center of Analysis and Planning (CEBRAP). All datasets are available for download in the IBGE (www.ibge.gov.br) and in the Brazilian Health Ministry site (https://bvsms.saude.gov.br/bvs/pnds/). Both National Health Surveys were approved by the National Ethics in Research Commission (CONEP) under protocol No 328159 for PNS-2013 and No 3529376 for PNS-2019.

Anthropometric measurements were performed for all subjects in 6 of the surveys. In PeNSE-2015, PNS-2013 and PNS-2019, anthropometric measurements were recorded only in a subsample. The original information about the national surveys (name, acronym, year, subjects' number available and used for analysis) are summarized in Table 13.1. The data for year 2019 (results presented in Table 13.2 and 13.3) come from the first report of National Study of Food and Child Nutrition (Estudo Nacional de Alimentação e Nutrição Infantil [ENANI]), a survey carried out by a team of the University Federal of Rio de Janeiro and other partners. The tables and results can be accessed at https://enani.nutricao.ufrj.br/index.php/2022/02/08/relatorio-7-estado-nutricional-antropometrico-da-crianca-e-da-mae/.

Table 13.1 Surveys name, sampling place, age range and number of individuals used for analysis

Survey (year)	Individual sampling was carried out at	Age group	Number of subjects (n) available in survey	Number subjects (n) used for analysis
ENDEF (1975)	Household	All (0–110 year)	321,374	274,769
PNSN (1989)	Household	All (0–108 year)	64,813	62,977
PNDS (1996)	Household	Children (0–5 year)	4,818	4,104
POF (2003)	Household	All (0–109 year)	182,333	168,250
PNDS (2006)	Household	Children (0–5 year)	4,820	4,385
POF (2009)	Household	All (0–110 year)	190,159	180,452
PNS (2013)	Household	All (18–109 year)	63,332	59,222
PeNSE (2015)	School	Adolescents (10–19 year)	16,556	16,553
PNS (2019)	Household	All (0–112 year)	6,827	6,570

Table 13.2 Stunting trend (%) among children under 5 years of age according to age group, place of household and socioeconomic status

Age groups (years)	Stunting % (95% CI)				
	1975	1989	1996	2006	2019
Brazil (whole population)	37.1 (34.6; 39.6)	19.9 (17.8; 21.9)	13.5 (12.1; 14.9)	7.1 (5.7; 8.5)	7.0 (6.0; 7.9)
0–0.9	31.5 (29.1; 33.9)	13.6 (10.9; 16.3)	10.0 (7.9; 12.2)	4.9 (2.8; 6.9)	9.0 (6.7; 11.3)
1–1.9	42.1 (38.9; 45.3)	21.2 (18.3; 24.1)	18.2 (15.3; 21.2)	12.7 (7.5; 18.0)	10.2 (8.1; 12.2)
2–4.9	37.3 (34.8; 39.8)	21.4 (19.0; 23.8)	13.3 (11.6; 14.9)	6.1 (4.9; 7.3)	5.2 (3.6; 6.8)
Place of household					
Urban	29.7 (26.9; 32.6)	16.1 (13.4; 18.8)	10.4 (9.1; 11.7)	7.0 (5.4; 8.6)	7.0 (6.1; 8.0)
Rural	45.4 (42.6; 48.2)	28.2 (25.5; 30.9)	23.5 (20.0; 27.1)	7.5 (5.2; 9.9)	5.0 (1.7; 8.2)
Wealth quintiles					
1 (poorest)	59.0 (57.1; 61.0)	39.1 (35.5; 42.7)	30.0 (26.1; 34.0)	11.1 (8.4; 13.7)	7.1 (6.2; 7.9)
2	50.8 (48.6; 52.9)	30.6 (25.9; 35.2)	19.9 (16.4; 23.3)	9.2 (5.0; 13.4)	8.5 (6.6; 10.3)
3	38.5 (36.6; 40.3)	16.6 (13.9; 19.3)	8.6 (6.6; 10.5)	7.7 (4.3; 11.1)	8.3 (5.5; 11.0)
4	25.7 (24.3; 27.1)	7.2 (5.0; 9.5)	5.6 (3.7; 7.5)	3.7 (2.0; 5.4)	6.5 (4.5; 8.5)
5 (richest)	12.1 (10.8; 13.4)	5.1 (3.4; 6.7)	5.6 (3.6; 7.6)	4.0 (1.7; 6.3)	4.4 (2.4; 6.4)

Brazil 1975–2019
CI Confidence Interval

Table 13.3 Overweight trend (%) among children under 5 years of age according to age group, place of household and socioeconomic status

Age groups (years)	Overweight % (95% CI)				
	1975	1989	1996	2006	2019
Brazil (whole population)	12.3 (11.9; 12.7)	8.5 (7.6; 9.4)	7.5 (6.6; 8.4)	7.2 (5.9; 8.4)	10.1 (9.0; 11.1)
0–0.9	19.1 (17.9; 20.3)	9.0 (6.7; 11.3)	7.7 (5.7; 9.6)	6.5 (4.2; 8.8)	9.6 (7.4; 11.9)
1–1.9	18.4 (17.3; 19.5)	13.4 (10.8; 16.0)	12.3 (9.8; 14.8)	8.0 (4.6; 11.5)	13.7 (11.7; 15.6)
2–4.9	8.4 (7.9; 8.8)	6.7 (5.6; 7.7)	5.9 (4.8; 6.9)	7.1 (5.6; 8.7)	9.2 (6.6; 11.5)
Place of household					
Urban	11.9 (11.3; 12.4)	9.0 (7.7; 10.3)	7.5 (6.4; 8.6)	7.4 (5.9; 8.8)	10.0 (8.9; 11.1)
Rural	12.7 (12.1; 13.3)	7.3 (6.4; 8.2)	7.7 (6.0; 9.4)	6.3 (4.5; 8.1)	12.8 (9.1; 16.5)
Wealth quintiles					
1 (poorest)	11.9 (11.0; 12.8)	5.6 (4.2; 7.0)	9.1 (7.2; 11.1)	4.4 (2.5; 6.2)	8.3 (7.5; 9.1)
2	13.1 (12.2; 14.1)	7.2 (5.4; 9.0)	5.9 (4.2; 7.7)	7.8 (4.6; 11.0)	9.7 (7.8; 11.7)
3	11.6 (10.7; 12.6)	9.5 (7.2; 11.8)	7.2 (5.2; 9.1)	8.2 (5.1; 11.3)	10.5 (8.1; 13.0)
4	11.1 (10.3; 12.0)	7.6 (5.5; 9.7)	8.7 (6.4; 11.0)	6.4 (4.3; 8.5)	10.3 (8.1; 13.4)
5 (richest)	13.6 (12.7; 14.6)	13.0 (10.3; 15.8)	6.8 (4.8; 8.9)	8.6 (5.7; 11.5)	11.7 (7.9; 15.5)

Brazil 1975–2019
CI Confidence Interval

The second block of analysis encompasses primary data from field research conducted among Quilombola (afroderived) rural populations living in several areas of the Amazon basin, composing a wide range of groups and environments, representative of the socioecological diversity of the region (Melo & Silva, 2015; Guimarães & Silva, 2015; Guimarães et al., 2018).

The data for this analysis come from research projects developed between 2008 and 2018 which followed international guidelines of research ethics and were approved by the Research Ethics Committee of the Institute of Health Sciences of the Federal University of Pará – ICS/UFPA (CAAE: 21328913.3.0000.0018). The objective is to present results obtained from the database of representative samples drawn from the populations, thus providing information about these rural, afroderived communities. The sampling strategy was random, and voluntary participation of individuals and communities.

Methodologically, the research team carried out fieldwork and visited the households of each Quilombola locality and asked the parents or guardians to allow the participation of their children. All participants over 18 years of age and/or legal guardians of minors were informed about the stages of the research and they agreed to participate voluntarily, by signing the Free and Informed Consent Term (TCLE).

The sample consists of 664 individuals aged 0–19 years (358 women, 306 men), being 178 children aged 0–4 years (99 girls, 79 boys), 188 children aged 5–9 years (91 girls, 97 boys), 166 early-adolescents aged 10–14 (83 women, 83 men) and 132 late-adolescents aged 15–19 (85 women, 47 men), from 318 Quilombola families.

Anthropometric data included height, weight, waist and hip circumferences, triceps, subscapular, suprailiac and gastrocnemius (calf) skinfolds. These measurement procedures followed the protocols proposed by Frisancho (2008), Weiner and Lourie (1981), WHO, (1995), and the Food and Nutrition Surveillance System – SISVAN (Ministério da Saúde, Brazil, 2008). The health assessment consisted of clinical examination with anamnesis, disease incidence and vaccination records, and it was performed by the health professionals of our team. In addition, structured questionnaires were applied to the adults of the families. These included questions on sex, age, race/color, marital status, educational status, family income, enrollment in government aid, house situation, number of rooms per household, type of material used for housing construction, water supply and treatment, sewage and garbage disposal, work activities, livelihood strategies and consumer goods available at home and type of food, following Silva (2001).

The Quilombolas included in this study encompass the main groups in Pará state. Some of them are officially recognized and others are in the process. They are known as África, Laranjituba, Santo Antônio, Mangueiras, Mola, Abacatal, Cachoeira Porteira, Juquirizinho, Erepecuru, Bacabal, and Arancuan. Details about the locations and socioecology of the communities are described elsewhere (Filgueiras & Silva, 2020; Guimarães et al., 2018; Melo & Silva, 2015; Silva et al., 2021).

13.2.1 Nutrition Indicators

BMI was calculated as weight (in kg) divided by height squared (m^2). Height and BMI-for-age were calculated by estimating z-scores of subject height or BMI according to the reference value in the WHO-2006 distribution. Values of height-for-age below −2 standard deviation (SD) z-scores indicate that the child is growing below expected average for its sex and age. WHO assigns this health condition as stunting. Values of BMI-for-age equal or superior to 1 SD z-score indicate that subject is gaining body mass above the expected for its sex and age. WHO assigns this health condition as overweight.

To assess nutritional status among the Quilombola, we used the indicators adopted by Frisancho (2008) and WHO (1995): weight-for-age (W/A), height-for-age (H/A) and BMI-for-age (BMI/A). The WHO Anthro and Anthro Plus programs were used. WHO (1995) establishes the z-score cut-off point less than −2 SD to indicate when the child is underweight for age, low H/A and low weight-for-height, which represents acute undernutrition, chronic undernutrition, and acute/chronic undernutrition, respectively and less than −3 SD for severe undernutrition. In contrast, values greater than +2 SD and +3 SD classify children as overweight and obese, respectively. For people over 10 years old, the weight-for-age parameter is not a good indicator because it cannot distinguish between height and body mass in an age period where many children are already going through puberty and can be understood as an excess of weight when in fact, they are just taller. BMI/A is the most appropriate indicator to assess thinness, overweight and obesity in the age group from 10 to 19 years. For the national sample, nutritional status of individuals aged ≥18 years was classified as underweight when their BMI (kg/m^2) was <18.5 and as obese when their BMI was ≥30 (Monteiro et al., 2009).

Among individuals below 20 years of age (children and adolescents), all figures presented for estimations of stunting and overweight prevalence follow the current age distribution as the percentages of age structure virtually does not change among surveys. Among adults, all estimations of underweight and obesity were age standardized to age distribution in 2019, the last available survey.

Household *per capita* income was calculated as the mean of the income values of all household residents, then household *per capita* income was converted into quintiles in every survey. In the 1996 and 2006 surveys, wealth index values were employed to calculate quintiles. These quintiles were used to stratify nutritional indicators according to social status.

The evolution of obesity prevalence among surveys was considered as an exponential series. Therefore, the annual growth rate calculated by dividing the obesity prevalence in that point of survey by that in the previous one and that ratio was raised to the power calculated as the inverse of the time span between surveys.

All indicators and statistics were estimated by considering the specific survey design (sample strata, cluster, and weighing structure). Analyses were performed by using *svy* prefix commands in Stata version 15.1. For the Quilombola, all data were incorporated into a database in the SPSS program, where absolute and relative frequencies for socioeconomic and demographic data were obtained. For the quantitative variables, mean, SD and Student's t test were used. There was no personal identification, ensuring the confidentiality of the participants in all research stages.

13.3 Results

13.3.1 The Current Anthropometric Picture of Brazil: General Trends

Among children under 5 years of age, prevalence of stunting dropped from 37.1% in 1975 to 7.1% in 2006. From 2006 to 2019 it remained stable. From 1975 to 2006 the reduction in stunting prevalence was more intense among the children from the poorest families (from 59% to 11.1%), and among children living in rural areas (from 45.4% to 7.5%) (Table 13.2). While there is some fluctuations within the time span, the period from 1975 to 2006 was marked by the reduction in social inequality and stunting prevalence. In 1975, stunting was almost 5 times more frequent among children from the poorest families relatively to that in the richest ones; in 2006 the same ratio dropped to 2.8.

From 2006 to 2019, overall stunting diminished among the children from the poorest families (from 11.1% to 7.1%), and among children living in rural areas (from 7.5% to 5.0%). On the other hand, among infants in the first year of life, the prevalence of stunting went from 4.9% to 9.0%, in opposition to the trend of the other age groups (Table 13.2).

Prevalence of overweight among children under 5 years of age in Brazil has evolved in a complex way. Overweight diagnosis relies upon the BMI which expresses the body mass adjusted for body area. While the child is growing, overweight will only be observed if weight gain surpasses the height gain at the given age. Overall, the overweight trend among children under 5 years in Brazil presents a U-shaped evolution. From 1975 to 2006 the overweight prevalence dropped from 12.3% to 7.2% and then increased to 10.1% in 2019 (Table 13.3).

The social stratification of the changes in overweight indicates that the decrease in overweight has reversed from 1996 to 2006, except for the children in the poorest social strata, and keep increasing, now for all social strata, from 2006 to 2019 (Table 13.3).

Among children and adolescents from 5 to 19 years, the school age years, there is a limitation for analysis as the data presented in Table 13.4; cannot be compared directly as there are different age ranges and, moreover, adolescent data from PeNSE 2015 were collected at school sites while the previous surveys collected data in the households. Nevertheless, it is still possible to infer from the data available that from the 5 to 9 years, there is a trend towards an increase in the prevalence of overweight for boys and girls. In the last available survey, almost 1 in 3 pre-adolescent children was overweight in the country (Table 13.4).

At the adolescent age range, 10–19 years, there is a huge increase in the prevalence of overweight among boys and girls. Especially in 15–19 years age group, the last available survey indicates that almost 1 in each 4 adolescents is overweight in Brazil (Table 13.4).

The distribution of overweight among school age children is influenced by gender when subject to social and ethnic stratification. Among boys, overweight is more frequent in individuals self-identified as white or yellow; among girls, overweight is more frequent in individuals self-identified as black or indigenous (Table 13.4). When considering social stratification, overweight is more frequent among individuals from the poorest families relative to the richest counterparts in both sexes. Overweight is more frequent in girls, relative to the boys, and among families from the 4th and 5th quintiles of wealth index across the time span observed (Table 13.4).

Among adults, the nutrition transition from underweight to high obesity prevalence from 1975 to 2019 draw the classical decreasing in underweight associated associated with increasing obesity trajectories. Underweight age standardized prevalence has decreased from 8.7% to 2% among men, and from

Table 13.4 Overweight trend (%) among school children 5–19 years of age according to age group, place of household, socioeconomic status and sex

Categories	Overweight % (95% CI)									
	Male					Female				
Survey year	1975	1989	2003	2009	2015**	1975	1989	2003	2009	2015**
Brazil prevalence	3.1 (2.9; 3.3)	5.8 (5.2; 6.5)	9.5 (9.0; 10.0)	13.3 (12.9; 13.8)	24.6 (23.3; 25.9)	17.9 (17.0; 18.8)	23.7 (20.2; 27.2)	9.1 (8.8; 9.4)	15.0 (14.0; 16.0)	25.9 (24.6; 27.2)
Age (years)										
5–9	10.9 (10.4; 11.5)	15.0 (13.3; 16.7)	a	34.8 (33.2; 36.4)	a	8.6 (8.2; 9.1)	11.9 (10.3; 13.4)	a	32.1 (30.4; 33.7)	a
10–14	4.4 (4.1; 4.8)	9.7 (8.3; 11.2)	21.3 (19.8; 22.8)	28.0 (26.5; 29.5)	29.0 (27.2; 30.8)	6.5 (6.1; 6.9)	13.3 (11.7; 14.9)	17.7 (16.2; 19.1)	22.4 (21.1; 23.8)	28.5 (26.7; 30.2)
15–19	2.7 (2.4; 3.1)	5.1 (3.9; 6.2)	12.1 (10.7; 13.5)	15.0 (13.8; 16.3)	21.0 (19.2; 22.8)	9.1 (8.4; 9.7)	14.0 (12.0; 16.0)	12.0 (10.7; 13.3)	15.5 (14.2; 16.7)	23.7 (21.7; 25.6)
Place of household										
Urban	7.1 (6.8; 7.5)	12.2 (11.0; 13.5)	18.7 (17.4; 19.9)	28.6 (27.5; 29.7)	24.8 (23.5; 26.1)	8.7 (8.3; 9.0)	13.9 (12.6; 15.2)	15.7 (14.5; 16.9)	25.2 (24.1; 26.3)	26.2 (24.8; 27.5)
Rural	5.7 (5.3; 6.1)	6.7 (6.0; 7.5)	10.6 (9.4; 11.8)	21.8 (20.6; 23.0)	21.7 (15.8; 27.6)	7.0 (6.5; 7.4)	10.3 (9.4; 11.3)	12.9 (11.6; 14.2)	20.1 (18.9; 21.3)	22.1 (15.8; 28.4)
Wealth quintiles										
1 (poorest)	0.6 (0.5; 0.8)	3.0 (2.6; 3.4)	1.5 (0.9; 2.1)	10.0 (8.4; 11.6)	27.4 (24.6; 30.2)	4.6 (4.1; 5.2)	12.3 (11.3; 13.3)	7.5 (6.9; 8.2)	16.4 (15.5; 17.2)	28.0 (25.1; 30.9)
2	1.7 (1.4; 2.0)	6.8 (6.2; 7.4)	3.3 (2.4; 4.3)	13.4 (11.5; 15.4)	28.4 (25.4; 31.3)	8.4 (7.3; 9.5)	15.0 (13.8; 16.2)	10.5 (9.6; 11.4)	18.2 (17.1; 19.2)	2c1 (23.4; 28.8)
3	3.1 (2.6; 3.5)	10.7 (10.0; 11.5)	5.2 (3.8; 6.6)	17.2 (14.8; 19.7)	23.0 (19.9; 26.1)	9.0 (7.9; 10.0)	15.7 (14.4; 17.0)	13.8 (12.7; 14.9)	19.8 (18.7; 21.0)	23.1 (20.0; 26.1)
4	4.3 (3.8; 4.8)	13.9 (13.0; 14.7)	8.8 (6.9; 10.7)	17.7 (15.3; 20.1)	22.2 (19.4; 25.0)	11.0 (9.7; 12.3)	16.1 (14.6; 17.5)	15.8 (14.6; 16.9)	19.7 (18.5; 21.0)	27.3 (24.4; 30.1)
5 (richest)	6.6 (6.0; 7.3)	11.8 (11.0; 12.7)	10.3 (8.4; 12.2)	17.2 (14.8; 19.5)	20.8 (18.3; 23.3)	13.9 (12.4; 15.5)	14.9 (13.3; 16.4)	17.9 (16.6; 19.2)	19.6 (18.2; 21.0)	24.2 (21.2; 27.3)
Ethnicity										

(continued)

Table 13.4 (continued)

Categories	Overweight % (95% CI)									
	Male					Female				
White	a	7.9 (6.9; 9.0)	15.8 (14.5; 17.1)	6.7 (5.1; 8.3)	27.2 (25.1; 29.3)	a	13.8 (13.1; 14.6)	12.5 (11.0; 14.0)	21.4 (19.6; 23.2)	25.1 (23.0; 27.2)
Black	a	4.2 (1.5; 6.8)	20.0 (14.8; 25.2)	7.9 (7.3; 8.6)	19.4 (16.4; 22.4)	a	4.1 (1.2; 7.0)	11.6 (11.0; 12.2)	18.2 (17.5; 18.9)	28.6 (24.6; 32.6)
Yellow	a	2.9 (2.3; 3.6)	13.2 (11.7; 14.6)	8.1 (2.0; 14.3)	26.3 (19.6; 33.0)	a	6.5 (1.9; 11.2)	11.5 (4.0; 19.0)	15.1 (7.6; 22.5)	22.9 (17.3; 28.4)
Brown	a	7.0 (−1.7; 15.6)	6.8 (−3.9; 17.5)	19.7 (7.7; 31.8)	24.0 (22.0; 26.1)	a	14.9 (14.2; 15.7)	11.9 (5.3; 18.6)	18.5 (9.7; 27.4)	25.9 (23.9; 27.9)
Indigenous	a	a	11.0 (10.2; 11.9)	15.4 (14.5; 16.3)	23.3 (17.4; 29.1)	a	a	19.0 (18.2; 19.8)	20.4 (19.0; 21.8)	30.9 (22.8; 38.9)

Brazil 1975–2019

**PeNSE- School-based survey; a- Variable not collected/available in this year

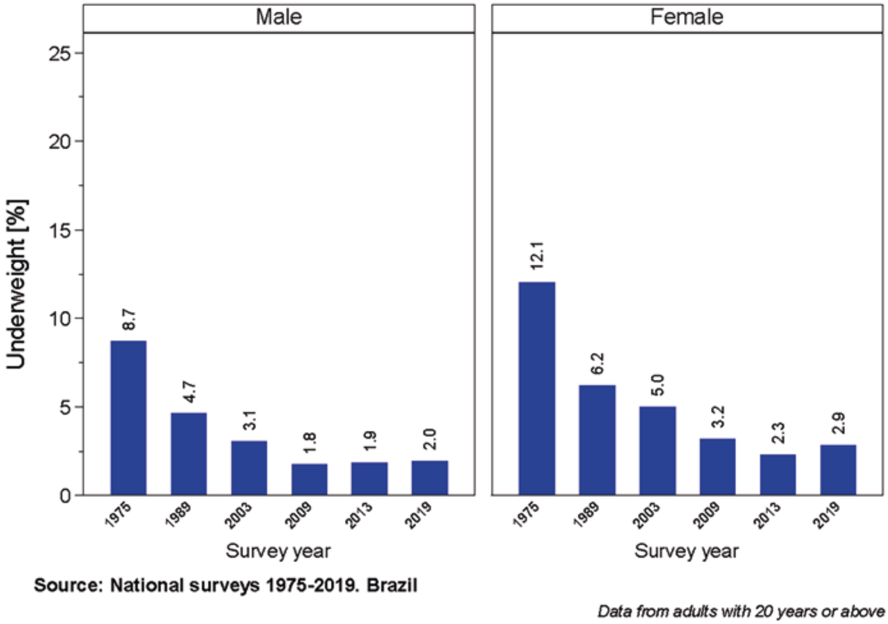

Fig. 13.1 Underweight trend (%) among Brazilian adults (above 20 years of age) in six national surveys according to sex. Brazil, 1975–2019

12.1% to 2.8% among women throughout that time span (Fig. 13.1). In the 2010s only among youngest children and the oldest adults underweight reached a prevalence above 4%. Underweight prevalence trend showed its last expressive decline from 2003 to 2009 (4.1–2.5%). Since 2009, underweight prevalence has virtually flattened at very low figures for males and females throughout the country.

In the opposite way, obesity prevalence trajectories scaled up from 3.1% to 23.7% among men, and from 9.1% to 30.1% among women in the general population (Tables 13.5 and 13.6). In both sexes, age range 40–59 year showed the highest prevalence, and increasing rate over the time observed. In the 2010s, at the age of 60 years or above, approximately one in every 4 Brazilians was obese.

If we inspect the trend of obesity prevalence separately by sex, men present exponential increase over time. From 1975 to 2019, the prevalence of obesity multiplied by 7. The increase in obesity prevalence is especially high from 2003 to 2013 surveys, in that period prevalence raised by about one percentage point per year. Among women, obesity prevalence has tripled from 1975 to 2019. From 1989 to 2003, obesity prevalence among women had flattened across ages, except for the oldest. From 2003 onwards, obesity prevalence increased continuously. At the starting point, in 1975, obesity prevalence among women was 3 times that observed among men (Fig. 13.2). This difference could explain partially the distinct increase rate for obesity between sexes in Brazil.

In general, for the adults, while underweight is virtually stabilized at very low prevalence since 2009, obesity has been increasing along all the time span observed.

Table 13.5 Obesity standardized prevalence (%) among Brazilian male adults (20 or + years) according to age group, place of household and socioeconomic status in six national surveys for both sexes

	Obesity % (95% CI)					
Survey year	1975	1989	2003	2009	2013	2019
Brazil prevalence	3.1 (2.9; 3.3)	5.8 (5.2; 6.5)	9.5 (9.0; 10.0)	13.3 (12.9; 13.8)	17.9 (17.0; 18.8)	23.7 (20.2; 27.2)
Age groups (years)						
20–29	1.0 (0.8; 1.2)	2.5 (1.8; 3.2)	4.2 (3.6; 4.7)	7.2 (6.6; 7.9)	11.9 (10.2; 13.6)	12.6 (7.8; 17.4)
30–44	2.9 (2.6; 3.2)	5.7 (4.8; 6.7)	10.0 (9.2; 10.7)	13.2 (12.5; 14.0)	17.9 (16.6; 19.2)	21.1 (16.9; 25.2)
45–59	4.4 (4.0; 4.8)	7.7 (6.3; 9.1)	12.4 (11.2; 13.5)	16.6 (15.7; 17.6)	21.4 (19.5; 23.2)	33.0 (23.9; 42.1)
60 to +	3.2 (2.7; 3.7)	5.7 (4.3; 7.2)	8.9 (7.7; 10.1)	13.2 (12.1; 14.3)	17.9 (16.0; 19.9)	21.3 (15.0; 27.6)
Place of household						
Urban	4.3 (4.0; 4.6)	7.1 (6.3; 8.0)	10.4 (9.8; 11.0)	14.1 (13.6; 14.7)	19.1 (18.0; 20.1)	24.5 (20.6; 28.3)
Rural	1.5 (1.3; 1.7)	2.2 (1.7; 2.6)	5.5 (4.9; 6.1)	9.5 (8.8; 10.2)	11.8 (10.3; 13.3)	14.8 (11.9; 17.7)
Wealth quintiles						
1 (poorest)	0.6 (0.5; 0.8)	1.5 (0.9; 2.1)	4.6 (4.1; 5.2)	7.5 (6.9; 8.2)	12.2 (10.7; 13.8)	17.9 (13.3; 22.6)
2	1.7 (1.4; 2.0)	3.3 (2.4; 4.3)	8.4 (7.3; 9.5)	10.5 (9.6; 11.4)	15.3 (13.4; 17.2)	18.3 (11.0; 25.5)
3	3.1 (2.6; 3.5)	5.2 (3.8; 6.6)	9.0 (7.9; 10.0)	13.8 (12.7; 14.9)	17.3 (15.2; 19.3)	19.8 (11.4; 28.2)
4	4.3 (3.8; 4.8)	8.8 (6.9; 10.7)	11.0 (9.7; 12.3)	15.8 (14.6; 16.9)	18.8 (16.9; 20.8)	32.1 (23.7; 40.5)
5 (richest)	6.6 (6.0; 7.3)	10.3 (8.4; 12.2)	13.9 (12.4; 15.5)	17.9 (16.6; 19.2)	24.3 (22.1; 26.4)	25.2 (18.8; 31.6)
Ethnicity						
White	a	7.9 (6.9; 9.0)	11.0 (10.2; 11.9)	14.9 (14.2; 15.7)	20.4 (19.0; 21.8)	25.5 (20.8; 30.2)
Black	a	4.2 (1.5; 6.8)	6.7 (5.1; 8.3)	12.5 (11.0; 14.0)	18.1 (14.8; 21.3)	29.0 (15.2; 42.8)
Brown	a	2.9 (2.3; 3.6)	7.9 (7.3; 8.6)	11.6 (11.0; 12.2)	15.3 (14.2; 16.5)	19.5 (14.9; 24.2)
Yellow	a	7.0 (−1.7; 15.6)	8.1 (2.0; 14.3)	11.5 (4.0; 19.0)	5.6 (2.4; 8.9)	0.0 (0.0; 0.0)
Indigenous	a	a	19.7 (7.7; 31.8)	11.9 (5.3; 18.6)	19.6 (7.0; 32.3)	42.8 (9.9; 75.7)

Brazil 1975–2019 [2019 standardized]
a- Variable not collected/available in this year. *CI* Confidence Interval

Table 13.6 Obesity standardized prevalence (%) among Brazilian female adults (20 or + years) according to age group, place of household and socioeconomic status in six national surveys for both sexes

	Obesity % (95% CI)					
Survey year	1975	1989	2003	2009	2013	2019
Brazil prevalence	9.1 (8.8; 9.4)	15.0 (14.0; 16.0)	14.9 (14.3; 15.5)	18.8 (18.3; 19.3)	26.3 (25.4; 27.2)	31.1 (27.7; 34.6)
Age groups (years)						
20–29	2.3 (2.1; 2.6)	4.6 (3.7; 5.5)	5.5 (4.9; 6.2)	8.0 (7.4; 8.7)	15.5 (13.8; 17.2)	22.0 (12.1; 31.8)
30–44	7.1 (6.7; 7.5)	12.0 (10.7; 13.3)	12.3 (11.5; 13.2)	16.0 (15.2; 16.8)	24.9 (23.4; 26.3)	29.2 (22.7; 35.7)
45–59	12.4 (11.7; 13.0)	19.4 (17.5; 21.4)	18.7 (17.5; 19.9)	23.0 (22.0; 24.1)	31.4 (29.5; 33.2)	38.7 (32.2; 45.3)
60 to +	10.8 (10.0; 11.5)	18.1 (15.9; 20.4)	18.0 (16.5; 19.4)	22.0 (20.8; 23.2)	27.6 (25.7; 29.4)	27.6 (22.8; 32.4)
Place of household						
Urban	10.9 (10.4; 11.3)	16.3 (15.1; 17.5)	15.1 (14.4; 15.8)	19.0 (18.4; 19.6)	26.8 (25.8; 27.7)	30.6 (26.9; 34.3)
Rural	6.0 (5.5; 6.4)	10.6 (9.7; 11.5)	13.8 (12.9; 14.7)	18.0 (17.1; 19.0)	23.4 (21.4; 25.4)	28.1 (24.1; 32.1)
Wealth quintiles						
1 (poorest)	3.0 (2.6; 3.4)	10.0 (8.4; 11.6)	12.3 (11.3; 13.3)	16.4 (15.5; 17.2)	25.4 (23.5; 27.3)	31.1 (25.2; 37.1)
2	6.8 (6.2; 7.4)	13.4 (11.5; 15.4)	15.0 (13.8; 16.2)	18.2 (17.1; 19.2)	26.6 (24.6; 28.6)	33.4 (26.6; 40.3)
3	10.7 (10.0; 11.5)	17.2 (14.8; 19.7)	15.7 (14.4; 17.0)	19.8 (18.7; 21.0)	27.7 (25.8; 29.7)	30.5 (23.8; 37.1)
4	13.9 (13.0; 14.7)	17.7 (15.3; 20.1)	16.1 (14.6; 17.5)	19.7 (18.5; 21.0)	28.6 (26.4; 30.7)	29.8 (20.4; 39.2)
5 (richest)	11.8 (11.0; 12.7)	17.2 (14.8; 19.5)	14.9 (13.3; 16.4)	19.6 (18.2; 21.0)	23.4 (21.4; 25.4)	26.5 (19.1; 34.0)
Ethnicity						
White	a	15.8 (14.5; 17.1)	15.4 (14.5; 16.3)	19.0 (18.2; 19.8)	26.9 (25.5; 28.3)	29.9 (24.8; 35.0)
Black	a	20.0 (14.8; 25.2)	17.1 (14.6; 19.6)	21.4 (19.6; 23.2)	30.0 (27.1; 33.0)	36.1 (27.6; 44.5)
Brown	a	13.2 (11.7; 14.6)	13.8 (13.1; 14.6)	18.2 (17.5; 18.9)	25.0 (23.7; 26.3)	29.4 (24.3; 34.4)
Yellow	a	6.8 (−3.9; 17.5)	4.1 (1.2; 7.0)	15.1 (7.6; 22.5)	17.1 (10.4; 23.7)	30.3 (0.5; 60.2)
Indigenous	a	a	6.5 (1.9; 11.2)	18.5 (9.7; 27.4)	25.9 (15.3; 36.6)	9,7 (−7.9; 27.3)

Brazil 1975–2019 [2019 standardized]
a- Variable not collected/available in this year. *CI* Confidence Interval

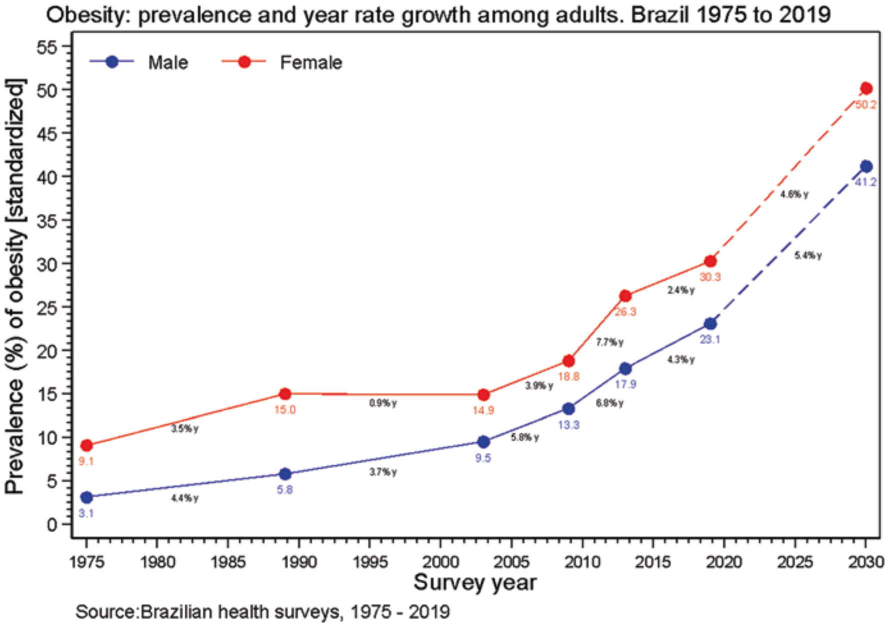

Fig. 13.2 Change trend (%) for obesity prevalence calculated from the six national surveys (1975–2019), and estimated for this decade among Brazilian adults (above 20 years of age)

The annual growth rate of obesity between surveys varies inversely with income quintiles for men and women. The period 1989–2003 has the lowest rates across the time frame analyzed. From 2009 to 2013, prevalence of obesity increased by a rate near 8% per year. Overall, the differences top-bottom income quintiles for growth rate are larger among women than among men (Tables 13.5 and 13.6).

The summary of all the analyses performed of the adult are shown in Fig. 13.2, which brings up the latent trajectory of obesity in Brazil over 45 years when socioeconomic and demographic variables were balanced across the time. The latent men obesity trajectory remains like the observed trajectory, showing continuous step up among periods. The latent obesity among women, conversely, shows a singular trajectory with a flat period followed by two exponential growth periods. Furthermore, this singular trajectory starts from a point three times the latent prevalence in men.

13.3.2 The Quilombolas and the Impact of Recent Socioecological Changes in Growth and Health of Rural Amazonian Populations

Quilombolas are groups formed by the populations originated from black Africans who were brought to Brazil as slaves, and then they fled away and ended up surviving, constituting social groups that occupied free and isolated lands to avoid recapture. They are considered vulnerable populations due to their living conditions, economic forms of survival, history of violence, racism, among others, and this situation ends up directly influencing their health, especially that of children (Guimarães et al., 2018; Kisil & Silva, 2022).

According to the IBGE (2020) there are 5,972 Quilombola locations in Brazil, but only 709 are officially delimited. In the northern region, there are 873 identified by the IBGE, with 516 in Pará. This state is emblematic of the national situation, as it is the state that has the largest number of Quilombola areas officially recognized. There are 141 collective titles, covering more than 6,000 families in 64 municipalities. However, it is unknown exactly how many Quilombola communities there are in the country, as these, were only included for the first time in the 2022 national census. Nevertheless, they represent one of the largest segments of the rural population in the country and, overall, their health and environmental situation is almost as precarious as that of the native American populations (Souzas et al., 2021).

The Quilombola communities discussed here are located in the dry land and in floodplains, far from large urban centers. Their houses are usually arranged close to each other, usually in a linear fashion at the edge of the rivers. They use roads, canoes or motorboats to travel to the nearest centers and establish contacts, seek medical help, sell their goods such as handicrafts, manioc flour, which they produce in their gardens and other products from the subsistence agriculture and gathered from the forest. They also hunt and fish, however, due to the access to income transfer programs, such as *Bolsa Família*, retirements, pensions, they began to buy industrialized foodstuffs in the city and take those to their families.

Almost half of the population sampled has only incomplete elementary education (46.11%). Income varies from 1 to 3 times the minimum national wage of Brazil (50.16%) putting them, in general, in the two lowest groups in wealth index.

The number of residents per house varies from 1 to 5 (64.58%) and they live in the houses made of wood (68.14%) and brick (20.59%), with clay tiles (71.92%). Kitchen is most often inside the house (83.44%), however only 18.85% of the families have a washroom inside the house, with a toilet in 39.94% of the cases. There is no sewage system in most of the communities, being the waste dumped in open air (56.6%) and burned (85.37%). Most of the communities still use the "*fossa negra*" (black pit), a hole dug in the ground to drain the water from bathroom or toilet (72.33%). The water for drinking and domestic use comes mostly from rivers or streams. The main economic activities can be differentiated by gender: for men agriculture (56%), fishing (22%), and domestic service for women (18.06%).

Many young people stopped studying because schools, when they are present in their communities, only offer elementary education, usually up to the 7th or 8th grade. To continue their studies, they have to leave their communities and go elsewhere, live with their relatives, which they consider unfeasible due to the cost of maintaining themselves. Therefore, they drop out of school and end up helping the family in fishing, hunting and taking care of their small gardens, often characterizing a situation without many perspectives.

In relation to their health, many Quilombolas choose folk medicine, as there are no health services in most communities. When there is a need for consultation or an emergency, they go to the nearest centers. They claim there are few community health workers and their services are limited. The most frequent diseases reported by the participants are diarrhea, intestinal worms, respiratory problems, especially in children.

The adult men present high rates of overweight and obesity (34.0% and 24.8%, respectively). Women present less overweight (28.57%) but more obesity (29.0%) than men. In Table 13.7 the parameters H/A, W/A and BMI/A of children and adolescents aged 0–19 years old are presented, and in the Table 13.8 nutritional status of the Quilombola groups is shown, with a significant difference only for the BMI parameter by age for the age groups from 10 to 14 years, and from 15 to 19 years old are presented. Different from what is seen in the overall Brazilian population, there is still a high prevalence of undernutrition among the Quilombola children and only a moderate prevalence of overweight and obesity.

13.4 Discussion

In almost all Latin American countries, there is currently a considerable tendency towards the reduction of undernutrition rates and the occurrence of the nutrition transition, which is a transition from undernutrition to obesity (Popkin & Reardon, 2018).

Monteiro et al. (2009) in their analysis of four Brazilian national surveys over a period of 33 years, observed a permanent decline in the national prevalence of undernutrition from 37.1% to 7.1%, and this decline was more accentuated between 1996 and 2007 when there was an increase in economic power of the poorest families, greater access to education, especially for mothers, basic health (prenatal care) facilities, modern contraceptive use, and water services. The proportion of children under 5 years whose H/A z-score +2 SD or more were above average suggests there are three main explanations for these improvements: (1) the reactivation of economic growth, (2) a gradual increase in the minimum wage and (3) greater expansion of income transfer programs to poorer families, such as *Bolsa Família*. However, as shown here this situation is not the same for all Brazilian regions and the different population groups.

Da Silva and Bacha (2014) emphasize that the economic and population growth of the northern region of the country does not occur in a balanced and sustainable way, and perhaps one of the factors that contributes to this scenario is the lack of access of a large part of the population to basic sanitation and education services.

Jaime and collaborators (2014) highlight that between 1996 and 2006 there was a decrease in H/A deficits in the north of Brazil (from 20.7% to 14.8%), the northeast region showed a decrease from 22.1% to 5.8% and the central-west of 10.7% to 5.5%, but they reaffirm that the northern region presents little reduction and continue to have the highest prevalence of chronic undernutrition. They state that despite the decrease in undernutrition, indigenous and Quilombola groups need greater articulation of specific public policies.

Table 13.7 Comparison of mean values, standard deviation (SD) and t-test results of the analyzed parameters of the 664 individuals (358 females, 306 males) from 0 to 19 years of age representing the Quilombola communities studied in the State of Pará, Amazonia, Brazil, with emphasis on the negative means and significant differences

Parameters	**0–4 years old**					**5–9 years old**				
	Female		**Male**		***p* value**	**Female**		**Male**		***p* value**
	Mean	**SD**	**Mean**	**SD**		**Mean**	**SD**	**Mean**	**SD**	
Age	2.3	1.3	2.1	1.4	0.250	6.78	1.46	7.09	1.31	0.123
Height/Age	−0.9	1.5	−0.7	4.5	0.755	−0.64	1.12	−0.85	1.09	0.189
Weight/Age	−0.4	1.2	−0.2	2.8	0.542	−0.64	1.02	−0.58	1.14	0.679
BMI/Age	0.2	1.3	0.4	1.9	0.556	−0.37	1.15	−0.07	1.08	0.066
	10–14 years old					**15–19 years old**				
	Female		**Male**		***p* value**	**Female**		**Male**		***p* value**
Parameters	**Mean**	**SD**	**Mean**	**SD**		**Mean**	**SD**	**Mean**	**SD**	
Age	12	13	11.95	1.45	0.823	17.24	1.46	16.77	1.51	0.092
Height/Age	−0.99	1.14	−1.09	1.31	0.643	−1.26	0.88	−1.4	1.19	0.509
BMI/Age	0.13	1.03	−0.28	1.2	0.022	0.4	1.05	−0.17	0.87	0.001

$p < 0.05$*

Table 13.8 Comparison of the percentages of the nutritional status parameters height-for-age and BMI for age of the 664 participants (358 females, 306 males), 0–19 years of age of the sampled Quilombola communities in the State of Pará, Amazonia, Brazil

	Height-for-age		BMI for age				
0–4 years old							
Groups	Severe delay in growth	Delay in growth	Severely thin	Thin	Overweight risk	Overweight	Obesity
	<−3 SD (%)	<−2 SD (%)	<−3 SD (%)	<−2 SD (%)	>+1 SD (%)	>+2 SD (%)	>+3 SD (%)
Both sexes	5.8	20.5	2	4.6	19	5.9	0.7
Male	9.9	23.9	0	4.3	18.8	5.8	1.4
Female	2.4	17.6	3.6	4.8	19	6	0
5–9 years old							
Both sexes	1.7	12.4	0.6	4	10.2	2.8	1.1
Male	3.2	14.9	0	5.3	9.6	3.2	2.1
Female	0	9.5	1.2	2.4	10.8	2.4	0
10–14 years old							
Both sexes	3.2	12	0	3.8	16.3	1.9	1.3
Male	3.8	16.5	0	6.3	16.3	2.5	1.3
Female	2.5	7.6	0	1.3	16.3	1.3	1.3
15–19 years old							
Both sexes	4.1	25.6	0	1.7	17.4	5	0.8
Male	8.9	31.1	0	4.4	0	0	0
Female	1.3	22.4	0	0	27.6	7.9	1.3

The largest study of Quilombola groups, the Nutritional Quilombola Call (Chamada Nutricional Quilombola, 2006) investigated 2,941 children in 22 Brazilian states and the deficit was 11.6% for H/A, W/A was 8.1%, overweight-for-age represented 2.4% and overweight-for-height 3.9%. These results are in line with the data from the Pará communities described here.

Studies conducted among the Quilombola in the northeast (Ferreira et al., 2011; Silva, 2007; Neves et al., 2021) reported high rates of underweight for their age and height, elevation of overweight rates with age, low access to health services, high dependency on government cash transfer programs and a situation of food insecurity.

In the North (Guerrero, 2010; Guimarães & Silva, 2015; Oliveira et al., 2011; Pinho et al., 2013; Correa & Silva, 2022); research has also identified precarious living conditions, difficulty of access to health care, high rates of low W/A and H/A among children, increasing rates of overweight and obesity, and elevated presence of chronic degenerative diseases and smoking habits.

The available data show that despite overall reduction in undernutrition and an increase in overweight/obesity trend in the rural populations of the North and Northeast of Brazil, socioecological determinants still end up interfering with growth and nutrition of children and adolescents. In the sample reported here, stunting still presents high frequency but, at the same time, there are considerable values of overweight risk for many children and young people, which characterizes that populations are undergoing nutrition transition. This framework can impact their adult health, with the emergence of chronic diseases such as obesity, changes in blood pressure and diabetes.

Especially among the rural groups, with the advent of *Bolsa Família* and other governmental cash transfer programs, some families began to consume processed and ultra-processed foods. In relation to their traditional foods, these types of foods are easy to transport, do not spoil easily, last longer, are relatively quick to prepare, and cost-effective in most of the occasions, despite being extremely caloric and poor in important nutrients. However, with this income obtained from the transfer programs, some families chose to distance themselves from their agricultural and extractive practices (Piperata et al., 2011). As a result, many report that the packaged foods end before the ending of the month and they suffer from food insecurity (Filgueiras & Silva, 2020; Silva & Filgueiras, 2019).

Overall, the data presented here shows some of the complex picture of Brazilian children growth and health trends, nutritional status of children, adolescents and adults and highlights the need for a broad range of public policies designed to address the diversity of populations and environments in the country. Data of adults regarding the patterns of changes in nutritional status through decades help us to understand what might be the future of Brazilian children and thereby develop strategies to ensure better health status in their adulthood.

13.5 Conclusions

Overweight and obesity are major health problems worldwide and among the main causes of other morbidities and mortality. Early interventions to prevent obesity in children and young people are more rational and less expensive ways to reduce the incidence of chronic degenerative diseases and loss of quality of life as the population ages.

The main results of general analysis of growth and nutritional status patterns of Brazilian populations presented here can be summarized as: (a) child undernutrition measured by stunting prevalence has declined in an accelerated rate until the first decade of this century and remains at low levels in the last decade; (b) children overweight, conversely, has presented a U-shape trend and has been increasing in the last two decades; (c) school-going early-adolescent overweight has presented an increasing trend in the surveys where weight could be measured; (d) late-adolescent overweight has increasing and achieved a frequency of 1 in each 4 individuals in the last survey; (e) adult obesity has increased sharply in the last 2 decades and achieved virtually 1 in each 4 men and 1 in each 3 women with a tendency to continual increase in the current decade.

In relation to the Quilombola, as a representative of one of the rural populations of the country, which often are not included in the largest surveys, like the Ribeirinhos and the Native American populations, they have been suffering from social and environmental inequities, the result of institutional discrimination, which ends up reflecting their poor quality of life, health and nutritional status, especially for children and young people who have never been able to reach the international standard optimum values for physical growth and nutritional status. High frequency of growth deficit estimated by low H/A or stunting is a permanent public health problem and has lately been accompanied by a growing trend in excess weight (overweight and obesity), demonstrating that these populations are experiencing a process of nutrition transition in some ways, but not entirely, similar to the overall Brazilian population.

The analyses carried out in this chapter show that the overall health of the children and adolescents has improved in relation to undernutrition, but many social determinants of health continue to exert a force contrary to this situation, especially in the rural populations which still continue to live without favourable environmental conditions in the households, difficulties in accessing safe drinking water, limited access to health care and medication, low education and formal employment opportunities. Brazil has the largest Black population outside the African continent and despite the creation of the National Policy for the Integral Health of the Black Population (PNSIPN, 2009), which is specific to this group, the Quilombolas continue to be among the most vulnerable populations in the country.

The available data shows that the Quilombola adults present nutritional status patterns similar to that of general population of the country, but the children and adolescents differ quantitatively from their urban counterparts. The National Plan for Racial Equality from 2009, the Statute of Racial Equality (Law no. 12.288/2010), the PNSIPN, among others, recognize the existence of institutional racism, which imposes serious impacts on people's lives and health that need to be corrected urgently. In order to improve health, growth and nutritional status of the Brazilians, combating social-cultural and economic inequalities, discrimination and marginalization must be the pillars of all spheres of government policies.

References

Bogin, B. (2021). Social-Economic-Political-Emotional (SEPE) factors regulate human growth. *Human Biology and Public Health, 1*. Available at: https://doi.org/10.52905/hbph.v1.10. Last accessed 06 Nov 2022.

Brasil, & Centro Brasileiro de Análise e Planejamento (Orgs.). (2009). *Pesquisa nacional de demografia e saúde da criança e da mulher: PNDS 2006, dimensões do processo reprodutivo e da saúde da criança* (1st ed.). Ministério da Saúde: Centro Brasileiro de Análise e Planejamento.

Chamada Nutricional Quilombola. (2006). *Sumário Executivo*. Ministério do Desenvolvimentos Social e Combate à Fome, Secretaria de Avaliação e Gestão da Informação, Departamento de Avaliação e Monitoramento, Brasília-DF.

Correa, N. A. F., & Silva, H. P. (2022). Comida de Quilombo e a desnutrição infantil na Amazônia Paraense: uma análise com base no mapeamento da Insegurança Alimentar e Nutricional. *Segurança Alimentar e Nutricional, Campinas, 29*, 1-16.e022020.2022. Available in: https://periodicos.sbu.unicamp.br/ojs/index.php/san/article/view/8670218. Last accessed 10 Feb 2023.

Coutinho, J. G., Gentil, P. C., & Toral, N. (2008). A desnutrição e obesidade no Brasil: o enfrentamento com base na agenda única da nutrição. *Cadernos de Saúde Pública, 24*, s332–s340.

Da Silva, R. R., & Bacha, C. J. C. (2014). Acessibilidade e aglomerações na Região Norte do Brasil sob o enfoque da Nova Geografia Econômica [Accessibility and agglomerations in Brazilian Northern Region according to New Economic Geography]. *Nova Economia, Economics Department, Universidade Federal de Minas Gerais (Brazil), 24*(1), 169–190.

Ferreira, H. S., Lamenha, M. L. D., Xavier Júnior, A. F. S., Cavalcante, J. C., Santos, A. M. (2011). Nutrição e saúde das crianças das comunidades remanescentes dos quilombos no Estado de Alagoas, Brasil. 2011. *Revista Panamericana de Salud Pública, Washington, 30*(1), 51–58. Available at: http://www.scielosp.org/scielo.php?script=sci_arttext&pid=S1020-49892011000700008&lng=en&nrm=iso. Last accessed 29 Sept 2022.

Filgueiras, L. A., & Silva, H. P. (2020). Socioecologia e saúde de populações Quilombolas do Pará, Amazônia, Brasil. *Tessituras, Dossiê Antropologia Biológica, 8*(2), 351–370.

Frisancho, R. A. (2008). *Anthropometric standards: An interactive nutritional reference of body size and body composition for children and adults*. University of Michigan Press.

Gomes, D., Sichieri, R., Verly-Jr, E., Boccolini, C., Souza, A., & Cunha, D. (2019). Trends in obesity prevalence among Brazilian adults from 2002 to 2013 by educational level. *BMC Public Health, 19*(1), 965 (7 pages).

Guerrero, A. F. H. (2010). *Situação nutricional de populações remanescentes de quilombos do município de Santarém, Pará – Brasil*. Doctoral Thesis. Rio de Janeiro: Escola Nacional de Saúde Pública Sérgio Arouca.

Guimarães, R. C. R., & Silva, H. P. (2015). Estado nutricional e crescimento de crianças Quilombolas de diferentes comunidades do Estado do Pará. Amazônica. *Revista de Antropologia, 7*(1), 186–209.

Guimarães, R. C. R., Silva, H. P., & Ramos, E. M. L. S. (2018). Condições socioecológicas familiares e os primeiros dois anos de crianças Quilombolas no Pará: um estudo de base populacional. *Ciência e Saúde, 11*(2), 90–99.

IBGE (Instituto Brasileiro de Geografia e Estatística). (1978). *Estudo nacional da despesa familiar – ENDEF: consumo alimentar – despesas das famílias*. IBGE. 122 p.

IBGE (Instituto Brasileiro de Geografia e Estatística). (1990). *Pesquisa Nacional Sobre Saúde e Nutrição: Resultados Preliminares* [Internet]. Ministério da Saúde. Available at: https://biblioteca.ibge.gov.br/visualizacao/livros/liv81879.pdf. Last accessed 29 Sept 2022.

IBGE (Instituto Brasileiro de Geografia e Estatística). (1997). *Brasil: pesquisa nacional sobre demografia e saúde – 1996* (p. 182). Sociedade Civil Bem-Estar Familiar no Brasil. Available at: https://dhsprogram.com/pubs/pdf/fr77/fr77.pdf. Last accessed 29 Sept 2022.

IBGE (Instituto Brasileiro de Geografia e Estatística). (2004). *Pesquisa de orçamentos familiares 2002–2003*. IBGE. 3 p. Available at: https://biblioteca.ibge.gov.br/visualizacao/livros/liv81847.pdf. Last accessed 29 Sept 2022.

IBGE (Instituto Brasileiro de Geografia e Estatística). (2010). *Brasil: pesquisa nacional sobre demografia e saúde*. Available at: https://censo2010.ibge.gov.br/. Last accessed 29 Sept 2022.

IBGE (Instituto Brasileiro de Geografia e Estatística). (2015). *Brasil: pesquisa nacional sobre demografia e saúde*. Available at: https://biblioteca.ibge.gov.br/visualizacao/livros/liv94074.pdf. Last accessed 29 Sept 2022.

IBGE (Instituto Brasileiro de Geografia e Estatística). (2016). *Brasil: Pesquisa nacional de saúde do escolar: 2015*. Available at: https://biblioteca.ibge.gov.br/visualizacao/livros/liv97870.pdf. Last accessed 29 Sept 2022.

IBGE (Instituto Brasileiro de Geografia e Estatística). (2020). *Brasil: pesquisa nacional sobre demografia e saúde*. Available at https://biblioteca.ibge.gov.br/visualizacao/livros/liv101748.pdf. Last accessed 29 Sept 2022.

Jaime, P. C., Vaz, A. C. N., Nilson, E. A. F., Fonseca, J. C. G., Guadagnin, S. C., Silva, S. A., Sousa, M. F., & Santos, L. M. P. (2014). Desnutrição em crianças de até cinco anos beneficiárias do Programa Bolsa Família: análise transversal e painel longitudinal de 2008 a 2012. *Cadernos de Estudos Desenvolvimento Social em Debate: Resultados, Avanços e Desafios das Condicionalidades de Saúde do Bolsa Família.* Ministério do Desenvolvimento Social e Combate à Fome; Secretaria de Avaliação e Gestão da Informação.

Kisil, M., & Silva, H. P. (2022). Racismo estrutural e saúde da criança negra. In J. L. Setúbal & M. Kisil (Orgs.), *Saúde Infantil e o Desenvolvimento Sustentável da Sociedade Brasileira* (1ª ed., pp. 215–248). Fundação José Luiz Egydio Setúbal. Available at: https://fundacaojles.org.br/?doing_wp_cron=1649906006.8415050506591796875000. Last accessed 29 Sept 2022.

Melo, M. F. T., & Silva, H. P. (2015). Doenças crônicas e os determinantes sociais da saúde em Comunidades Quilombolas do Pará, Amazônia, Brasil. *Revista da ABPN, Dossiê Saúde da População Negra, 7*(16), 168–189.

Ministério da Saúde. Secretaria de Atenção à Saúde. Departamento de Atenção Básica, Brasil. (2008). *Protocolos do Sistema de Vigilância Alimentar e Nutricional – SISVAN na assistência à saúde* (Série B. Textos Básicos de Saúde) (p. 61). Ministério da Saúde.

Monteiro, C. A. (2003). A dimensão da pobreza, da desnutrição e da fome no Brasil. *Estudos Avançados, 17*(48), 7–20.

Monteiro, C. A., Conde, W. L., & Popkin, B. M. (2004). The burden of disease from undernutrition and overnutrition in countries undergoing rapid nutrition transition: A view from Brazil. *American Journal of Public Health, 94*(3), 433–434.

Monteiro, C. A., Benicio, M. H. D., Konno, S. C., da Silva, A. C. F., de Lima, A. L. L., & Conde, W. L. (2009). Causes for the decline in child under-nutrition in Brazil, 1996–2007. *Revista Saúde Pública, 43*(1), 35–43.

Monteiro, C. A., Benicio, M. H. D., Conde, W. L., Konno, S., Lovadino, A. L., Barros, A. J., et al. (2010). Narrowing socioeconomic inequality in child stunting: The Brazilian experience, 1974–2007. *Bulletin of World Health Organization, 88*(4), 305–311.

Neves, F. J., Ferreira, A. A., & Welch, J. R. (2021). Nutritional status and factors associated with stunting in children under five years of age in maroon communities in Northeast Brazil. *Cadernos de Saúde Pública, 37*(7), 19. https://doi.org/10.1590/0102-311X00060220. Last accessed 29 Sept 2022.

Oliveira, A. S. Jr., Rodrigues, F. E. N., Correia, L. S. S., Tavares, M. E., Monteiro, T. L. (2011). *Quilombolas do Pará: condições de vulnerabilidade nas comunidades de remanescentes de quilombo*. 1. ed. Assis: Gráfica Triunfal e Editora, 1. 114p.

Pinho, P. M. de, Pamplona, V. M. S., Ramos, E. M. L. S. (Orgs.). (2013). *Avaliação nutricional em quilombolas marajoaras*. Belém: UFPA/POEX, 158p.

Piperata, B. A., Spencer, J. E., Da-Gloria, P., & Hubbe, M. (2011). The nutrition transition in Amazon: Rapid economic change and its impact on growth and development in ribeirinhos. *American Journal of Physical Anthropology, 146*(1), 1–13.

PNSIPN (Política Nacional de Saúde Integral da População Negra). (2009). *Ministério da Saúde, Brasília, DF*. Available at: http://bvsms.saude.gov.br/bvs/saudelegis/gm/2009/prt0992_13_05_2009.html. Last accessed 29 Sept 2022.

Popkin, B., & Reardon, T. (2018). Obesity and the food system transformation in Latin America. *Obesity Reviews, 19*, 1028–1064.

Rtveladze, K., Marsh, T., Webber, L., Kilpi, F., Levy, D., Conde, W., McPherson, K., & Brown, M. (2013). Health and economic burden of obesity in Brazil. *PLoS One, 8*(7), e68785.

Silva, H. P. (2001). *Growth, development, nutrition and health in Caboclo populations from the Brazilian Amazon*. PhD dissertation, Department of Anthropology. The Ohio State University.

Silva, J. A. N. (2007). Condições sanitárias e de saúde em Caiana dos Crioulos, uma comunidade Quilombola do Estado da Paraíba. *Saude Sociedade, 16*(2), 111–124.

Silva, H. P., & Filgueiras, L. A. (2019). Biological anthropology of children's growth in Amazonia. In D. Ubelaker & S. E. Colantonio (Eds.), *Biological anthropology of Latin America: Historical development and recent advances* (Smithsonian contributions to anthropology, 51, pp. 41–58). Smithsonian Institution Scholarly Press. Available at https://doi.org/10.5479/si.11365715

Silva, H. P., Padez, C., Moura, E. A. F., & Filgueiras, L. A. (2016). Social determinants of health among traditional Amazon populations: Obesity, hypertension and the epidemiologic transition. *Annals of Human Biology, 43*(4), 371–381.

Silva, H. P., Arroyo, J. C. T., & Almeida, P. B. (Orgs.). (2021). *Como lidar com uma Amazônia sensível: Identidades, direitos e qualidade de vida em comunidades urbanas, rurais, ribeirinhas e quilombolas no Pará*. UNAMA.

Souzas, R., Silva, H. P., Varga, I. V. D., Moura, R. F., & Araújo, E. M. (2021). Desafios para a saúde da população negra e indígena em tempos de pandemia: Como e por que "esperançar." In D. Stefano & M. L. Mendonça (Orgs.), *Direitos Humanos no Brasil 2021: Relatório da Rede Social de Justiça e Direitos Humanos* (pp. 217–226). Outras Expressões. Available at: https://www.social.org.br/images/pdf/direitos_humanos_2021.pdf. Last accessed 29 Sept 2022.

Victora, C. G., Aquino, E. M., Leal M do C, Monteiro, C. A., Barros, F. C., & Szwarcwald, C. L. (2011). Maternal and child health in Brazil: Progress and challenges. *The Lancet, 377*(9780), 1863–1876.

Weiner, J. S., & Lourie, J. A. (Eds.). (1981). *Practical human biology*. Academic.

WHO (World Health Organization). (1995). *Physical status: The use and interpretation of anthropometry*. World Health Organization.

World Bank. (2022). *Gini index – Brazil* | Data [Internet] [citado 3 de agosto de 2022]. Available at: https://data.worldbank.org/indicator/SI.POV.GINI?locations=BR. Last accessed 29 Sept 2022.

Chapter 14
Obesity in Chilean Schoolchildren and the Importance of the Diagnostic Criteria: Body Mass Index, Body Fat Percentage, and Biotype

Pablo A. Lizana, Lydia Lera, and Cecilia Albala

14.1 Introduction

In recent decades, Chile has experienced important sociocultural and economic developments which have profoundly changed the lifestyle habits of its population. The country is going through a phase of nutritional and post-epidemiological transition, with practically the same characteristics that developed countries have, characterized by greater consumption of hypercaloric foods, increased sedentarism, and rise in per capita monthly income of households, leading to the changes in lifestyle habits, which has affected the rise of obesity in the Chilean population (Kain et al., 2005; Ministerio de Salud, 2017; Vio et al., 2008). During the 1960s, Chile had high rates of infant and maternal mortality due to high prevalence of infectious diseases and malnutrition. However, during the 1990s, there was a drop in the infant mortality rate, gradually passing into an increase of the prevalence of malnutrition in the form of excess weight (overweight plus obesity), a rise in chronic non-transmissible diseases (CNTD) and cardiovascular diseases being the main cause of death (Albala et al., 2001; Kain et al., 2005; Vio et al., 2008). Therefore, in Chile, excessive malnutrition represents a relevant health problem in the populations of all ages.

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However, recent reports indicate the appearance of double burden (coexistence of chronic undernutrition and excess weight) in pediatric ages (*Junta Nacional de Auxilio Escolar y Becas* (JUNAEB), 2021), which should be observed carefully given that the reports mentioned these cases had been eradicated.

Childhood obesity is currently an urgent topic for public health systems worldwide (Moreno, 2013), and Chile is no exception (Kain et al., 2009; Stanojevic et al., 2008; Vio et al., 2019), not only because this population continues to show obesity in adulthood, but also because excess weight increases the risk of facing psychosocial complications, CNTD and multi-systemic problems, such as coronary artery disease, diabetes, and metabolic syndrome (Bibbins-Domingo et al., 2007; Ebbeling et al., 2002; Lizana et al., 2015a, b; Muñoz, 2019). There are various systematic studies that reported greater risk for overweight and obese youths to become overweight adults (Singh et al., 2008). Obesity arising in young adults is 10.3 times more common among children who had been obese between the ages of 6 and 9, by contrast with people who were not obese in that age (Whitaker et al., 1997).

During adolescence, exogenous factors are the main drivers for developing obesity, which are mainly related with hypercaloric diets, a lack of scheduled physical activity, and more time for sedentary activities such as computer use and watching television (García-Hermoso & Marina, 2015; Reyes et al., 2011). These factors have had notable impacts on the body mass index (BMI), higher percentages of body fat (BF%), increased abdominal obesity, and greater endomorphy among children and adolescents in recent decades (Lizana et al., 2011, 2015a, b, 2016, 2018a, b). The objective of the present study was to describe the changes which have arisen among Chilean children with respect to BMI, BF% and somatotype in recent years.

14.2 Obesity by Body Mass Index in Chile

Annual health evaluation of children and adolescents in Chile is done by the National Board for Aid and Grants (JUNAEB). The database of JUNAEB has information about weight, height and BMI for kindergarteners and preschoolers, 1st graders, 9th graders since 2003, and for 5th graders since 2018. The data reported by JUNAEB is aimed at helping health and educational institutions to evaluate the scope and impact of policies, programs or interventions related to the nutritional problems and to redefine them, where necessary (JUNAEB, 2021, 2022). The annual records on nutritional status of children and adolescents allowed us to observe obesity prevalence in Chile. Figure 14.1 shows obesity trends among Chilean children and adolescents, indicating a positive trend in obesity increase, with the greatest effects in the preschool and kindergarten levels. Since data for 5th graders only cover the years 2018–2021, they are not included in the figure. However, 5th graders do show high obesity rates in the 4 years evaluated (27.7%, 27.9%, 27.9%, and 36.3%, respectively). Childhood obesity in the last three decades has tripled among

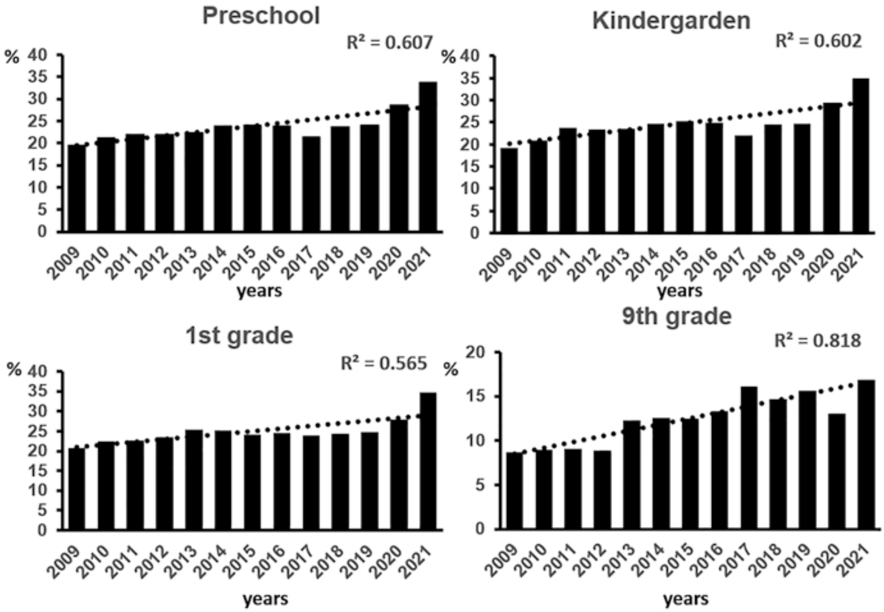

Fig. 14.1 Trend of BMI-based childhood obesity in Chile, 2009–2021. Data of prevalence of nutritional status are reported by the Chilean government (JUNAEB (2021, 2022) with data expressed in percentages)

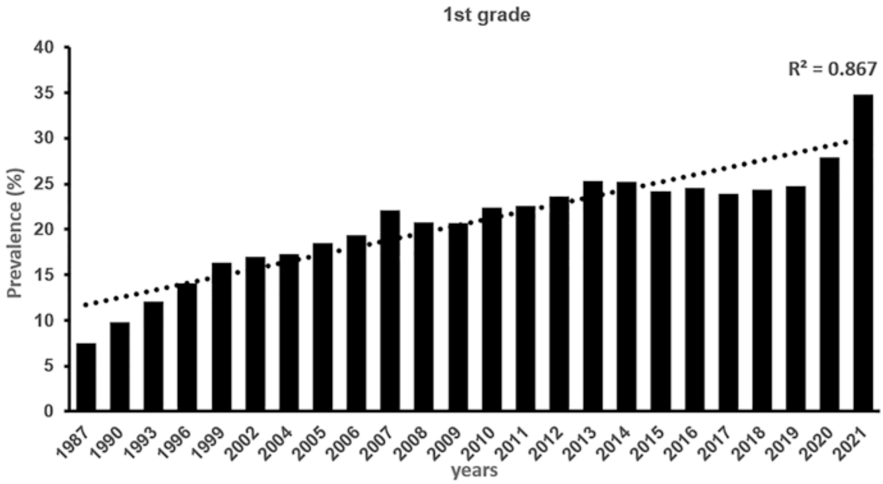

Fig. 14.2 Prevalence of BMI-based obesity among 1st graders, 1987–2021. (Data are presented in percentage *Junta Nacional de Auxilio Escolar y Becas* (JUNAEB) (2021, 2022) and Vio et al. (2019))

6-year-olds (see Fig. 14.2) while among 14-year-olds, obesity has risen by 60%, along with adults, in less than a decade (Vio et al., 2019). In addition, remarkable increase in obesity was observed during the COVID-19 pandemic, with obesity exceeding 30% (34.8 first grade; JUNAEB, 2022).

Regarding the rise in obesity, it has been observed that in Chile an important rise in severe obesity, i.e., BMI ≥ +3 SD, following WHO-2007 reference. Therefore, we can observe a sustained rise in severe obesity among chidren through the decades. One exception is observed among 9th grade students, which dropped 3% in 2020. By contrast, the greatest reported increase appears at the lowest level (preschool) with a rise of 3.2% (JUNAEB, 2021). Unfortunately, severe obesity continues to increase in all grades according to the recent JUNAEB 2022 report, severe obesity increased 3.1 percentage point (pp) with respect to the previous year, with the highest increase in the fifth grade with 4.9 pp (JUNAEB, 2022). In this sense, we observed that severe obesity is associated with greater negative impacts on health and nutrition in the Chilean pediatric population in comparison with children who have comaparatively lower levels of obesity (non-severe obesity such as a z-score of BMI ≥ +2 to >+3 SD). The results from the comparison between children with severe obesity indicate that children with higher category of obesity (BMI z-score ≥ +3 SD) were at greater risk for central obesity (OR: 12.9), insulin resistance (OR: 3.2), arterial hypertension (OR: 2.67) and metabolic syndrome (OR:1.92) in contrast with children with non-severe obesity (children aged 11.4 ± 0.98 years). This definition of severe childhood obesity helps us in the identification of children with greater cardio-metabolic comorbidity (López Lucas et al., 2022), aiding in focusing secondary prevention efforts and more opportune treatment.

Another variable reported in the JUNAEB report of 2021 is the normal weight category, indicating that all education levels had decrease in normal weight (BMI) category, compared to 2019 data except for 9th grade students. The greatest variation for normal weight decreases in kindergarten with −4.5 pp, followed by preschool with −3.8 pp and 1st grade with −3.5 pp. On contrary, obesity mainly rose in the lower levels. Therefore, we can see a rise of 4.7 pp in total obesity at the preschool and kindergarten levels.

One relevant aspect to consider in future public policy is the rise of double burden of malnutrition. According to the JUNAEB 2021 report, malnutrition (coexistence of undernutrition and excess weight) began to be detected in comparison with 2019. The most affected levels were preschool with a rise of 1.7 pp, and kindergarten with a rise of 1.3 pp. We should carefully note that these two grades also had increased prevalence of obesity. The JUNAEB 2021 report also includes relevant data about growth deficit in height. This regression increased at all levels, especially at the lowest levels (preschool 2.3 pp, kindergarten 2 pp, 1st grade 2.2 pp, 5th grade 1.2 pp, and 9th grade 0.6 pp). In the last JUNAEB 2022 report, an increase in stunting in all grades is observed. Delayed growth is one of the major concerns, as they indicate chronic undernutrition.

Apart from the annual JUNAEB evaluation, Chile has national health survey (NHS) which has helped to estimate disease prevalence in the population and what treatments should be used to run health policies. NHS is carried out among people living in Chile from 15 years of age onwards. Therefore, NHS data allow us to know the health parameters among Chilean adolescents. According to the 2009–2010 NHS done by the Health Ministry (*Ministerio de Salud de Chile*, 2010), 37.8% of Chilean respondents aged 15–24 years were overweight or obese. From the NHS 2009 to 2010 data and within the same age range (15–24 years), overweight people were 26.9% in both sexes, being higher among males (males 28.9%, females 25.2%). One notable fact from NHS 2010 data on obesity is the fact that figures for all ages are higher for males than females. The 2016–2017 NHS reported that 40.8% of the surveyed population aged 15–19 years were overweight or obese (27.6% overweight, 12.2% obese, 1% morbidly obese), indicating that the adolescent and young adult population has seen increasing obesity.

14.3 Socioeconomic Status and Obesity in Chile

The rise of obesity prevalence in Chile was observed to be higher among children representing lower household socioeconomic status (SES) (Vio et al., 2008). The most socioeconomically vulnerable groups in the city of Santiago were the ones with highest obesity rates. Students from the lowest quantile of SES showed student vulnerability index (SVI) that they were 44% more likely to be obese than students representing the highest quantile (6% more than 2019), and students from the highest quantile in the borough SVI were 22% more likely to be normal weight than students from boroughs in the lowest quintile (6% less than in 2019). Together with this background, 5th and 6th grade children have shown differences in food consumption and physical activity patterns by SES, with better nutritional status among children with higher SES (Liberona et al., 2011). Household SES effects on BMI in children and adolescents that have been relevant. However, the effects of SES do not only influence BMI, but also BF% and even skeletal robustness (Lizana et al., 2018a; Lizana & Hormazabal-Peralta, 2020).

14.4 Body Composition in Chilean Children and Adolescents

Nationwide screening in Chile for children, adolescents and adults is done where BMI is used as an indicator to evaluate nutritional status. Evaluation of BMI-based obesity have aided in carrying out important health policies over decades (Vio et al., 2019). However, BMI has its limitations given that it does not distinguish between fat mass and fat free mass components of human body. BMI-based evaluations thus do not help us to know about body fat, lean mass, muscle mass, and other individual traits, separately. BMI-based evaluations also do not help us to understand whether there has been an overestimation or underestimation of the body fatness associated with obesity. This point is particularly important during interventions, which needs to promote increased muscle mass and decreased fat mass components. With BMI, we cannot distinguish which components are being modified by the lifestyle habits and other environmental factors (Prado et al., 2015; Rothman, 2008).

Studies in Chile indicate that BMI-based evaluation underestimates childhood obesity. Other methods that report obesity from BF% are thus of greater use than that estimated only using BMI. For example, Lizana et al. (2016) compared nutritional status of rural and urban children in Valparaíso, Chile using BMI following WHO reference, and BF% (Ellis equations, Ellis, 1997). The results indicated that BMI showed 36.28% obesity in boys and 20.95% among girls. However, BF%-based obesity was 39.53% for boys and 54.73% among girls. This indicated that apart from underestimating childhood obesity using BMI, frequencies changed by sex where it was observed that girls had higher %BF than boys.

Another aspect that cannot be not measured by BMI is distribution of body fat. For example, using the subscapular/triceps skinfold index, peripheral or central body fat distribution was estimated among urban and rural children in Chile. Results from this parameter showed that girls had higher central adiposity than boys, and that was higher among rural girls than peers in urban sector (Lizana et al., 2016). Body fat distribution is therefore, cannot be estimated using BMI. Evaluation of body fat distribution is also relevant because the accumulation of central body fat increases cardiovascular risk (Staiano et al., 2014).

In the context of evaluating an approximation to the trend of body composition characteristics in Chilean adolescents (age 15–18 years), a comparison was done between a sample evaluated in 1984/1985 and another one in 2009/2010. The comparison was done with an evaluation based on BMI (CDC 2000 cut-off) and BF% (Slaughter equations), where a significant increase of BMI was observed. However, the highest change appeared in BF%. In this way, if we group together the obesity risk ranges (moderately high, high, and very high), the numbers shift from 2.82% in 1984/1985 to 68.6% among girls in 2009/2010, and from 2.33% in 1984/1985 to 25.97% in 2009/2010 among boys. These results indicate that %BF had a steady increase.

Till date, we have indicated the upward trend of BF%, especially among adolescent girls. However, changes have also been reported in skeletal robustness (frame index) of Chilean adolescents (Lizana & Hormazabal-Peralta, 2020). Frame index is a relation between height and the biepicondylar diameter of (Frisancho, 1990), indicating an approximation of skeletal robustness of the individual. A worldwide downward trend of skeletal robustness has been observed (Scheffler, 2011), possibly because of the decrease of physical activity (Rietsch et al., 2013). However, the effects of obesity, skeletal robustness and SES had not been reported in Chilean adolescents. Our studies indicate that adolescents who are obese as indicated by BF%, observed to have significantly higher frame index than non-obese adolescents. Females with lower SES have a higher frame index and BF% than females with higher SES. We have also observed a positive correlation between BF% and frame index for all SES levels (except in males of medium-high SES). Therefore, with these results we can understand that the burdens placed on bones were due to obesity that could modify the body structure. There is an observable increase in the frame index but there is no data about the quality of bone in its cortical and trabecular components among obese Chilean adolescents. More studies

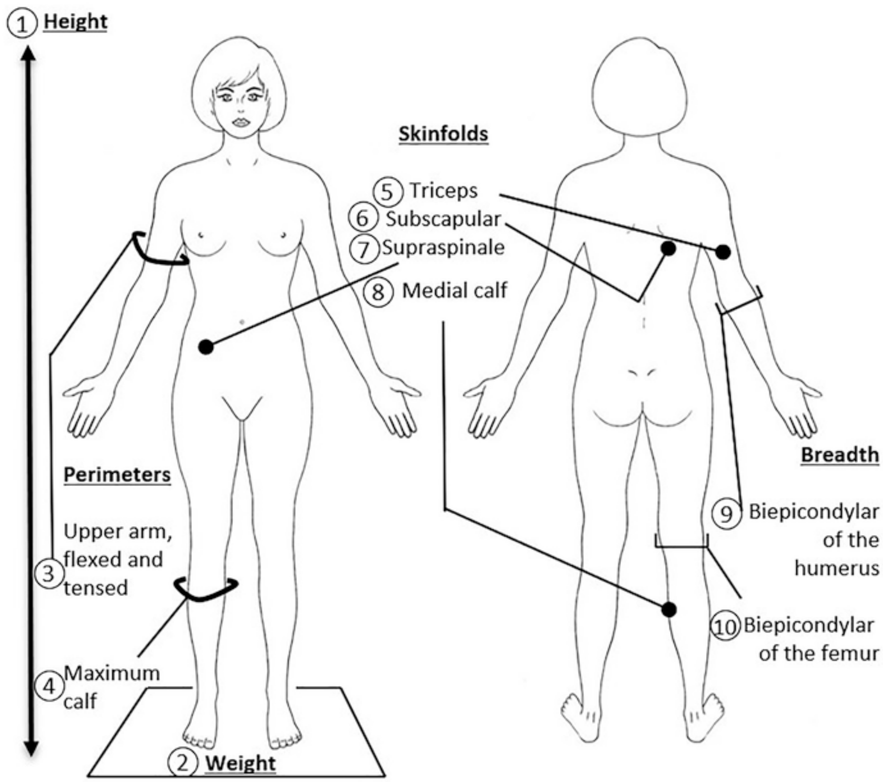

Fig. 14.3 Representation of the 10 measurements needed for anthropometric somatotype calculation

are needed to evaluate the frame index and bone quality (e.g. DEXA) among obese children and adolescents in order to consider frame index as a bone health screening parameter.

14.5 Somatotype in Chilean Adolescents and Children: Increase in the Endomorphic Component

Somatotype is the estimation of body type and its relative composition of fatness, muscle and leanness, which is expressed in three numerical values corresponding to the endomorphy, mesomorphy and ectomorphy components, respectively. This parameter provides information about body fat, musculoskeletal development and relative linearity respectively, obtaining the overall morphological characteristics of an individual (Carter, 1990, 1996). There are different methods of somatotyping, Heath – Carter anthropometric somatotype being the mostly used (Carter, 1990,

1996) and the most often reported in Chile (Lizana et al., 2015a, b). Ten measurements are needed for anthropometric somatotype evaluation (Fig. 14.3) in order to follow the criteria and standard evaluation procedure (Carter, 1990, 1996).

Somatotype has demonstrated its association with health risk factors in children and adolescents (Baltadjiev et al., 2009; Makgae et al., 2007), as well as with body composition (Slaughter & Lohman, 1976). Researchers have thus recognized the value of somatotype characteristics in populations which are growing and maturing, as well as their changes over time (Bruneau-Chávez et al., 2015; Lizana et al., 2012, 2015a, b, 2018b; Marrodan, 1991; Marrodán Serrano et al., 2001; Mladenova et al., 2010).

The biotype of children and adolescents in Chile has been described via the Heath-Carter anthropometric somatotype, reporting sustained increases in endomorphy, principally among girls (Lizana et al., 2018a, b; Tapia et al., 2013). If we observe somatotype changes over time, the data of 1980s already described somatotypes of students of both sexes, reporting sexual dimorphism by age, where the endo-mesomorphic component was characteristic for the girls without significant age differences. However, boys had significant changes in mesomorphy, which were statistically significant between the ages of 15, 16, 17 and 18 years. In this case, boys presented an inclination towards meso-ectomorphy (Toro et al., 1983a, b). At this point, considering the trend among boys towards mesomorphy, the same group of researchers emphasized their description of the relation between somatotype and age, which found that balanced mesomorphy only appeared between the ages of 13.7 and 15.9 years, and there was a trend towards ecto-mesomorphy in the age-groups between 15.10 and 18.9 years (Toro et al., 1983a).

Similar somatotypes were described in 1986 among boys and girls aged 15–21 years, with different dispersions between the ages of 16 and 18. However, in spite of similarities, the average of the subjects placed males with a somatotype of 4-5-4 as balanced mesomorph, and females with a somatotype of 6-6-2 in the endomorph-mesomorph (Almagià et al., 1986). In 1989, muscle mass development was described in adolescents incorporating age, sex, and maturation status variables in the region of Valparaíso, Chile, finding clear sexual dimorphism by somatotype, body composition and muscle strength, with higher values for males, as well as later sexual maturity among males than females (Toro & Almagià, 1989). Somatotypes described by the researchers for the female population were 6.3 – 4.4 – 2.1, while for males the numbers were 5.3 – 4.8 – 2.6 for ages between 11 and 14.11 years. They found a biotype characterized by endomorphy, with this being greater among females than males (Toro & Almagià, 1989).

In the 1990s, somatotype descriptions were reported from a sample of children and adolescents between the ages of 6 and 23 years in Valparaíso, Chile. One major observation of the study was that endomorphy component in females was characterized by being double that of males. The difference was found to be rather strong above 14 years. For example, at 18 years the reported endomorphy component was 2.3 for males and 4.7 for females. These data already indicated the high increase of relative adiposity, especially among adolescent girls (Almagia et al., 1996). Due to

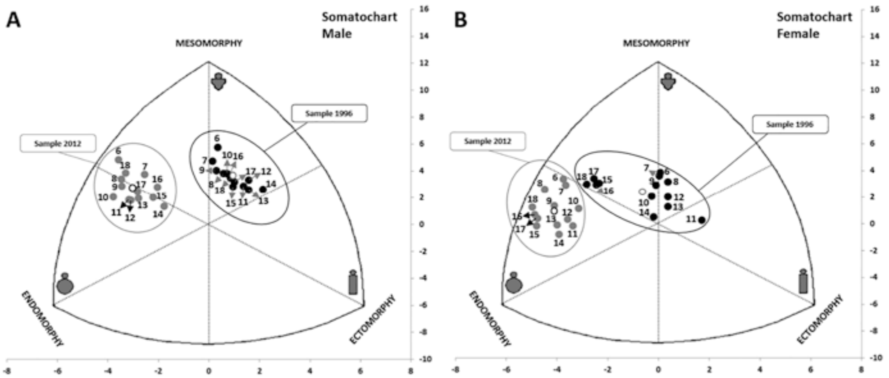

Fig. 14.4 Comparative somatotypes of Chilean children and adolescents, mean somatopoints by year, age, and sex. Black circles indicate 1996 sample and gray circles 2012 sample. (Lizana et al., 2018b)

the progressive increase of endomorphy, our research group compared children and adolescents from 1996 with participants from 2011 in the same region previously studied (Valparaíso, Chile), observing a displacement from the mesomorphic component towards the endomorphic component. The value of the endomorphic component shifted from 3.5 to 6.3 among girls between 6 and 13 years of age, and from 3.9 to 6.8 among girls between 14 and 18 years. Among male schoolchildren, the endomorphic component shifted from 3.6 to 5.6 between the ages of 6 and 13 years, and from 4.0 to 5.3 between the ages of 14 and 18 years. In this background, we can observe an important increase of endomorphy among adolescent females within a span of 15 years (1996–2011, Fig. 14.4). Furthermore, increase of endomorphy by 6.8 is considered high according to the Carter categories (endomorphy above 5.5 is considered high, and above 7.5 is extremely high, Carter, 1990). The rise in endomorphy, especially among women, also coincides with other studies done in our laboratory with adolescents (Lizana et al., 2012, 2018a, b; Tapia et al., 2013). Subsequent studies on somatotypes of children and adolescents in Valparaíso, Chile (n = 1,409) reported high endomorphic component among adolescent girls (>5.5), indicating that the adiposity increase trends continued. In this sense, using the cut-off point proposed by Carter (1990) for high endomorphy, some factors were identified which could be associated with high childhood and adolescent endomorphy. High endomorphy (>5.5) is thus significantly associated with females and with low SES (OR 2.31 and OR 2.19 respectively). In addition to the sustained increase of endomorphy among females, there was also an association of higher endomorph with low SES. One example of progressive endomorphic increase among females by SES occurs with levels from 9th to 12th grade, where endomorph values were 4.8 for the very high and high SES category; 5.4 for medium–high SES; 6.1 for medium SES; and 6.7 for medium–low and low SES (Lizana et al., 2018a).

There are also some interesting studies in Chile about somatotypes among children in southern ethnic groups, particularly among the Mapuche Indians, where observations have been made via a comparative study between Mapuche and non-Mapuche schoolchildren between 10 and 13 years of age. Mapuche students had lower body fat than non-Mapuche students, and the predominant somatotype among the Mapuche was mesomorph, with lower endomorph components as age increased. In this sense, various authors have reported that the predominant somatotype among the Mapuche is endomorphic mesomorph, where the musculoskeletal component was greater than relative fatness (Bruneau-Chávez et al., 2015; Martínez et al., 2012). The characteristics of Mapuche children and adolescents require further study to determine the genetic load, eating habits and physical activity, and geographical and cultural aspects determining their somatotypic traits.

14.6 Final Commentaries and Conclusion

BMI is a very basic indicator for nutritional status evaluation; the Chilean government has kept up continuous evaluations allowing for observation of a sustained rise in obesity, principally in the earliest educational levels. It has also carried out various childhood obesity management campaigns, without any real deep success (Kain et al., 2012). Several studies observed that BF% and endomorphy have increased, being higher than reported obesity by BMI. Evaluation using BMI is thus an underestimate, and does not allow us to understand clearly the distribution of body fat, which have been observed to be higher in girls. Therefore, we suggest continuing BMI evaluations at a populational level and incorporating body composition and body fat distribution evaluations. Due to the rise in childhood obesity which continues into adulthood, campaigns also must be stronger and more effective.

On another note, the school community is also made up of teachers. In this sense, it has been observed that teachers show high obesity rates (BMI and BF%) and central obesity as well, along with hypertension, musculoskeletal disorders, and other ailments (Lizana et al., 2020; Robalino & Körner, 2005; Vega-Fernández et al., 2021, 2022) as well as mental health problems (Lizana et al., 2021; Lizana & Lera, 2022; Lizana & Vega-Fernadez, 2021; Portilla et al., 2022). We may recommend that interventions done in schools should therefore, include the entire school community, especially teachers, given that teachers have the highest interactions with students and have been reported to be the role models for students. However, the few initiatives were taken with teachers which indicate their low flexibility and lack of time (Kain et al., 2012), an aspect that needs to be addressed (Lizana et al., 2020; Robalino & Körner, 2005). In this case, we may suggest that intervention programs to control obesity and promotion of a better quality of life related to health need to involve the educational environment (tutors, management, students and teachers, among others) to incorporate healthy habits at every level. These could include health education in the curriculum, better access to healthy foods, selling healthy products (and banning the sale of non-healthy products), and promoting physical activity (Vio et al., 2019). Although all of these initiatives require major planning to have long-term results, they are relevant for instilling healthy habits in the general population.

References

Albala, C., Vio, F., Kain, J., & Uauy, R. (2001). Nutrition transition in Latin America: The case of Chile. *Nutrition Reviews, 59*(6), 170–176. http://www.ncbi.nlm.nih.gov/pubmed/11444593

Almagià, A., Toro, T., Costa, L., Silva, E., & Díaz, C. (1986). Antropometría de damas y varones de 15 a 21 años de una muestra de estudiantes de Viña del Mar. *Anales de Anatomía Normal, 4*, 106–113.

Almagia, A., Toro, T., Cabrera, E., & Marinao, A. (1996). Aproximacion a un perfil morfoestructural y dimorfismo de jovenes de ambos sexos de 6 a 23 años de edad caracterizados por el somatotipo. *Revista Chilena de Anatomia, 14*, 189–197.

Baltadjiev, A., Baltadjiev, G., & Kaleva, N. (2009). Somatotypological characteristics of children with type 1 diabetes mellitus. *Folia Medica (Plovdiv), 51*(4), 29–33.

Bibbins-Domingo, K., Coxson, P., Pletcher, M. J., Lightwood, J., & Goldman, L. (2007). Adolescent overweight and future adult coronary heart disease. *The New England Journal of Medicine, 357*(23), 2371–2379. https://doi.org/10.1056/NEJMsa073166

Bruneau-Chávez, J., España-Romero, V., Lang-Tapia, M., & Chillón Garzón, P. (2015). Diferencias en la Composición Corporal y Somatotipo de Escolares de Etnia Mapuche y no Mapuche de la Comuna de Temuco – Chile. *International Journal of Morphology, 33*(3), 988–995. https://doi.org/10.4067/s0717-95022015000300029

Carter, L. (1990). *Somatotyping development and applications*. Cambridge University Press.

Carter, L. (1996). Somatotyping. In K. Norton & T. Olds (Eds.), *Anthropometrica* (pp. 147–170). University of New South Wales.

Ebbeling, C. B., Pawlak, D. B., & Ludwig, D. S. (2002). Childhood obesity: Public-health crisis, common sense cure. *Lancet, 360*(9331), 473–482. https://doi.org/10.1016/S0140-6736(02)09678-2

Ellis, K. (1997). Body composition of a young, multiethnic, male population. *The American Journal of Clinical Nutrition, 66*(6), 1323–1331. http://ajcn.nutrition.org/content/66/6/1323.short

Frisancho, A. (1990). *Anthropometric standards for the assessment of growth and nutritional status*. The University of Michigan Press.

García-Hermoso, A., & Marina, R. (2015). Relationship of weight status, physical activity and screen time with academic achievement in adolescents. *Obesity Research & Clinical Practice*., [Epub ahead of print], *11*, 44–50. https://doi.org/10.1016/j.orcp.2015.07.006

Junta Nacional de Auxilio Escolar y Becas (JUNAEB). (2021). *Informe mapa nutricional 2020*. https://www.junaeb.cl/

Junta Nacional de Auxilio Escolar y Becas (JUNAEB). (2022). *Informe mapa nutricional 2021*. https://www.junaeb.cl/

Kain, J., Uauy, R., Lera, L., Taibo, M., & Albala, C. (2005). Trends in height and BMI of 6-year-old children during the nutrition transition in Chile. *Obesity Research, 13*(12), 2178–2186. https://doi.org/10.1038/oby.2005.270

Kain, J., Concha, F., Salazar, G., Leyton, B., Del Pilar Rodríguez, M., Ceballos, X., & Vio, F. (2009). Prevención de obesidad en preescolares y escolares de escuelas Municipales de una Comuna de Santiago de Chile: Proyecto piloto 2006. *Archivos Latinoamericanos de Nutricion, 59*(2), 139–146.

Kain, J., Uauy, R., Concha, F., Leyton, B., Bustos, N., Salazar, G., Lobos, L., & Vio, F. (2012). School-based obesity prevention interventions for Chilean children during the past decades:

Lessons learned. *Advances in Nutrition (Bethesda, Md.), 3*(4), 616S–621S. https://doi.org/10.3945/an.112.001966

Liberona, Y., Castillo, O., Engler, V., Villarroel, L., & Rozowski, J. (2011). Nutritional profile of schoolchildren from different socio-economic levels in Santiago, Chile. *Public Health Nutrition, 14*(1), 142–149.

Lizana, P. A., & Hormazabal-Peralta, A. (2020). External skeletal robustness and adiposity in adolescents of low socioeconomic status: A cross-sectional analysis of body composition. *American Journal of Human Biology: The Official Journal of the Human Biology Council, 32*(3), e23346. https://doi.org/10.1002/ajhb.23346

Lizana, P. A., & Lera, L. (2022). Depression, anxiety, and stress among teachers during the second COVID-19 wave. *International Journal of Environmental Research and Public Health, 19*(10). https://doi.org/10.3390/ijerph19105968

Lizana, P. A., & Vega-Fernadez, G. (2021). Teacher teleworking during the covid-19 pandemic: Association between work hours, work–family balance and quality of life. *International Journal of Environmental Research and Public Health, 18*(14). https://doi.org/10.3390/ijerph18147566

Lizana, P., Almagia, A., Simpson, C., Binvignat, G., Ivanovic, D., & Berral, F. (2011). Aproximación a la tendencia secular del estado nutricional y composición corporal en escolares de enseñanza secuendaria, V Región, Chile: 1985–2010. *International Journal of Morphology, 29*(2), 473–478.

Lizana, P., Almagiâ, A., Simpson, C., Ivanovic, D., Binvignat, O., & Berral, F. (2012). Changes of somatotype in high school students, V Region, Chile: 1985–2010. *Nutrición Hospitalaria, 27*(1), 270–275. https://doi.org/10.3305/nh.2012.27.1.5500

Lizana, P., Olivares, R., & Berral, F. J. (2015a). Somatotype tendency in Chilean adolescents from Valparaíso: Review from 1979 to 2011. *Nutrición Hospitalaria, 31*(3), 1034–1043. https://doi.org/10.3305/nh.2015.31.3.8425

Lizana, P. A., Simpson, C., Yáñez, L., Saavedra, K., Yanez, L., & Saavedra, K. (2015b). Body image and weight status of children from rural areas of Valparaíso, Chile [Autopercepción del estado nutricional en escolares de contextos rurales de Valparaíso, Chile]. *Nutricion Hospitalaria, 31*(2), 698–703. https://doi.org/10.3305/nh.2015.31.2.7794

Lizana, P. A., Cisternas-vallejos, P., Araya, L., Aguilera, F., & Mora, M. (2016). Obesity, body fat distribution, and physical activity in school-age children: An urban and rural comparison. *Biomedical and Environmental Sciences, 29*(11), 834–839. https://doi.org/10.3967/bes2016.112

Lizana, P. A., González, S., Lera, L., & Leyton, B. (2018a). a. Association between body composition, somatotype and socioeconomic status in Chilean children and adolescents at different school levels. *Journal of Biosocial Science, 50*(1), 53–69. https://doi.org/10.1017/S0021932017000025

Lizana, P. A., Simpson, M. C., Farias, P., & Berral, F. J. (2018b). b. Somatotypes of schoolchildren from Chile: Higher endomorphic components among adolescent girls. *Nutricion Hospitalaria, 35*(5), 1033–1041. https://doi.org/10.20960/nh.1749

Lizana, P. A., Aballay, J., Vicente-Rodríguez, G., & Gómez-Bruton, A. (2020). Low interest in physical activity and higher rates of obesity among rural teachers. *Work, 67*(4), 1015–1022. https://doi.org/10.3233/WOR-203351

Lizana, P. A., Vega-Fernadez, G., Gomez-Bruton, A., Leyton, B., & Lera, L. (2021). Impact of the covid-19 pandemic on teacher quality of life: A longitudinal study from before and during the health crisis. *International Journal of Environmental Research and Public Health, 18*(7). https://doi.org/10.3390/ijerph18073764

López Lucas, M. J., Barja, S., Villarroel del Pino, L., Arnaiz, P., Mardones, F., López Lucas, M. J., Barja, S., Villarroel del Pino, L., Arnaiz, P., & Mardones, F. (2022). Riesgo cardiometabólico en niños con obesidad grave. *Nutrición Hospitalaria, 39*(2), 290–297.

Makgae, P., Monyeki, K., Brits, S., Kemper, H., & Mashita, J. (2007). Somatotype and blood pressure of rural South African children aged 6–13 years: Ellisras longitudinal growth and health study. *Annals of Human Biology, 34*(2), 240–251.

Marrodan, M. (1991). Somatotypes in Spanish children. *International Journal of Anthropology, 6*(3), 257–265.
Marrodán Serrano, M. D., Aréchiga Viramontes, J., & Moreno Romero, S. (2001). Cambios somatotípicos durante el crecimiento en población mexicana masculina (Lomas de la Estancia, México D.F.). *Antropo, 1*, 43–50. www.didac.ehu.es/antropo
Martínez, C., Silva, H., & Collipal, E. (2012). Somatotipo y estado nutricional de 10 a 14 Años de edad en una muestra de mapuches de la IX Región, Temuco-Chile. *International Journal of Morphology, 30*(1), 241–246.
Ministerio de Salud. (2017). Encuesta Nacional de Salud 2016-2017 Primeros resultados. *Departamento de Epidemiología, División de Planificación Sanitaria, Subsecretaría de Salud Pública, 61*. http://web.minsal.cl/wp-content/uploads/2017/11/ENS-2016-17_PRIMEROS-RESULTADOS.pdf
Ministerio de Salud de Chile. (2010). *II Encuesta Nacional de Salud (ENS) Chile 2009–2010*. Gobierno de Chile.
Mladenova, S., Nikolova, M., Andreenko, E., & Boyadjiev, D. (2010). Somatotypological characterization of Bulgarian children and adolescents (Smolyan region). *Collegium Antropologicum, 34*(3), 963–971. http://www.ncbi.nlm.nih.gov/pubmed/20977090
Moreno, L. (2013). Obesity in children and adolescents. A critical review. *Endocrinología y Nutrición: Órgano de La Sociedad Española de Endocrinología y Nutrición, 60*(Suppl 1), 7–9. http://www.ncbi.nlm.nih.gov/pubmed/24490216
Muñoz. (2019). Relación de los índices de masa corporal y cintura-cadera con la capacidad residual funcional pulmonar en niños chilenos obesos versus normopeso: un estudio transversal. *Archivos Argentinos de Pediatria, 117*(4), 230–236. https://doi.org/10.5546/aap.2019.230
Portilla, A., Meza, M., & Lizana, P. (2022). Association between emotional exhaustion and tobacco consumption in teachers. *International Journal of Environmental Research and Public Health, 19*(5), 2606.
Prado, C. M., Gonzalez, M. C., & Heymsfield, S. B. (2015). Body composition phenotypes and obesity paradox. *Current Opinion in Clinical Nutrition and Metabolic Care, 18*(6), 535–551. https://doi.org/10.1097/MCO.0000000000000216
Reyes, M., Díaz, E., Lera, L., & Burrows, R. (2011). Ingesta y metabolismo energético en una muestra de adolescentes chilenos con sobrepeso y obesidad. *Revista Médica de Chile, 139*(4), 425–431. http://www.scielo.cl/scielo.php?pid=S0034-98872011000400002&script=sci_arttext
Rietsch, K., Eccard, J., & Scheffler, C. (2013). Decreased external skeletal robustness due to reduced physical activity? *American Journal of Human Biology, 25*, 404–410.
Robalino, M., & Körner, A. (2005). *Condiciones de trabajo y salud docente: estudios de casos en Argentina, Chile, Ecuador, México, Perú y Uruguay* (Issue October 2015).
Rothman, K. J. (2008). BMI-related errors in the measurement of obesity. *International Journal of Obesity, 32*(Suppl 3), S56–S59. https://doi.org/10.1038/ijo.2008.87
Scheffler, C. (2011). The change of skeletal robustness of 6–12 years old children in Brandenburg (Germany) – Comparison of body composition 1999–2009. *Anthropologischer Anzeiger, 68*(2), 153–165. https://doi.org/10.1127/0003-5548/2011/0095
Singh, A. S., Mulder, C., Twisk, J. W. R., Van Mechelen, W., & Chinapaw, M. J. M. (2008). Tracking of childhood overweight into adulthood: A systematic review of the literature. *Obesity Reviews, 9*(5), 474–488. https://doi.org/10.1111/j.1467-789X.2008.00475.x
Slaughter, M. H., & Lohman, T. G. (1976). Relationship of body composition to somatotype. *American Journal of Physical Anthropology, 44*(2), 237–244. https://doi.org/10.1002/ajpa.1330440205
Staiano, A. E., Gupta, A. K., & Katzmarzyk, P. T. (2014). Cardiometabolic risk factors and fat distribution in children and adolescents. *The Journal of Pediatrics, 164*(3), 560–565. https://doi.org/10.1016/j.jpeds.2013.10.064
Stanojevic, S., Kain, J., & Uauy, R. (2008). Secular and seasonal trends in obesity in Chilean preschool children, 1996–2004. *Journal of Pediatric Gastroenterology and Nutrition, 47*(3),

339–343. http://journals.lww.com/jpgn/Abstract/2008/09000/Secular_and_Seasonal_Trends_in_Obesity_in_Chilean.13.aspx

Tapia, L., Lizana, P., Orellana, Y., Villagrán, F., Arias, V., Almagià, A., Burrows, R., & Ivanovic, D. (2013). Somatotype and intellectual ability (Raven progressive matrices test) in Chilean school-age children. *Nutrición Hospitalaria, 28*(5), 1552–1557. https://doi.org/10.3305/nh.2013.28.5.6735

Toro, T., & Almagià, A. (1989). Influencia de la edad, sexo y estado de maduración en el desarrollo de la masa muscular en un grupo de adolescentes de la Quinta Región, Valparaíso, Chile. *Anales de Anatomía Normal, 9*(87), 98.

Toro, T., Arenas, G., & Almagià, A. (1983a). Relación entre somatotipo y edad en estudiantes secundarios varones de Valparaíso. *Anales de Anatomía Normal, 1*, 107–108.

Toro, T. D., Gloria Arenas, D., & Atilio Almagia, F. (1983b). Caracterización somatotípica de jóvenes estudiantes de Valparaíso. *Anales de Anatomía Normal, 1*, 100–106.

Vega-Fernández, G., Lera, L., Leyton, B., Cortés, P., & Lizana, P. A. (2021). Musculoskeletal disorders associated with quality of life and body composition in urban and rural public school teachers. *Frontiers in Public Health, 9*, 607318. https://doi.org/10.3389/fpubh.2021.607318

Vega-Fernández, G., Olave, E., & Lizana, P. A. (2022). Musculoskeletal disorders and quality of life in Chilean teachers: A cross-sectional study. *Frontiers in Public Health, 10*, 1–9. https://doi.org/10.3389/fpubh.2022.810036

Vio, F., Albala, C., & Kain, J. (2008). Nutrition transition in Chile revisited: Mid-term evaluation of obesity goals for the period 2000–2010. *Public Health Nutrition, 11*(4), 405–412. https://doi.org/10.1017/S136898000700050X

Vio, F., Albala, C., & Kain, J. (2019). Descripción de la progresión de la obesidad y enfermedades relacionadas en Chile. *Revista Médica de Chile, 147*(9), 1114–1121. https://doi.org/10.1017/S136898000700050X

Whitaker, R. C., Wright, J. A., Pepe, M. S., Seidel, K. D., & Dietz, W. H. (1997). Predicting obesity in young adulthood from childhood and parental obesity. *The New England Journal of Medicine, 337*(13), 869–873. https://doi.org/10.1056/NEJM199709253371301

Chapter 15
Growth, Body Composition, and Some Influential Factors in Infants, Children, and Adolescents from Cuba

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15.1 Introduction

Double burden of malnutrition has its repercussions from the first 1000 days of life, from conception to the child's second year, influencing health not only in childhood but also in later life. Malnutrition is estimated to contribute to more than a third of all child deaths and is associated with high adiposity among survivors, and also causes growth retardation. Childhood obesity is also underestimated as a public health problem in the social-cultural environments that often consider an overweight child is healthy (WHO, 2016).

High adiposity and body mass index (BMI)-based obesity coexisting with undernutrition have reached their alarming rates in Latin American and Caribbean (LAC) countries (Apaza-Romero et al., 2014). According to the 2019 report of UNICEF on the global status of growth and nutrition in infancy, in Latin America, it is estimated that 9% of children under 5 years of age with stunted growth (low height-for age), 3% wasting, and 7.5% are overweight or obese (UNICEF, 2019). Equally, obese children follow the path of obese adults and contribute to the high prevalence of chronic non-communicable diseases (NCDs). This problem continues to have a significant impact on the health budgets of all LAC countries, because these diseases cause 76% of deaths in the region, with a population of more than 580 million people.

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Evaluation of growth and body composition in infants is essential to assess the quality of growth in the first 2 years of age and NCDs in adult life. Surveillance and control in subsequent years provide sufficient data to achieve healthy adolescence and continue on the path to adulthood with a good quality of life.

Inadequate food and nutrition from an early age and low levels of physical activity (PA) continue to have significant effects on child growth and health, which in current times can grow and develop an obesogenic environment, both in the communities and families with good income, as well as in those groups, which live in the situations of poverty in the countries of the LAC region. An important aspect is added, which are the cultural traditions, framed in collective beliefs and imaginaries about food and obesity.

In each social context, complex systems of representations related to human nutrition are built. Likewise, eating habits encompass complicated interactions that can be metabolic, psychological, social, economic, and cultural. This is expressed in ecological pressures, social possibilities, and limitations, in cultural patterns that indicate an individual or collective preferences and aversions towards food. But, specifically, the need to feed is indissolubly linked to the survival of the human species and its varied subsistence conditions; this need is modified by the way in which human beings, organized in society, value food processes and is also related to knowledge about health and diseases, they also have their symbolism in the image of their own body, which also has a societal impact.

Cuba as a low-income Caribbean country is no exception. Despite the existence of control over growth, maturation, and development of the child population, with emphasis on early ages and promoted through the Ministry of Public Health through the primary health care units, an increase in overweight and obesity in recent years has been observed without high prevalence of undernutrition (stunting or wasting) being a health problem. This text will present some of the results found in recent times, and data from national surveys.

15.2 Nutrition, Growth, and Body Composition Characteristics of Infants

15.2.1 Breast Milk Intake and Nutritional Status in 3-Month-Old Infants

Feeding practices at an early age impact child growth and health status, with future implications. Breastfeeding is the first form of feeding that child should receive during the first 6 months of life, followed by adequate complementary feeding that must be accompanied by continued breastfeeding until 2 years of age. These are the bases of recommended global strategy for infant and young child feeding, the monitoring and follow-up actions proposed by the United Nations (WHO, 2003, 2017; WHO/UNICEF, 2021).

Breastfeeding has transcended biological limits and has crossed social and cultural barriers. It has gone through historical stages, where it has been accepted, rejected, in some cases misunderstood, dismissing its undeniable benefits for growth and health of infants (Díaz Sánchez et al., 2015). This scenario has not been the same in the different countries of the LAC in terms of early initiation, type of breastfeeding, and duration; breastfeeding has a significance in alleviating the double burden of malnutrition in this region (Mazariegos & Ramírez Zea, 2015).

In economically poor communities, breastfeeding guarantees the survival of children up to certain ages, but in other groups there is a loss of cultural values, accompanied by certain unfavorable attitudes, which do not promote this practice of feeding in infancy and early childhood. According to the UNICEF reports, in LAC countries many babies do not receive breast milk and are fed with formula foods (UNICEF, 2019).

The decrease of breastfeeding in children is a risk factor for obesity in childhood, which favors NCDs in adult life (Ma et al., 2020; Mazariegos & Ramírez Zea, 2015). It also constitutes a cultural loss that affects natural upbringing and affective bonds between mother and child (Paricio Talayero, 2004).

In Cuba, breastfeeding has been monitored through the MICS surveys (Multiple International Cluster Indicators) conducted by the UNICEF. Through these studies, a downward trend has been observed, despite the health actions carried out. Cuban medical institutions advise starting to breastfeed within the first hour of delivery, exclusively during the first 6 months, and continuing for 2 years or more, as recommended by the United Nations (WHO, 2022).

According to the latest survey (DRMES, 2020), breastfeeding rate has improved over the previous years (DRMES, 2015) in Cuba. Breastfeeding exclusively in infants under 6 months of age reached 40.9%. Between these ages, the percentage of infants who received breast milk as the predominant source of nutrition was 54%. However, the frequency of children who continued breastfeeding for up to 1 year and 2 years decreased.

On the other hand, the possibility of measuring breast milk intake by the child was an important issue considered in Cuba in previous years, with the utility of validating health surveys and increasing knowledge about feeding practices in childhood. Using stable isotope techniques, it was possible to measure actual milk intake by the 3-month-old infants, in addition to anthropometric measurements and assessment of the social environment (IAEA, 2010; Díaz Sánchez et al., 2014).

Only 9.2% of the mothers provided exclusive breastfeeding, and 42.9% predominant breastfeeding, possibly related to the practices that still exist socially around breastfeeding; 47% accompanied breastfeeding with other types of milk and some solid foods. The amount of milk ingested varied between 10 and 1,241 ml/day.

Exclusively breastfed infants ingested greater volume and grew better, with longer body size (length/height), body proportions, and better nutritional status than mixed-fed infants; in the latter was found a more frequency of overweight and obesity. Infants who ingested little breast milk had poor nutritional status with a possibility to be overweight and obese. That is due to the existence of inappropriate cultural practices in the population.

In short, exclusive breastfeeding was infrequent, with mixed feeding predominating, including solids not recommended at this stage. The high percentage of mothers who gave their child breastfeeding with the accompaniment of water is a reflection of the cultural representations of the population. There was a significant trend toward food introduction very early by mothers with obesity, due to poor eating practices in the population, despite the different educational interventions realized in the country.

These studies can help clarify the false negatives found in the breastfeeding surveys due to the misperceptions when applying the monitoring and evaluation instruments and the characteristics of the social imaginary in the country.

15.2.2 Feeding, Growth, and Body Composition in Children from 6 to 23 Months

Studies of nutrition and growth, including body composition characteristics of young children, have not been very numerous in the LAC countries. Those carried out in other areas of the world have provided knowledge that allows us to have a vision of the changes with age and sex in this period of rapid growth. The stable isotope technique is safe for obtaining total body water (TBW), and we can estimate fat-free mass (FFM) and fat mass (FM) using a two-component model.

The International Atomic Energy Agency (IAEA) has promoted this type of study as part of its actions to improve child health and in the fight to reduce obesity and its impact in adulthood with the appearance of NCDs. As part of a regional study carried out in 12 countries of LAC region, between 2019 and 2021, feeding practices, growth, nutrition and body composition characteristics of Cuban infants between 6 and 23 months were evaluated using feeding survey, anthropometry and deuterium dilution (IAEA, 2013; IAEA/WHO/MBCRS, 2014; Díaz Sánchez et al., 2021).

More than half of the infants consumed vitamin complexes (59.5%). Although the practice of breastfeeding was a requirement for inclusion, at the time of the study, 59.5% of the infants were still receiving it, whose average age limit was 7.8 months; however, there were cases in which it extended to a year of age or older. Exclusive or predominant breastfeeding is administered only for up to 5.9 months, as an average value. The start of complementary feeding was at 5.6 months for the group.

The ENDIS (Nutrition, Child Development and Health Survey) evaluated household food insecurity (ENDIS, 2019), which indicated 56.8% of the infants in the study came from households with good food security, and the rest showed a low level of insecurity. Compared to the results of ENDIS in Uruguay, a country taken as a methodological reference, Cuban children had a similar degree of household food security.

Feeding pattern of infants moderately varied. Diet stood out for the daily consumption of cereals, root vegetables, bread, dairy products, and meat. Almost 77% of the mothers added oils to the infant meals. However, fried foods were not common in the diet. Likewise, butter or margarine, pre-made and pre-fried foods such as nuggets, hamburgers, croquettes, and sausages; 50% consumed instant purée, soups, and broths daily, and artisanal vegetable purees were consumed less frequently. Fish was very rare in the diet, as were eggs and legumes. Sugar and sweets varied in the intake; a group of infants consumed them in isolation, but others daily. A similar pattern was observed for candies, chocolates, filled cookies, and biscuits. More than 40% infants consumed packaged juices regularly, and in the case of soft drinks, a higher percent, rarely. Fruits and vegetables were underrepresented in these infants' meals. Finally, the water consumption was bottled or filtered (Llera, 2021).

In growth and body composition characteristics, there were differences between the sexes. Weight, length, TBW (kg), and FFM (kg) were significantly higher in boys. Skinfold-assessed adiposity and FM tended to be higher in girls. The average FM was high for these ages in girls and boys (Díaz Sánchez et al., 2021, 2022).

In the reports from other countries, the same predisposition has been found, with a similar FM between girls and boys, but with a higher FFM in boys (Wells, 2006). On the other hand, there are changes in body composition during growth. In Cuban infants, an increase of FFM with age, in each sex, is also observed.

Information obtained from growth curves confirm that FFM and TWB increase with age in both sexes, more rapidly in boys during the first 2 years of life, and weight continues to slow down. In contrast, FM without difference between sexes, body fat accumulation in girls is slightly faster that shows a decline after 3 months of age. FM on average, accumulate per year is approximately 2.5 kg in both sexes (Wells et al., 2020).

Behavior of fat is influenced by age and infancy is the stage when growth rate is high. At 6 months of age of the infants, in a classic study carried out in the 1980s, %FM values between 25% and 26% were reported, then gradually decreased, reaching figures of 19–20% at 2 years of age, with a slight predominance in girls (Fomon et al., 1982). In contrast, weight gain continues gradually during childhood, mainly due to an increase in FFM, with simultaneous decrease in %FM. In Cuban infants at 6 months, the %FM values oscillated between 29% and 32% and around 2 years of age from 30% to 31%, higher than those previously reported and following an increasing pattern until 15 months of age when it started reducing (Díaz Sánchez et al., 2022).

The studies are even rare with the indices of height square-adjusted body composition traits (FMI and FFMI). From growth curves, it has been possible to estimate the following behavior (Wells et al., 2020): among male infants, FFMI shows a stabilization around 1 year of age, indicating that the accretion of FFM exceeds growth in length during the first years of life and this pattern disappears later; among female infants, this pattern is less evident, with an accumulation of FFM proportional to height from 1 year of age. For the FMI, an increase is identified up to 6 months of age with a subsequent decline, initially faster and then slows down, evidencing a slope almost flat at 2 years of age in girls and boys. That could explain fat is gained in proportion to height during early childhood.

Figure 15.1 displays an approach designed to compare FMI and FFMI among children. The FMI appears on the ordinate axis and the FFMI on the abscissa. Most of the infants are at the center of distribution, between 10 and 14 kg/m^2 for FFMI and from 3 to 7 kg/m^2 of FMI, with values close to those reported in some studies among infants and other age groups (Wells, 2006; Wells et al., 2020) but higher in FMI than in infants under 1 year of age (López-Jiménez et al., 2015). According to the Fig. 15.1, most of these infants have intermediate values of FFM and FM. Nevertheless, there is a group that, having a normal FFM, has an FM with some excess.

Plotting BMI versus FMI (Fig. 15.2), we can see that BMI has more frequent values between 15 and 20 kg/m^2. FMI corresponds in the same way as FFMI, with almost the same number of individuals with excess fat compared to the BMI. In this case, the BMI represents higher than FFM. That is due to the greater relevance of this component in infants under 2 years of age.

Anthropometric evaluation of growth and nutritional status (weight, height, BMI, skinfolds) have established increases in size and adiposity, but they do not provide direct information on body composition, which could allow differentiating FM and FFM components. A clear example is BMI, which, although is body weight adjusted for height, does not fully identify adiposity, since this index cannot distinguish between FM and FFM (Wells, 2014). That means, two people can have the same BMI, one of them can have higher total adiposity, and in another person, maybe due to FFM that contributes higher weight.

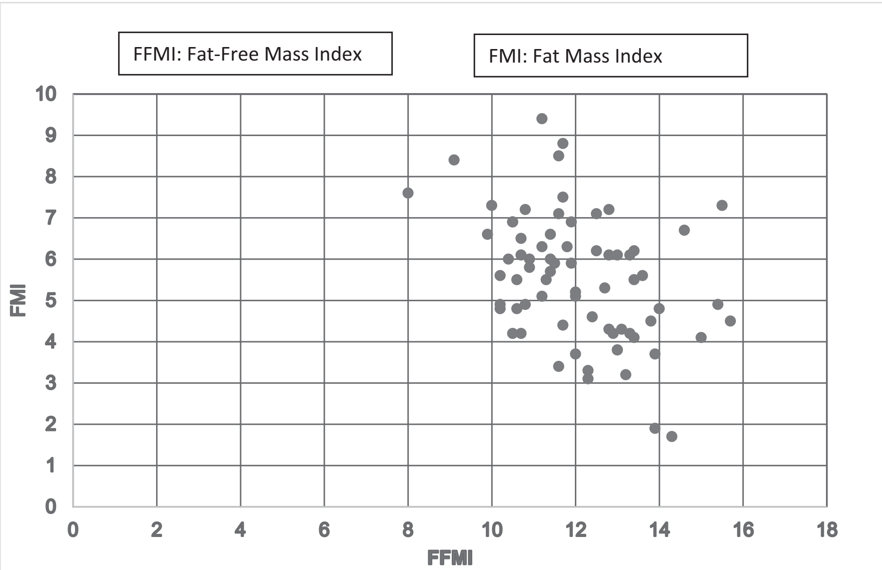

Fig. 15.1 Distribution of FMI and FFMI in infants

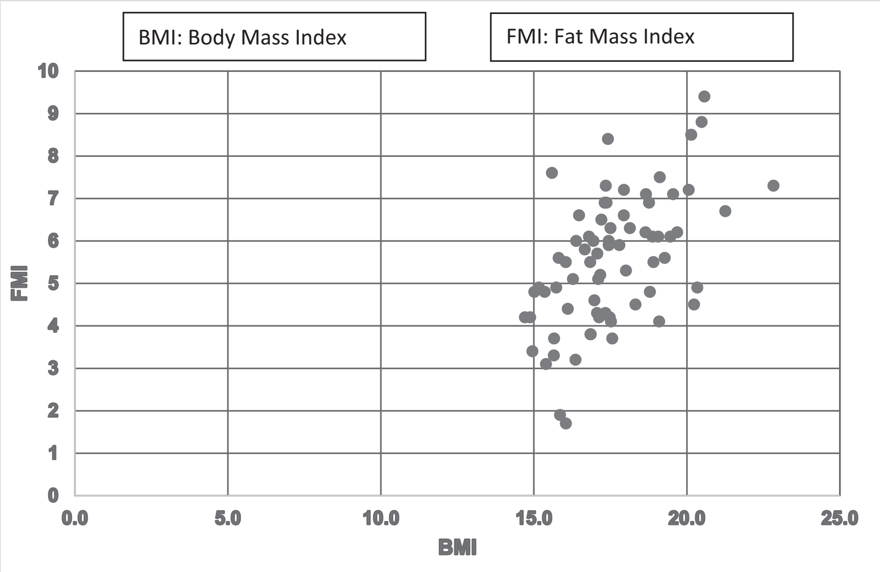

Fig. 15.2 Distribution of BMI versus FMI in infants

On the other hand, maximum velocity for BMI in childhood has been identified as a predictor of future obesity risk (Davies & Lucas, 1990). However, it is difficult to understand how this implies the accumulation of FM during the early years of life or in a faster growth rate. Regarding skinfolds, it is known that subcutaneous body fat with deposits at specific locations correlate poorly with total adiposity at some ages (Davies & Lucas, 1990). These techniques do not measure total body fat in accurate terms (Wells, 2001).

Nutritional assessment indicated that, in our case, more than 80% of infants had normal weight-for-height and BMI (between −2 SD and +2 SD) according to WHO (de Onis et al., 2006). Global overweight prevalence was 9.5% (Díaz Sánchez et al., 2021). On the other hand, 87.3% of infants had an FMI within ≥−2 SD and ≤ +2 SD, and only 8.5% was >+2 SD in the IAEA references IAEA (Murphy-Alford et al., 2023). More than 15% had %FM >+2 SD. Regarding FFM, 93% was within ≥−2 SD and ≤+2 SD and corresponded to the value obtained for the FFMI (91.5%) (Díaz Sánchez et al., 2022).

This work makes it possible to establish some trajectories of change in body composition in the first 1000 days of life, a period in which growth is sensitive to the environmental stimuli, with considerable impacts on health. The present work initiates the knowledge of these patterns in Cuban infants, and it is suitable to know body composition characteristics during growth, although the comparison was made with data from other countries. It is necessary to establish local variations. There are influences of factors such as obesogenic environments, practice or not of breastfeeding, measurement methods, and others. In the case of infants, they came from relatively adequate environments; dietary patterns moderately varied. All of them were exclusive breastfed until the fourth month, and many continued with this practice. Most of the infants had normal BMI and infrequently were overweight and obese.

In conclusion, the results of anthropometric evaluation of infant growth and nutrition showed a certain correspondence with those of body composition at these ages. Boys were taller, had higher weight, and FFM, but girls had a tendency to gain higher body fat. Overweight prevalence was closed to 10%, explained by excess adiposity. But, in this case, BMI seems to be more identified with the FFM. The existing differences in the growth velocities of the body components influence the findings, as this is a period of higher growth rate. The study demonstrated the usefulness body composition by assessing nutritional status.

15.3 Beliefs and Perceptions About the Feeding of School-Age Children with Overweight and Obesity

Despite the interest in the topic of obesity, it has not been possible to stop its increase in different parts of the world and constitutes a manifestation of a social problem, globally. In Cuba, obesity has increased in the last 15–20 years, assessed with a multifactorial approach; however, the population's representations, beliefs, and opinions regarding the problem are not fully known that influences the perception of risk.

The use of qualitative approaches to study overweight and obesity can provide other points of view capable of giving a better contextual understanding of the problem and allow glimpses of solutions that strengthen actions to achieve transformations in the framework of interventions, so it is necessary to consider the cultural and social particularities, as well as the expressions of the daily life of those who suffer from this condition (Angulo-Muñoz, 2014).

Household environment, which plays a fundamental role in the transmission of eating habits, customs, and practices, should be well documented about the impact of these aspects towards the development of obesity, but it often lacks timely information. And the relatives impose opinions and beliefs that may have repercussions on the children's food habits and nutrition (Restrepo & Gallego, 2005).

This part of the chapter has tried, among other aspects, to explore the beliefs and perceptions about the feeding of overweight and obese children and their relatives (Puentes Márquez, 2015). For these purposes, qualitative and quantitative methods were applied to schoolchildren and their families, from four municipalities in Havana. Group discussion, questionnaires, and semi-structured interviews were used. Diagnosis of overweight/obesity was made based on anthropometry among 463 schoolchildren of 5th and 6th-grade in school, to whom ethnographic questionnaires on lifestyle habits were also applied. Of the total number of children measured, 154 were overweight and obese, identified using local growth reference (Esquivel & Rubí, 1991), and only 19% had family participation in the qualitative research. Data analysis was done through the triangulation of all the sources of information.

According to BMI, 48.1% of schoolchildren were overweight and 51.9% obese. This analysis is also supported by abdominal adiposity evaluated using waist circumference; BMI does not offer an exact diagnosis of this excess weight, being able to erroneously attribute the total content of adipose tissue to the higher muscle development (Wells, 2001). Among growing children, other causes intervene as confounding factors in the diagnosis of nutritional status, including age, relationship between trunk (sitting height) and lower extremities, distribution of body fat, variations in the content of body water, in bone mass and muscle tissue; however, in extreme cases, BMI can be considered as an indicator of body fat content, particularly central (Aguilar Cordero et al., 2012).

From the questionnaires applied, it was understood that more than 90% of mothers lived with their children, so they were responsible for deciding their eating habits, education, and care; percentage of fathers who shared this family obligation was low. Lifestyle habits, such as breakfast with family were practiced by 30% of the mothers with their children. Father's presence was less relevant as they did not live with the children for reasons such as divorce, migration, and occupation etc.

In general, meals were prepared at home, in the presence of mothers or fathers, and they only ate outside the house at special occasions. In most of the cases, there was no habit of consuming elaborate meals, although more than 10% did so in the weekend, and a slightly higher percentage than the latter practiced it once or twice a week (Puentes Márquez et al., 2015).

Household environment is of crucial importance in the health status of children. Parents are responsible for their children's first experiences of food, and although they are often not fully aware of it, they have the power to shape their children's preferences and taste for food. Several studies relate the knowledge or parents' habits with the eating patterns of their offspring (Kral & Rauh, 2010). Therefore, parents concerned about their children's excess weight, practice lower consumption of high energy foods and drinks than those who do not recognize where it shows an increase in the consumption of less healthy foods (Rodríguez et al., 2012).

15.4 What the Children Described

Children used to consume high-calorie foods frequently, engaged themselves in little sports activity and spent a higher duration of time watching television. Both aspects: high-calorie consumption and sedentary lifestyle facilitate overweight and obesity. Regarding eating habits, they mostly had breakfast, and milk was the priority, followed by bread. A similar situation occurred in snacks, bread was the most consumed food, and soft drinks were in the second place. The rest of the foods, such as fruit juice, sausage, cookies, and other foods, did not reach 30% (Puentes Márquez et al., 2015).

Children liked fruits and vegetables. A large percentage used to accompany their meals with water, and around 40% did so with sugary juices (more than 70% added sugar) or soft drinks; consumption of the latter varied in frequency between sometimes, once a day, and several times, for approximately 40%. Most of these schoolchildren had preferences for fried foods, and of these, half did so frequently.

Among the food preferences, pizzas and spaghetti were in the first place. The most ignored food was fish, among the vegetables, avocado, and beetroot; however, the latter not widely consumed by the Cuban populations. Comparable results have been found in other studies in Cuba (Macías et al., 2012).

The preferred fruits were mango, apple, and guava; among the favorite vegetables, tomato reached around 40% and cabbage slightly less than 10%. Of the snacks, the brand 'Pelly' was the favorite with 13%, chocolates with 11%, candies with 10%, and cookies with 9%.

Field studies carried out by the Institute of Nutrition and Food Hygiene of Cuba report seasonality for mango and guava between May and September (Pita et al., 2001). Interviews of the schoolchildren were carried out at this same time of year. Preference could be permeated not only by the availability and family food habits but also by the time of year they could purchase.

High preference for tomato among the vegetables, is justified by the fact that it is considered the most popular vegetable in Cuba due to the level of consumption that the population had at that time and the different preparations that contain it (Moya et al., 2001). The preference for cabbage is in correspondence with some studies about the food consumption of the Cuban population, which place it among the most liked vegetables (Martín et al., 2006).

Cookies and chocolates have always been parts of the taste of Cuban population and also the favorites of children. Preferences for 'Pelly' and other foods called 'junk' are slightly more recent; these contain high levels of fats, salt, condiments, or sugars -which stimulate appetite and thirst- as numerous food additives. Prepared foods provide the consumer with fat, cholesterol, sugars, and salt. More than 60% of the children interviewed consumed this type of food after leaving school; or as snacks bought by their parents, including potato chips with saturated fats, fried foods, and patties, among others.

On the other hand, consumption of high-energy sugary drinks in children and adolescents are very high in Cuba and most countries that report negative health consequences in comparison with habits of drinking water, and consumption of milk, juices, or natural shakes. High-energy drinks cause health damages (Aeberli et al., 2011). Sugar is not an essential nutrient, and there is strong evidence of its impact towards the development of overweight and obesity.

15.5 What Parents Think

Family perception is coded into eight assumptions: meaning of obesity, body image perception, weight compliance, interpersonal relationships, causes of fatness, physical exercises, screen habits (watching television, working with computer), and food consumption.

15.5.1 Weight Conformity

Many parents were not satisfied with their children's weight and considered themselves to blame for their child's overweight; they thought that the adults were responsible for obesity of the child because they are who purchased food and introduced the habits to life. But discrepancies in the opinions of the parents were observed. The parents' higher educational level did not improve their degree of perception or identification of their children's overweight and obesity.

Some felt responsible for the body shape of their children not only because they bought food. They also did not have much time to prepare healthy meals; others raised concern about the little availability of healthy foods at an affordable price in the market. But some parents did not show the perception of risk that obesity entails and openly denied the importance of the problem. They spoke without genuine knowledge about their children's feelings, which evidenced a lack of communication. Another group of parents were not bothered by their children's excess weight and sought a justification as heredity, denied having bad eating habits, and minimized the problem.

15.5.2 Causes of Fatness

Individual perception varied, excessive consumption, genetic predisposition, bad eating habits, and a types of food that cause fatness; medications and lack of physical exercise had relatively less importance. Rather than overeating, many mothers and grandmothers attributed excess weight to genetic factors, considering that many children were fat since birth and that situation was natural. Some others said about feeding habits, the type of food consumed at home, or physical activity. Even though they expressed opinions such as excessive indulgence of child's food preference or that they served them large portions "so that they do not repeat". They saw the cause of obesity as something natural since they (their parents) were also obese or overweight in childhood.

Overeating, fried foods were hardly the causes of obesity as mentioned by parents and caregivers. However, they concluded that it is modifiable if they follow a diet or go to a specialist (nutritionist). Obesity has a multifactorial origin; culturally determined food traditions directly influence feeding habits from grandparents to the youngest member of the family. Taste of sweets or fried foods continue through the generations, not perceiving the cause of these habits in the formation of behaviors that lead to obesity, but assuming that they are overweight or obese that a condition commonly inherited.

In addition, mother imposes her own representations on the child's wishes. In many families, there was a tendency to think that since everyone was excess weight, the child must also be overweight. Although it was not a generalized opinion, many parents used to make the child happy with food when they had problems or as a stimulus because it is the parents themselves who move away or comfort eating, which makes children behave similarly.

15.5.3 Food Consumption

Taste and perception for fried foods, sweets, bread, and carbonated soft drinks were reported. They were not used to repeat same food, and tried to make children happy with what they wanted to eat and offered sweets and other junk foods. High price of foods was also pointed out, which did not help their healthy eating, and the children liked pizzas, bread, and high-energy foods. They described the mid-day meal (lunch) at school as bad, and some had additional snack. They expressed the need to strengthen the evening meal. A diversity of opinions was expressed on the importance of meals of the day.

In the interviews, it was possible to detect that the taste for food varied in the family and very caloric for the most part, without an established breakfast habit, only a coffee before going to work, because they did not consider this as the most important meal of the day; however, most of the children stated in the questionnaire that they had breakfast.

Regarding the way of eating, the parent affirmed that food dishes were of a standard size, often deep, and that amount of food was not repeated, because that were regulated by themselves. Children should have their stomach full, and this perception conditioned an excess of food consumption, which goes beyond their satiety, and due to the family pressure.

In the households, taste for fried foods was linked to the excess consumption of bread and soft drinks in late evening. Parents began to prepare food when they returned home from work and therefore, they did not have enough time to prepare healthy meals always. The parents also alleged that the children came home from school, they were very hungry, and the food *par excellence* was bread "… with something" and a soft drink to wait for the dinner to be prepared. Economic reason was not expressed in some cases, nor was time, information, or willingness to prepare a juice or serve fruit as a snack.

Those with a better economy, gave money to children to eat after school, where street vendors proliferated with carts full of sweets, chips, and flour patty, among other products. The practice of buying food around the school has been reported from other countries (Cabello Garza & De Jesús Reyes, 2011). Indulgence of child's taste was demonstrated in almost all the interviews, but they lacked the necessary awareness to know which foods favored them the most, and the parents felt guilty for not being able to indulge those whims.

In addition to the consumption of saturated fats, and fried foods almost daily, they used sauces on top of the food stating "the children eat with more pleasure". There was a widespread consumption of lard due to the high cost of vegetable oil in the market. Fruits and vegetables were not preferred items in the families; many did not have this habit or considered that the priority was meat and stated "…if the children do not eat meat, they are not well-fed…". Others alleged their high prices, or they bought those to "eat something else". Some others also recognized their importance in food habit.

A significant detail was they ate while watching television, sometimes together with their parents, other times alone. That did not help to have a clear sense of satiety because they are busy in eating what was served, and they did not know that they have already consumed and what was necessary. This fact has become common among Cubans; many parents wait for the web series to start to sit with the plate in hand, or watch some other programs, while the children watch television or play computer games. This erroneous practice results in a lack of communication and the elimination of chatter when the family members sit altogether in the table, they talk about daily activities, share life activities, and enjoy food.

15.6 Food Consumption Surveys

15.6.1 Consumption Evaluation

Energy, total protein, and fat were excessive in the diet consumed, concerning nutritional recommendations by age and sex for the Cubans. Vitamins A and C were also excessively consumed. According to the classification of intake, complex carbohydrates, thiamin, and pyridoxine were optimal. Niacin, calcium, iron, and zinc were deficient in this classification. Folic acid was evaluated as insufficient because it was below 70% of adequacy level in the diet.

Consumption of inappropriate foods with excess energy and fat that respond to hypercaloric diets promoting overweight and obesity. Excess of protein in the diet corresponded to false perceptions of the parents about what they considered as adequate diet, in which they overvalued the role of this nutrient. The behavior of vitamins was irregular, and all minerals were insufficient in the diet.

15.6.2 Frequency of Consumption

Frequency of food consumption of children declared by the mothers interviewed, and in accordance with the results of ethnographic questionnaires applied in schools, showed high consumption of rice, pasta, bread, and cookies, as well as oil, fat spread, added sugar, carbonated soft drinks, and candies. The sweetened fruit juices made in the house were found among 53.8% of children.

Almost 85% of the children had a frequent or daily consumption of milk or natural yogurt even though at that age they no longer received it as a product subsidized by the State. These products are not consumed in sufficient quantities to guarantee an adequate intake of calcium, because milk and yogurt are only given in the breakfast.

Consumption of fruits was more frequent than vegetables, although the latter is very limited to the little variety in taste declared in the questionnaire. White meats, mainly represented by chicken, were the most consumed, despite not being among the favorites. Beans, as a source of vegetable protein, are consumed by about a third of these schoolchildren. Eggs were also well represented in more than 50% of the surveys.

Almost 40% of the children had sausage in their usual meals, represented by hot dog, both in the school snack and in meals at home. This has become a representative food item for the Cubans, due in the first place, the families considered it a protein with "high biological value"; it was accessible compared to other foods, and it was easy to prepare.

15.6.3 Food Consumption Practices

Survey of frequency of food consumption reflected the concordance between what was reported by the mothers in the interviews and feeding habit survey data. Lunch and dinner were the principal meals of the day. They dedicated most interest for guaranteeing breakfast and the morning snack offered at school; the principal breakfast item was milk or yogurt. Eating bread was the second option accompanied by spreadable fats (margarine, butter, mayonnaise, etc.), although to a lesser amount.

Literature survey reports that obese adults do not have the habit of eating breakfast (Bonet, 2014). Most of the parents interviewed, who were obese, skipped breakfast, but they do guarantee this first meal of the day for their children and additional snacks in the morning, as well as food reinforcement at lunch with eggs, hot dogs, hamburgers, among others, preferably of something that are quick in preparation and easy to preserve.

Among the way of preparing different foods, they ate mainly fried foods, whole beans, mostly fried/roasted meats or in sauce, fried eggs or omelets, fruits in juices, and raw vegetables. The "Cuban Food Guides" recommend reducing the consumption of fried foods, sauce, and other preparations such as breaded or battered, which absorb a large amount of fat (Porrata et al., 2011). These foods should be substituted by others, and prepared with different cooking methods, such as roasted, grilled, steamed, and boiled etc.

The way of preparing egg and meat was in correspondence with the taste of population for food as reported by the survey on food consumption and preferences of the Cuban populations over 15 years of age (Porrata-Maury, 2009). Consumption of raw vegetables is influenced by their availability in different seasons of the country. On the other hand, vegetables that require cooking are not usually consumed by the population, not only because of access and availability but also because of taste and lack of knowledge about other preparation methods.

In general, family food consumption habits influenced children's preferences towards certain foods so that, if one of the parents did not like a food, they did not buy it in the market, even though there was accessibility and availability for it. The same frequently occurred in the taste for vegetables, which were not consumed by the children because their parents did not like. The same thing happened with the preference for fried and sweet foods.

Indulging children by rewarding them through food is another increasingly widespread situation; if the child gets good marks in the examination, parents take him/her to eat in a restaurant or somewhere else or if the child behaves well at home and school, they give him/her some stimulus consisting of generally sweet or junk food. In this case, food represents a goal to strive for, which has inappropriate connotations. It was not observed that the prize could be fruits and vegetables. Rather it was ice cream, soft drinks, or other sweets.

A relevant aspect of food consumption was practices, customs, and habits of children in the school canteen. This fact contributes a significant percentage of daily consumption calories, because lunch is one of the main meals of the day. Many students had lunch at school canteen, which had repercussions not only from the nutritional point of view but fundamentally in the acquisition of eating habits.

Some of the parents considered that the food offered in the school canteens was of low quality, and for this reason, it was necessary to reinforce the children with food at home; the parents thought the children could be hungry, and they believed that the school food was inadequate, bland, monotonous and many children rejected. In general, schools do not offer vegetables or fruits. Often dessert is bread with syrup, which is not appropriate from the point of view nutritional value.

The school plays as important role in the formation of values, although not everything is the absolute responsibility of the institution. Its influence can be in healthy habits, good table manners, and proper nutrition. During the last decades, there has been a worsening of health indicators related to overweight and obesity, which was attributed, in part, to changes in diet. Consumption of foods high in sugar and fat has increased. Many forms of food preparation are inadequate; there is little creativity in different ways of cooking to make healthy; the recommended meal frequencies are not met. It is necessary an increase in the consumption of fruits and vegetables and to reduce the excess calories from sugar and fat so that it will be possible to acquire an awareness aimed at raising the knowledge of appropriate food and nutrition in the Cuban population.

It can be concluded that family beliefs about obesity were fundamentally directed toward an esthetic conception, related to heredity, as a natural condition that could not be modified by their offspring. Fundamentally, the parents believed that fatness is not synonymous with obesity. Sedentary lifestyle, use of medications, and high consumption of food were widely spread beliefs to identify obese people, undervaluing the type, quality, and way of food preparation.

Family members did not have a correct perception of obesity, nor the repercussions at physical, psychological, and social levels, which could allow them to understand child health problem. Mothers had difficulty in recognizing their children's overweight; consequently, there was perceived underestimation of weight. There were difficulties in controlling children's food intake. On the other hand, the mothers facilitated the transgression of diet toward contradictory behavior, which facilitated the child's anxiety and desire to eat.

Evaluation of consumption, behaviors, and habits allowed us to identify a lifestyle tributary to an obesogenic environment. In the eating behavior of parents and children, a high proportion of fried and sweet foods, addition of sugar to juices and soft drinks, abuse of sausage and spreadable fats, preference for fast food, consumption of snacks and other eating habits of the day outside the usual hours, late evening sitting in front of a computer or television were the general lifestyle habits in Cuban households that need intervention programs to aware the parents of their health along with their child's health and nutrition. The mothers provide foods with a high calorie content to gratify the children. Importance of healthy diet and physical exercise were not perceived.

The approach applied in this study served as the basis for establishing strategies and carrying out actions in the fight to reduce obesity in the Cuban population, with a more comprehensive perspective, emphasizing the household environment.

15.7 Physical Activity and Nutritional Status in Adolescents

Sedentary lifestyle in childhood and adolescence have been increasing in recent years, globally with Latin America being a region with a marked decrease in physical activity (PA). Among the countries with the worst figures are Brazil, Costa Rica, Argentina, and Colombia (Fernández, 2018; Werneck et al., 2019). On the other hand, an increase in the number of hours in front of the television, computers, including video games are other issues to consider. These correspond to the high rates of overweight/obesity and associated comorbidities. This situation also occurs in Cuba, and has been evidenced in national studies (Bonet, 2014).

Similar trend showed in data on PA, growth, and nutritional status of 688 Cuban adolescents between 12 and 15 years old from a school in Havana. PA was assessed using the International Physical Activity Questionnaire (IPAQ) for adolescents: PAQ-A (Kowalski et al., 2004), and during interviews, the excessive use of television, computers, and video games were identified. Growth, body composition, and nutritional status were evaluated using anthropometry (Weiner & Lourie, 1969;

Boileau et al., 1985; Esquivel & Rubí, 1991). Among boys, height, waist circumference, and FFM values were higher, and girls had higher body fatness.

Sex is related to PA and sedentary behavior (SB) in the adolescent population. Boys are more physically active than girls; the girls spend more time in SB (Castillo et al., 2007; Díaz Sánchez et al., 2014a). PA was deficient with a difference between the sexes that denoted a worse condition among girls. However, participation in some sports and recreational activities was noted; 25% of boys participated in soccer seven times or more in a week. The girls excelled at Swiss jumping, walking (for exercise), and dancing. The last activity had frequency more than three times per week among more than 30% of the girls.

In physical education classes, boys were more active, engaging in higher-effort activities. That has been reported earlier (Lincoqueo-Huentecura et al., 2019) and was related to the meaning of patriarchal power, which was also manifested in sports and physical education, by giving males the highest praise for competitive results, raising their ego (Moreno et al., 2006).

There was a predominance of boys in running, skating, cycling, swimming, playing football, skateboarding, basketball, play court, athletics, weights, and active participation in physical education classes, among other activities. Volleyball showed no difference in girls and boys. The level of PA was higher after school in boys, 4–5 times a week. From 6 pm to 10 pm, boys were also more active. Before and after mealtime, there was a notable decrease in exercise, especially among girls.

Pubertal development appears to explain the sex differences in PA and the SB of adolescents (Lee, 2015). In the data analyzed, stages 3 and 4 of development of secondary sexual characteristics were more frequent in boys. In girls, advancement was observed compared to boys, with higher frequency in stages 4 and 5. This had some impact on PA, but no significant interrelationships were observed. A decrease in PA has been reported to influence sexual maturation, but there was no consensus to affirm the existence of an association (Gonçalves Campos et al., 2021).

Watching television, computer use, and video games was most frequent in the weekends, particularly among boys. In weekdays, 31.5% of girls spent more than 2 h in front of television compared to the boys (21.8%). At the end of the week, leisure time duration and use of computer and television watching time were higher (boys 34.2%; girls 50.4%). Video games were most frequent among boys; in the weekend, it reached about 27.3%. Use of computer predominated among girls; in the weekend, raised up to 23.9%. No significant association was found between recorded SB and PA ($p > 0.05$); however, a behavior was observed among adolescents of higher levels of watching television and computer use in those classified with low PA. Time dedicated to television, especially in the weekends, has been reported to be predominant among boys and girls, without observing significant associations between little PA and more time in sedentary activities (Abarca-Sos et al., 2010).

On the other hand, overall prevalence of BMI-based excess weight was 23.3% (overweight: 14.1% + obesity: 9.2%) among all students, being higher in boys. Abdominal adiposity was not very evident in boys and girls. FM was high in boys (37.7%) and girls (47.7%), by body composition analysis. A tendency to find higher

BMI and FM was observed in adolescents with a lower level of PA. This is a common finding in other studies in LAC countries with significant associations (Martínez & Benítez, 2022).

The results can analyze simply by describing already known associations between PA and nutritional status, growth, and body composition. But there are a series of influential factors that affect health and nutrition of the adolescents; among these are the cultural environment, socializing agents such as the family, relationship with peers, media, promotion of sports activities at school by the teachers, quality of physical education classes, physical attitude of individuals, and the motivation for sports.

There are various motivations for adolescents to involve in physical exercise. Although a large percentage of such motivation sustains a benefit for health, others realized it to socialize, make new friends, and for fun, and only in a small group do they perform with aspirations to stand out as a talent (Castillo et al., 2007). It has also been reported the need to overcome a goal, or an obstacle through skill and physical capacity. Other suggested purposes have been related to the emergence of an environment of call for sports competitions and belonging to recognized teams, which needs to generate social acceptance. An opposite aspect is a belief about an ineptitude of the individual in the practice of sports (Bianchi & Brinnitzer, 2009).

The approach to the problem is not only as it is associated with overweight and obesity. It is necessary to consider the family and group environment in which the children and adolescents grow and the entire set of socializing agents promote the importance of PA and not SB. Those items allowed the development of a human ecological model (Spence & Lee, 2003) to explain the magnitude of the problem.

15.8 Recent Data on Nutritional Status in Childhood and Adolescence

One of the goals of WHO reaffirmed in the "Sustainable Development Agenda to 2030" is to reduce malnutrition in children, in its double expression: chronic undernutrition, which persists, and overweight/obesity, which continues to increase in many countries (Etienne, 2016).

Excessive intake of high-energy foods, and insufficient PA, have generated the obesity epidemic, overweight, and nutrition-related NCDs. Low food quality and worsening sanitary conditions are the consequences of political instability, little economic development, social and economic inequalities, and globalization (IIIPA, 2016). Along with, humanitarian crises and climate changes negatively impact nutritional status of children worldwide (UNICEF, 2019). Different forms of malnutrition are the major risk factors for the global burden of diseases (Forouzanfar et al., 2015). Every year, raised prevalence of these chronic diseases increase health costs, and have economic consequences, causing a reduction in the gross domestic product of the countries (Fernández et al., 2017).

LAC is one of the regions in the world with the highest figures for obesity and still maintains representative values of undernutrition. The 2016 report denotes a reduction of stunting prevalence, which coexists with an increase of overweight affected in this same stage (IIIPA, 2016). Reports on nutritional status of school-going adolescents are not available much (UNICEF, 2019), which show prevalence, incorporated into the regional Reports of the United Nations agencies. According to the database of the "NCD Risk Factor Collaboration", undernutrition (wasting and stunting) in children and adolescents aged 5–19 years in LAC is only 2% and overweight 30%, (NCD-RIsC, 2017).

In Cuba, chronic malnutrition (stunted) and wasting are not the major public health problems. Data from the Risk Factors and Preventive Activities Surveys including adolescents (Bonet, 2014) showed that prevalence of overweight and obesity have increased gradually. The recent National Health Survey included data on nutritional status of children from 6 years of age and adolescents up to 19 years. Among 6–14 years old children and adolescents, 20% were overweight and 19.9% were obese. The percentages were higher in urban regions, with almost 21% in each category, compared to rural areas, with around 17% overweight and a similar value for obesity.

Among 6- to 9-year-old children, there was less prevalence of overweight (boys 16.6%, girls 19.1%) and higher obesity (boys 25.8%, girls 21%). In contrast, among 10- to 14-year-old adolescents, there was higher prevalence of overweight (boys 23.7%, girls 20.7%) and lower percentages of obesity (boys 18%, girls 14.7%). Among adolescents aged 15–19 years, the prevalence of overweight and obesity was 20.8% and 6.7%, respectively. However, there was evidence of greater obesity in childhood.

Higher overweight prevalence in adolescents could be related to the changes in body composition due to the pubertal growth spurt, explaining the higher development of FFM at this stage. Overweight prevalence is higher than that reported by the studies carried out in previous years among schoolchildren (Jiménez et al., 2013; Vázquez Sánchez et al., 2017) and adolescents between 15 and 19 years of age, of the National Survey of Risk Factors carried out in 2002 and 2010 (Díaz Sánchez, 2014; Díaz Sánchez et al., 2012, 2018).

In short, overweight and obesity prevalence have also increased in children and adolescents in Cuba, in recent decades, like adult population. The trend in Cuba is like that reported worldwide in high- and low-income countries. Overweight and obesity prevalence are increasing, covering a global scale and particularly relevant in LAC countries. In high- and middle-income countries, strategies have been realized to regulate the consumption of energy-dense foods and drinks, but few policies try to make healthier foods more affordable (NCD-RisC, 2017). Massive interventions are needed to reduce this problem in the child population to avoid its complications in future years.

15.9 Final Comments

Feeding practices influence growth and body composition from very early ages. Breastfeeding, despite its benefits and the good promotion that Cuba has, still does not reach optimal values. In recent times its practice has increased, but its duration has decreased. Data about the quantification of the volume of breast milk ingested shown, that exclusive breastfeeding infants could consume up to 1000 ml/day and had a better nutritional status. In contrast, those who received mixed breastfeeding tended to be overweight and obese.

Infants between 6 and 23 months, exclusively breastfed, had their complementary feeding with a moderately varied diet that guaranteed a high percentage of normal nutritional status. These data corresponded with the evaluation of body composition. Behavior of the components of body composition corroborates the trends of other studies on growth and serves as a basis to clarify the correct use of the indicators.

The beliefs and representations about food provide a needed approach in obesity studies. The family role is transcendent in the formation of children's eating habits. What is consumed and responsibilities of the person who prepares the food; because this individual develops taste, preferences, opinions, and appreciations, regardless of adequate knowledge about the repercussions that has for the children and adolescents. Other aspects of the family imaginary are the beliefs and perceptions about obesity. The parents of overweight and obese schoolchildren did not show clear information about the problem of obesity and its implications. Many parents were also overweight or obese, and thereby household environment was obesogenic. The children assimilated inadequate eating practices that led them to gain excess body weight.

The results confirmed the need to incorporate cultural, social, and psychological aspects in the management of obesity in a holistic perspective, which provides an additional element in the fight to reduce this condition, which increases the risk of NCDs and mortality in adulthood. In the analysis of PA habits, a holistic approach is necessary that considers multiple and coordinated influencing factors. The ecological model proposed by Spence and Lee in 2003 suggested that the biological factors influencing PA are related to the cultural ideals and social values. But there are psychological factors such as attitude, and efficacy, among others, the mediators of this interrelationship. These factors seem to contribute to the sex differences in PA, in addition to the onset of puberty, which can create favorable or negative consequences (Lee, 2015). The results found in Cuban schoolchildren and adolescents seem to agree with these approaches. In obese schoolchildren, influence of family environment is evident in the development of habit for reduced PA. Children understand that they realized little PA and excessive time in front of television, which implies an unhealthy behavior. Moreover, parents do not give much importance to PA. In some cases, they only argued about not having time to develop sports activities in their children. Among adolescents, PA was evaluated as deficient, at different times of the day, for a week, even though they practiced some sports, physical education, and recreational activities, but in other times of the week, SB was important, spending more than 2 hours for watching television and computer use.

Current reports on prevalence of nutritional status corroborate a trend toward underweight reduction that has been maintained in adolescents between 15 and 19 years of age. Other studies show the same tendency among those under 15 years of age. Undernutrition has not been a major health problem in Cuba for several decades. At this time, prevalence of overweight and obesity has increased in children and adolescents despite the figures are lower than that reported from other LAC countries.

References

Abarca-Sos, A., Zaragoza Casterad, J., Generelo Lanaspa, E., & Julián Clemente, J. A. (2010). Comportamientos sedentarios y patrones de actividad física en adolescentes. *Revista Internacional de Medicina y Ciencias de la Actividad Física y el Deporte, 10*(39), 410–427. From http://cdeporte.rediris.es/revista/revista39/artcomportamientos170.htm. Retrieved on 2nd August 2022.

Aeberli, I., Gerber, P. A., Hochuli, M., Kohler, S., Haile, S. R., Gouni-Berthold, I., Berthold, H. K., Spinas, G. A., & Berneis, K. (2011). Low to moderate sugar-sweetened beverage consumption impairs glucose and lipid metabolism and promotes inflammation in healthy young men: A randomized controlled trial. *American Journal of Clinical Nutrition, 94*, 479–485. From https://academic.oup.com/ajcn/article/94/2/479/4597872. Retrieved on 18th July 2021.

Aguilar Cordero, M. J., González Jiménez, E., García García, C. J., García López, P., Álvarez Ferre, J., Padilla López, C. A., & Mur Villar, N. (2012). Estudio comparativo de la eficacia del índice de masa corporal y el porcentaje de grasa corporal como métodos para el diagnóstico de sobrepeso y obesidad en población pediátrica. *Nutrición Hospitalaria, 27*(1), 185–191. From http://scielo.isciii.es/scielo.php?script=sciarttext&pid=S0212-16112012000100022&lng=es. Retrieved on 7th May 2018.

Angulo-Muñoz, R. A. (2014). Aproximaciones cualitativas al estudio de obesidad: nuevas contribuciones a la comprensión de la nutrición humana. *Revista de la Facultad de Medicina, 62*(Supl. 1), S81–S88.

Apaza-Romero, D., Celestino-Roque, S., Tantleán, K., Herrera-Tello, M., Alarcón Matutti, E., & Gutiérrez, C. (2014). Sobrepeso, obesidad y la coexistencia de desnutrición crónica en niños menores de 5 años. *Revista Peruana de Epidemiología, 18*(2), 1–5.

Bianchi, S., & Brinnitzer, E. (2009). Mujeres adolescentes y actividad física. Relación entre motivación para la práctica de la actividad física extraescolar y agentes socializadores. *Revista Digital, 5*(26), 1–3. From http://www.efdeportes.com. Retrieved on 2nd April 2013.

Boileau, R. A., Lohman, T. G., & Slaughter, M. H. (1985). Exercise and body composition of children and youth. *Scandinavian Journal of Sport, 1*, 17–27.

Bonet, M. (2014). *III Encuesta nacional de factores de riesgo y actividades preventivas de enfermedades no transmisibles Cuba 2010–2011* (pp. 69–80). ECIMED.

Cabello Garza, M. L., & De Jesús Reyes, D. (2011). Percepción de las madres de niños con obesidad sobre los hábitos alimenticios y sus responsabilidades en la alimentación de los hijos. *Revista de Salud Pública y Nutrición, 12*(1). From http://www.respyn.uanl.mx/xii/1/artículos/percepcion_madres.html. Retrieved on 20th November 2016.

Castillo, I., Balaguer, I., & García, M. L. (2007). Efecto de la práctica de actividad física y de la participación deportiva sobre el estilo de vida saludable en la adolescencia en función del género. *Revista de Psicología del Deporte, 16*(2), 201–210.

Davies, P. S., & Lucas, A. (1990). The prediction of total body fatness in early infancy. *Early Human Development, 21*, 193–198.

de Onis, M., Garza, C., Onyango, A. W., & Martorell, R. (2006). WHO child growth standards. *Acta Paediatrica Supplement, 450*, S5–S101.

Díaz Sánchez, M. E. (2014). Evaluación antropométrica. En Bonet Gorbea Mariano. *III Encuesta Nacional de factores de riesgo y actividades preventivas de enfermedades no transmisibles. Cuba 2010–2011* (pp. 106–135). ECIMED.

Díaz Sánchez, M. E., Jiménez, A. S., Bonet Gorbea, M., & García Roche, R. (2012). Análisis del sobrepeso de los adolescentes procedentes de la II encuesta nacional de factores de riesgo de cuba. In *XVI Congreso Latinoamericano de Nutrición*.

Díaz Sánchez, M. E., Santana Jardón, D., Rodríguez Domínguez, L., & Moreno López, V. (2014a). Actividad física y estado nutricional en adolescentes. Una visión de género. *Antropo, 31*, 39–49. From www.didac.ehu.es/antropo. Retrieved on 10th July 2015.

Díaz Sánchez, M. E., Ruíz Álvarez, V., Hernández Triana, M., Díaz, Y. A., Llera Abreu, E., Campos, D., Puentes, I., Domínguez, Y., & Santana Jardón, D. (2014b). Evaluación de la ingesta de leche materna y la composición corporal de infantes y sus madres, medidos por dilución de deuterio, como indicadores de buenas prácticas de alimentación y estado nutricional. ARCAL: Informe final del proyecto RLA 6071: CUBA. 2014 (inédito).

Díaz Sánchez, M. E., Ruiz Álvarez, V., Díaz Fuentes, Y., Llera Abreu, E., Campos Hernández, D., & Santana Jardón, D. (2015). Lactancia materna: un fenómeno biocultural. En R. Fleites (compiladora), *Investigación socioantropológica en salud. Enfoque de género* (pp. 54–62). Centro de Estudios Demográficos.

Díaz Sánchez, M. E., Jiménez-Acosta, S., & García-Roche, R. (2018). Contraste en la evaluación nutricional antropométrica por diferentes patrones de crecimiento en adolescentes cubanos. *XVIII Congreso Latinoamericano de Nutrición*. M397: 90.

Díaz Sánchez, M. E., Basabe Tuero, B., Lanyau Domínguez, Y., Llera Abreu, E., Puentes Márquez, I., Domínguez, D., & Llanio Nodarse, C. (2021). *Uso de la técnica de isótopos estables para el monitoreo e intervenciones para mejorar la nutrición del niño pequeño,* ARCAL CLVI: Informe final del proyecto RLA 6073: CUBA. 2021 (inédito).

Díaz Sánchez, M. E., Abreu, L., Tuero, B., Lanyau Domínguez, Y., Llanio Nodarse, C., Puentes Márquez, I., & Domínguez Álvarez, D. (2022). Nutrición y composición corporal por isótopos estables en el niño pequeño. Instituto Nacional de Higiene, Epidemiología y Microbiología. *Fórum de Ciencia y Técnica*, 2022 (inédito).

DRMES (Dirección de Registros Médicos y Estadísticas de Salud), Ministerio de Salud Pública. (2015). *Encuesta de Indicadores Múltiples por Conglomerados. Cuba, 2014*. Informe final.

DRMES (Dirección de Registros Médicos y Estadísticas de Salud), UNICEF Cuba. (2020). *Cuba Encuesta de Indicadores Múltiples por Conglomerados 2019*. Informe de resultados de la encuesta. Dirección de Registros Médicos y Estadísticas de Salud. MINSAP.

ENDIS (Encuesta de Nutrición, Desarrollo Infantil y Salud). (2019). From https://www.ine.gub.uy/web/guest/endis2019. Retrieved on 16th May 2021.

Esquivel, M., & Rubí, A. (1991). Valores cubanos del índice de masa corporal en niños y adolescentes de 0 a 19 años. *Revista Cubana de Pediatría, 63*(3), 181–190.

Etienne, C. F. (2016). Malnutrition in the Americas: Challenges and opportunities. *Revista Panamericana de Salud Pública, 40*(2), 102–103.

Fernández, C. F. (2018). *¿Por qué América Latina es la región más sedentaria?* From https://www.eltiempo.com/salud/por-que-america-latina-es-la-region-mas-sedentaria-269012. Retrieved on 26th December 2019.

Fernández, A., Martínez, R., Carrasco, I., & Palma, A. (2017). *Impacto social y económico de la doble carga de la malnutrición*. Comisión Económica para América Latina y el Caribe (CEPAL).

Fomon, S. J., Haschke, F., Ziegler, E. E., & Nelson, S. E. (1982). Body composition of reference children from birth to age 10 years. *American Journal of Clinical Nutrition, 35*(May), 1169–1175.

Forouzanfar, M. H., Alexander, L., Anderson, H. R., et al. (2015). Global, regional, and national comparative risk assessment of 79 behavioural, environmental and occupational, and metabolic risks or clusters of risks in 188 countries, 1990–2013: A systematic analysis for the Global Burden of Disease Study 2013. *Lancet, 386*, 2287–2323.

Gonçalves Campos, C., de Moura, F. C., Muniz, L. A., Costa Bila, W., de Oliveira, D. V., Caetano Romano, M. C., & Alves Lamounier, J. (2021). Physical activity and adolescent sexual maturity: A systematic review. *Ciência & Saúde Coletiva, 26*(5), 1823–1832.

IAEA. (2010). *Stable isotope technique to assess intake of human milk in breastfed infants* (IAEA human health series no. 7). From http://www.iaea.org/Publications/index

IAEA. (2013). *Body composition assessment from birth to two years of age* (IAEA human health series, N° 22). From http://wwwiaea.org/Publications/index.html

IAEA/WHO/Oxford Multi-Centre Body Composition Reference Study (MBCRS). (2014). *Anthropometry handbook* (pp. 1–58). IAEA/WHO/University of Oxford.

IIIPA (Instituto Internacional de Investigación sobre Políticas Alimentarias). (2016). *Informe de la Nutrición Mundial 2016: De la promesa al impacto: terminar con la malnutrición de aquí a 2030*.

Jiménez, A. S., Rodríguez Suarez, A., & Díaz Sánchez, M. E. (2013). La obesidad en cuba. Una mirada a su evolución en diferentes grupos poblacionales. *Revista Cubana de Alimentación y Nutrición, 23*(2), 297–308.

Kowalski, K., Crocker, P., & Donen, R. (2004). *The Physical Activity Questionnaire for Older Children (PAQ-C) and Adolescents (PAQ-A) manual*. College of Kinesiology University of Saskatchewa.

Kral, T. V. E., & Rauh, E. M. (2010). Eating behaviors of children in the context of their family environment. *Physiology & Behavior, 100*(5), 567–573.

Lee, E.-Y. (2015). *Biological maturation, physical activity, and sedentary behaviors among Korean adolescents*. Thesis, Faculty of Physical Education and Recreation. University of Alberta.

Lincoqueo-Huentecura, B., Carrasco-Alarcón, V., Delgado-Floody, P., Lorca-Tapia, J., & Cárcamo-Oyarzun, J. (2019). Actitudes de los escolares hacia las clases de educación física y la relación con sus niveles de actividad física. *Revista Horizontes Ciencias de la Actividad Física, 2*(10), 1–11.

Llera, E. (2021). *Estado nutricional, composición corporal por deuterio y alimentación en infantes de la Habana*. Thesis, Universidad de Ciencias Médicas.

López-Jiménez, C. A., Villegas-Valle, R. C., Antúnez-Román, L. E., Monreal-Barraza, B. I., Robles-Valenzuela, E. L., Sotelo-Cruz, N., Hurtado-Valenzuela, J. G., & Valencia, M. E. (2015). Composición Corporal de Lactantes Menores de un Año: Una Aplicación de los Índices de Masa Grasa y Masa Libre de Grasa. *Boletín Clínico del Hospital Infantil del Estado de Sonora, 32*(1), 16–21.

Ma, J., Qiao, Y., Zhao, P., Li, W., Katzmarzyk, P. T., Chaput, J. P., Fogelholm, M., Kuriyan, R., Lambert, E. V., Maher, C., Maia, J., Matsudo, V., Olds, T., Onywera, V., Sarmiento, O. L., Standage, M., Tremblay, M. S., Tudor-Locke, C., & Hu, G., & ISCOLE Research Group. (2020, July). Breastfeeding and childhood obesity: A 12-country study. *Maternal & Child Nutrition, 16*(3), e12984. https://doi.org/10.1111/mcn.12984. Epub 2020 Mar 5.

Macías, M. C., Díaz, M. E., Pita, G. M., Basabe, T. B., Herrera, D., & Moreno, L. V. (2012). Estilos de vida, sobrepeso y obesidad en adolescentes de enseñanza media de La Habana. *Revista Española de Nutrición Humana y Dietética, 16*(2), 45–53. From http://renhyd.org/index.php/renhyd/article/view/93. Retrieved on 3rd October 2014.

Martín, G. I., Mercader, C. O., & Macías, M. C. (2006). Intervenciones para promover el consumo de hortalizas y frutas en cuba. *Revista Chilena de nutrición, 33*(Supl 1), 301–305. From: http://www.scielo.cl/scielo.php?script=sciarttext&pid=S0717-75182006 000 300014& lng=es. Retrieved on 9th January 2015.

Martínez, M., & Benítez, K. (2022). Actividad física y su relación con el estado nutricional en adolescentes de la Unidad Educativa Fiscomisional Calasanz. *Ocronos, 5*(4) Abril, 43. Disponible en From https://revistamedica.com/actividad-fisica-estado-nutricional-adolescentes/. Retrieved 2nd August 2022.

Mazariegos, M., & Ramírez Zea, M. (2015). Lactancia materna y enfermedades crónicas no transmisibles en la vida adulta. *Archivos Latinoamericanos de Nutrición, 65*(3), 143–151.

Moreno, J. A., Hellín, P., Hellín, G., & Cervelló, E. (2006). Efectos del género, la edad y la práctica físico-deportiva en las estrategias de disciplina, la orientación disposicional y la motivación autodeterminada en estudiantes adolescentes de Educación Física. In A. Díaz (Ed.), *VI Congreso Internacional de Educación Física e Interculturalidad* (pp. 1–14). ICD.

Moya, C., Oliva, A., Álvarez, M., Morales, C., Florido, M., & Plana, D. (2001). Evaluación de nuevos cultivares de tomate (licopersicosesculentum MILL.) en los períodos tempranos y óptimos de siembra en el occidente de Cuba. *Cultivos Tropicales, 22*(3), 67–72. From http://www.redalyc.org/articulo.oa?id=193230161007. Retrieved on 2nd March 2014.

Murphy-Alford, A. J., Johnson, W., Nyati, L. H., Santos, I. A., Hills, A. P., Ariff, S., Wickramasinghe, V. P., Kuriyan, R., Lucas, N., Costa, C. S., Slater, C., Ahmad, T., Byrne, N. M., Divya, P. J., Kurpad, A. V., Cheikh-Ismail, L. I., Loechl, C., & Norris, S. Multicenter Infant Body Composition Reference Study. (2023). Body composition reference charts for infants from birth to 24 months: Multicenter Infant Body Composition Reference Study. The American Journal of Clinical Nutrition, https://doi.org/10.1016/j.ajcnut.2023.02.012

NCD Risk Factor Collaboration (NCD-RisC). (2017). Worldwide trends in body-mass index, underweight, overweight, and obesity from 1975 to 2016: A pooled analysis of 2416 population-based measurement studies in 128.9 million children, adolescents, and adults. *The Lancet, 390*(10113), 2627–2642.

Paricio Talayero, J. M. (2004). Aspectos históricos de la alimentación al seno materno. En: Comité de Lactancia Materna de la Asociación Española de Pediatría (editor). Lactancia Materna: guía para profesionales. Monografías de la A.E.P. Nº 5 (p. 7–25). Ergon.

Pita, G., Pineda, D., Serrano, G., Macías, C., Cabrera, A., Rodríguez, Y., Monterrey, P., Alonso, E., Martin, I., Alonso, E., Quintero, M. E., Díaz, M., Puentes, I., Ferret, A., Rodríguez, A., & Pérez, C. (2001). *Vitaminas antioxidantes en recién nacidos como factor de riesgo nutricional*. Informe final de proyecto. Instituto de Nutrición e Higiene de los Alimentos.

Porrata, C., Castro, D., Rodríguez, L., Martin, I., & Sánchez, R. y grupo colaborador. (2011). *Guías alimentarias de para población cubana mayor de 2 años de edad* (2da ed.). Molinos Trade S.A.

Porrata-Maury, C. (2009). Consumo y preferencias alimentarias de la población cubana con 15 y más años de edad. *Revista Cubana de Alimentación y Nutrición, 19*(1), 87–105.

Puentes Márquez, I. (2015). *Creencias y percepciones familiares sobre la obesidad infantil en escuelas primaria de La Habana.* MSc thesis, Instituto Superior de Ciencias Médicas.

Puentes Márquez, I., Díaz Sánchez, M. E., Rodríguez Vázquez, L., & Cabrera, A. (2015). Consumo, prácticas y conocimientos de los alimentos en escolares obesos. *Convención Internacional de Antropología Anthropos, 2015*, 296–2303 Research gate. ISBN 978-959-7091-85-1. https://doi.org/10.13140/RG.2.1.3927.2482

Restrepo, S. L., & Gallego, M. M. (2005). La familia y su papel en la formación de los hábitos alimentarios del escolar. Un acercamiento a la cotidianidad. *Boletín de Antropología Universidad de Antioquía, 19*(36), 127–418. From http://www.redalyc.org/articulo.oa?id=55703606. Retrieved on 5th February 2018.

Rodríguez, M. A., Novalbos, J. P., Villagran, P. S., Martínez, J. M., & Lechuga, J. L. (2012). La percepción del sobrepeso y la obesidad infantil por parte de los progenitores. *Revista Española de Salud Pública, 86*(5), 483–494. From http://scielo.isciii.esscielo.php?script=sci_arttext&pid=S1135-57272012000500003& lng=es. Retrieved on 3rd December 2018.

Spence, J. C., & Lee, R. E. (2003). Toward a comprehensive model of physical activity. *Psychology of Sport and Exercise, 4*(1), 7–24.

UNICEF. (2019). *Estado Mundial de la Infancia 2019.Niños, alimentos y nutrición: crecer bien en un mundo en transformación*. UNICEF.

Vázquez Sánchez, V., Niebla Delgado, D. M., Marrero Rodríguez, F. J., Ojeda, D. A., Gálvez Soler, J. L., & Hernández Machado, D. (2017). Estilos de vida de escolares habaneros con sobrepeso y obesos y de sus familiares. *Nutrición Clínica y Dietética Hospitalaria, 37*(2), 147–151. https://doi.org/10.12873/372vazquez

Weiner, J. S., & Lourie, J. A. (1969). *A guide to field methods. International biological programme* (Handbook no 9). Blackwell Scientific Publication.
Wells, J. C. K. (2001). A critique of the expression of paediatric body composition data. *Archives Disease of Childhood, 85*, 67–72.
Wells, J. C. K. (2006). The evolution of human fatness and susceptibility to obesity: An ethological approach. *Biological Review, 81*, 183–205.
Wells, J. C. K. (2014). Toward body composition reference data for infants, children, and adolescents. *Advances in Nutrition, 5*, 320S–329S.
Wells, J. C. K., Davies, P. S. W., Fewtrell, M. S., & Cole, T. J. (2020). Body composition reference charts for UK infants and children aged 6 weeks to 5 years based on measurement of total body water by isotope dilution. *European Journal of Clinical Nutrition, 74*, 141–148. https://doi.org/10.1038/s41430-019-0409-x
Werneck, A. O., Baldew, S. S., Miranda, J. J., Díaz Arnesto, O., Stubbs, B., & Silva, D. R. (2019). Physical activity and sedentary behavior patterns and sociodemographic correlates in 116 982 adults from six South American countries: The South American physical activity and sedentary behavior network (SAPASEN*). International Journal of Behavioral Nutrition and Physical Activity, 16*(1), 68.
WHO. (2003). *Global strategy for infant and young child feeding*. World Health Organization.
WHO. (2016). *Report of the commission on ending childhood obesity*, pp. 1–50.
WHO. (2017). *Guideline. Protecting, promoting and supporting breastfeeding in facilities providing maternity and newborn services*. World Health Organization.
WHO. (2022). *Breastfeeding*. https://www.who.int/health-topics/breastfeeding#tab=tab_1. Retrieved on 2nd August 2022.
WHO/UNICEF. (2021). *Indicators for assessing infant and young child feeding practices: Definitions and measurement methods*. https://www.who.int/publications/i/item/9789240018389. Retrieved on 4th August 2022.

Chapter 16
Height, Weight, and Body Mass Index in Salvadoran Schoolchildren from the Bajo Lempa Rural Region

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16.1 Introduction

Anthropometry enables us to describe the biological process of human growth in a simple and reproducible manner. By measuring only height and weight, it is possible to determine the changes in size during the ontogenetic process. Addition of

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S. Datta Banik (ed.), *Human Growth and Nutrition in Latin American and Caribbean Countries*, https://doi.org/10.1007/978-3-031-27848-8_16

other dimensions such as perimeters, diameters, or subcutaneous adipose skinfolds broadens the knowledge about the developmental pattern of body shape and composition.

Growth monitoring is an excellent strategy to assess health and nutritional status. However, the basis of all clinical and epidemiological diagnoses is comparison with reference values. For this reason, it is necessary to have patterns that serve as a reference when establishing assessment criteria. Growth curves and tables make it possible to check whether a given individual is within the limits of variability that correspond to the population by age and sex. These curves and tables show graphically and numerically the anthropometric values that correspond to the normal ontogenetic variation. These patterns are usually called standards for children below 5 years of age and references for the higher age-groups; curves are constructed from cross-sectional, longitudinal or semi-longitudinal studies for the standards and from cross-sectional studies for the latter. As rightly explained by Khadilkar (2013), a standard must be constructed from a study elaborated with strict inclusion and exclusion criteria to ensure that it is a healthy sample. The growth model of a standard therefore, represents how children "should grow" in conditions that allow them to express their full genetic potential. Whereas a reference simply shows how children and adolescents of a sample representing a given population grow.

Considering the world's vast ethnic and population diversity, the controversy over which standards or references to use is still open (Cole, 2022). In the past, researchers such as Waterlow et al. (1977) and Johnston (1986) were in favor of universal use of growth charts and curves derived from the study conducted between 1971 and 1975 by the American National Center for Health Statistics -NCHS (Hamill et al., 1977). Those were widely used by the World Health Organization (WHO) from different countries' health and nutrition surveillance programs. In addition, data from the National Health and Nutrition Examination Survey (NHANES) have also been frequently used as an international reference (Frisancho, 1990).

Some specialists defend the "universality of growth potential" in all populations, which means that all children who grow in optimal environment conditions from health, and nutritional point of view, should grow in the same way and with the same speed at least during the first 5 years of life (Onyango & de Onís, 2008). Based on that premise, in 2006, WHO published the growth standards for children under 5 years of age, based on a sample of children from different continents: Pelotas (Brazil) and Davis (USA) in the Americas, Accra (Ghana) in Africa, Delhi (India) and Muscat (Oman) in Asia and Oslo (Norway) in Europe. That study had a semi-longitudinal design, and the selected children were born to non-smoking mothers and had been exclusively breastfed for a minimum of 4 months. These conditions would guarantee a suitable environment for achieving the maximum level of growth. Therefore, these standards have a "prescriptive" character showing how children should grow.

In 2007, WHO published the growth references for boys and girls between 5 and 19 years of age, but in this case, data come from the First National Health Survey of the United States, known as NHANES I, which was carried out in the 1970s. The mathematical methods applied to fit and model the curves were updated, but it is worth asking to what extent these tables represent the ontogenetic variability of the world population. As indicated in previous paragraphs, the Multicenter Growth Study that gave rise to the standards for children under 5 years of age, very strict criteria were applied for the selection of sample. The inclusion and exclusion criteria ensured that the participating children were healthy and could represent an optimal growth pattern or aspirational goal for our species. In contrast, for the elaboration of the WHO references between 5 and 19 years of age, previously published studies (mostly national surveys) were used as a starting point. The WHO 2007 growth reference did not select the samples with a clear criterion of healthy children. Environmental or nutritional conditions were not controlled for, so the references are "descriptive" in nature, i.e., they describe how subjects grow in the absence of disease and in an environment that is not overtly adverse.

Some countries have their national references. For example, Tanner (1966) published patterns for the British population and Roede (1985) for European Dutch children. Later, references were published for Spain (Hernández et al., 1988; Carrascosa et al., 2008), Italy (Cacciari et al., 2002), Norway (Júlíusson et al., 2009) Finlad (Saari et al., 2011) and Croatia (Juresa et al., 2012), among others. In Asia, growth charts for Iran (Hosseini et al., 1998), Saudi Arabia (El-Mouzzan et al., 2007), Japan (Suwa & Tachibana, 1993), China (Li et al., 2009), Taiwan (Chen et al., 2010), India (Khadilkar et al., 2015) and Korea (Kim et al., 2018) are worth mentioning. In Latin America, Faulhaber (1976) elaborated on growth patterns for the population of Mexico, Jordan (1979) for the Cuban population, and Lejarraga and Orfila (1987) for the Argentine population. More recently, Carmenate et al. (2015) published references for the Dominican Republic.

All the cited references, which reflect a greater or lesser extent the ethnic and population diversity of each country, may be more appropriate for the medical diagnosis of individuals. Nevertheless, from an epidemiological point of view, the application of WHO references may be more beneficial for the contrast between populations, socioeconomic groups, meta-analysis studies, or secular trend research (Garrido-Miguel et al., 2017).

At present, El Salvador has no national growth reference curves to evaluate physical growth and nutritional status of its children. The current protocol of the Ministry of Health for evaluating nutritional status in children and adolescents considers the reference values for anthropometric measurements proposed by the WHO (MINSAL, 2013).

In this background, objective of the present study was to characterize the expression of child and adolescent physical growth in the Salvadoran school population of the Bajo Lempa region and to compare the growth pattern both with WHO references and with those corresponding to another population located in Central America, such as the Dominican Republic.

16.2 Materials and Methods

16.2.1 Population and Scope of the Study

This research was carried out in the Bajo Lempa region of El Salvador. It is an impoverished and relatively young rural area since the current population, made up mainly of families of ex-combatants and displaced persons from the civil war that the country suffered between 1979 and 1992, settled after the signing of the Peace Accords in 1992.

This region is strongly threatened by climatic factors that endanger crops and food reserves, such as frequent flooding due to rainfall and overflowing rivers, especially between May and October (*Asociación-Fundación para la Cooperación y el Desarrollo Comunal de El Salvador,* 2017). Previous studies conducted by the authors detected a high percentage of food insecurity (58.7%) in a survey among 143 families in the same region. Furthermore, stunting (low height-for-age) affected almost 9% of the school population (Pedrero-Tomé et al., 2020).

16.2.2 Sample Composition and Anthropometry

A semi-longitudinal growth study was conducted among 948 Salvadoran schoolchildren (458 boys and 490 girls) aged 5–16 years, attending six public schools (Guajoyo, Granzazo, Caserío Rancho Grande, San Bartolo, Santa Marta, and Los Naranjos) located in the Bajo Lempa region (Municipality of Tecoluca, Department of San Vicente, El Salvador) (Fig. 16.1). Data were collected in August 2018, October 2019, and September 2021.

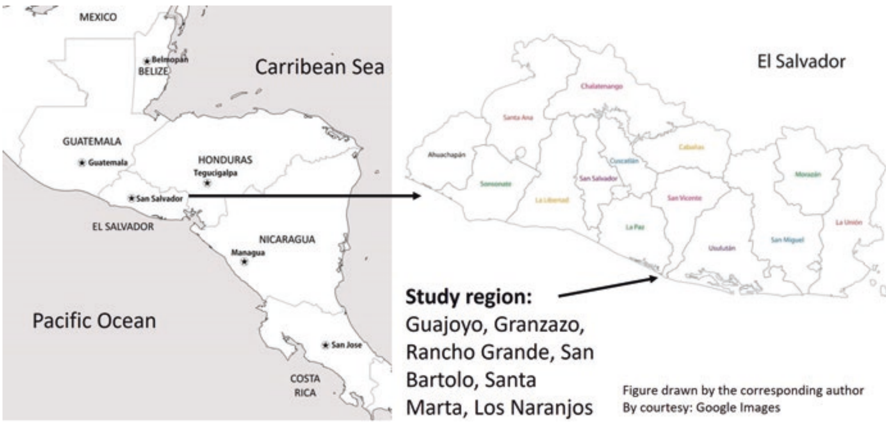

Fig. 16.1 Geographic location of the studied Salvadoran communities

Table 16.1 Distribution of the sample by sex and age

	Male (n = 458)		Female (n = 490)	
Age (years)	n	%	n	%
5	25	5.5	30	6.1
6	46	10.0	51	10.4
7	56	12.2	54	11.0
8	63	13.8	59	12.0
9	58	12.7	63	12.9
10	54	11.8	65	13.3
11	54	11.8	51	10.4
12	41	9.0	37	7.6
13	23	5.0	37	7.6
14	15	3.3	17	3.5
15	12	2.6	18	3.7
16	11	2.4	8	1.6

This research was conducted according to the ethical principles described by the World Medical Association (2013) and approved by the ethics committee of the Complutense University of Madrid and the National University of El Salvador. The objectives and procedures of the study were detailed in informal meetings at each school. The study included all the children who orally affirmed their collaboration and whose mothers, fathers, or legal guardians had previously signed the informed consent form (Table 16.1).

Anthropometric evaluations were performed by anthropometrists certified as level 1 by the International Society for the Advancement of Kinanthropometry (ISAK). The measurements were taken under the technical recommendations of the International Biological Program (IBP) (Weiner & Louire, 1981), with duly calibrated instruments before the commencement of each session. Three values were recorded for each variable. Weight (kg) was recorded using a TANITA digital scale with an accuracy of 100 grams, and height (cm) was taken using a SECA anthropometer with an accuracy of 1 mm. From these two anthropometric measurements, body mass index (BMI) was calculated using the formula [BMI = weight (kg)/height (m)^2].

16.2.3 Data Analysis

The LMS (lambda-mu-sigma) method was applied to model the growth curves for weight, height, and BMI of Salvadoran schoolchildren by age and sex. This technique transforms the anthropometric data using the Box-Cox method, adapting them to a normal distribution and significantly reducing the possible effects of asymmetry of the variables (Cole & Green, 1992); then models and combines three smoothed curves from which age- and sex-specific growth percentiles can be obtained (Cole, 1988; Cole & Green, 1992; Rigby & Stasinopoulos, 2005). These smoothed curves represent the parameters of the Box-Cox (Cole & Green, 1992). They are (1) the power needed to normalize data (lambda, L), (2) the median (mu, M), and (3) the coefficient of variation of the distribution for each age (sigma, S).

The results obtained were checked for compliance with the requirements of the LMS methodology, including that the percentile curves should grow (and not decrease) considering time, should change sufficiently with age, and should take into the account that growth pattern may be nonlinear (Muggeo et al., 2013; Ohuma & Altman, 2019).

The growth curves were created by calculating nine percentiles (3rd, 5th, 10th, 25th, 50th, 75th, 90th, 95th, and 97th) for each anthropometric variable. In addition, they were compared with the international growth reference of WHO (2007) and the Dominican Republic's national references (Carmenate et al., 2015). First, a graphical comparison was made by representing three centiles per group (3rd, 25th, and 97th). Secondly, the absolute differences between all possible combinations of the three references for the same centiles were plotted. Data processing was performed with the gamlss package of the R statistical analysis program R Core Team (2022).

16.3 Results

Tables 16.2, 16.3, 16.4, 16.5, 16.6 and 16.7 present the nine smoothed percentiles (3rd, 5th, 10th, 25th, 50th, 75th, 90th, 95th, and 97th) and the L, M, and S values for the variables weight (kg), height (cm), and BMI (kg/m^2) according to sex and age.

Figures 16.2, 16.3 and 16.4 illustrate the comparison of the 3rd, 50th, and 97th percentiles of the current Salvadoran sample's weight, height, and BMI references with the WHO international reference and the national reference of the Dominican Republic. Figure 16.2 shows the ontogenic evolution of weight in the different references. Very slight differences are detected for the 3rd and 50th percentiles. In contrast, for 97th percentile, both Central American series significantly exceed the values corresponding to the WHO references. This is the case for both boys and girls, especially in the Salvadoran sample.

Figure 16.3 shows height growth pattern. In general, growth of Salvadorans conforms reasonably close to the WHO curves up to prepubertal ages, being for all percentiles lower than that of Dominicans. However, the differences increase after 10 or 11 years, showing both Central American series clearly below the WHO values. This phenomenon is even more evident in the female series.

As shown in Fig. 16.4, and as expected, once the growth model for weight and height was known, the percentile values of BMI in Salvadoran children exceeded those corresponding to the WHO references. The distance between the curves is small for 3rd and 50th but very pronounced for 97th in both sexes.

Figures 16.5, 16.6 and 16.7 show the difference in absolute values for the 3rd, 50th, and 97th percentiles of weight, height, and BMI between the three references:

Table 16.2 Smoothed percentiles, and L, M, and S values for weight (kg) in boys

Age (years)	L	M	S	P3	P5	P10	P25	P50	P75	P90	P95	P97
5.0	1.00	18.52	0.23	14.62	14.97	15.57	16.77	18.52	21.01	24.47	27.61	30.42
5.5	1.00	19.72	0.20	15.42	15.81	16.47	17.79	19.72	22.48	26.30	29.78	32.90
6.0	1.00	20.97	0.20	16.25	16.67	17.40	18.85	20.97	24.00	28.22	32.05	35.48
6.5	1.00	22.26	0.21	17.08	17.55	18.34	19.93	22.26	25.59	30.21	34.39	38.13
7.0	1.00	23.59	0.23	17.94	18.45	19.31	21.05	23.59	27.23	32.25	36.79	40.82
7.5	1.00	24.97	0.24	18.82	19.37	20.32	22.21	24.97	28.92	34.35	39.21	43.51
8.0	1.00	26.41	0.24	19.73	20.33	21.35	23.40	26.41	30.67	36.49	41.66	46.19
8.5	1.00	27.89	0.23	20.66	21.31	22.42	24.64	27.89	32.47	38.69	44.14	48.87
9.0	1.00	29.42	0.23	21.62	22.32	23.52	25.92	29.42	34.34	40.94	46.66	51.56
9.5	1.00	31.01	0.23	22.61	23.37	24.66	27.25	31.01	36.27	43.24	49.21	54.26
10.0	1.00	32.66	0.24	23.62	24.44	25.84	28.62	32.66	38.25	45.59	51.78	56.93
10.5	1.00	34.36	0.25	24.68	25.56	27.06	30.05	34.36	40.29	47.96	54.32	59.55
11.0	1.00	36.12	0.26	25.78	26.73	28.34	31.54	36.12	42.38	50.35	56.84	62.10
11.5	1.00	37.95	0.26	26.94	27.95	29.68	33.09	37.95	44.51	52.74	59.32	64.57
12.0	1.00	39.85	0.25	28.15	29.24	31.08	34.71	39.85	46.69	55.14	61.78	66.98
12.5	1.00	41.81	0.24	29.43	30.59	32.55	36.40	41.81	48.93	57.56	64.22	69.36
13.0	1.00	43.84	0.23	30.77	32.00	34.09	38.16	43.84	51.21	60.01	66.67	71.75
13.5	1.00	45.94	0.21	32.16	33.48	35.69	40.00	45.94	53.57	62.51	69.17	74.17
14.0	1.00	48.11	0.19	33.61	35.01	37.36	41.90	48.11	55.99	65.07	71.73	76.67
14.5	1.00	50.36	0.19	35.12	36.60	39.09	43.88	50.36	58.49	67.71	74.37	79.26
15.0	1.00	52.69	0.19	36.67	38.24	40.88	45.92	52.69	61.08	70.45	77.12	81.97
15.5	1.00	55.11	0.17	38.27	39.94	42.72	48.03	55.11	63.75	73.28	79.98	84.80
16.0	1.00	57.60	0.16	39.90	41.68	44.63	50.22	57.60	66.53	76.23	82.97	87.78

Salvadorans children vs. WHO references (ES – WHO), Salvadorans vs. Dominicans children (ES – DR) and Dominicans children vs. WHO references (DR – WHO).

Figure 16.5 shows the absolute differences between the 3rd, 50th, and 97th percentiles for weight growth patterns among the three references. Practically in all cases, Salvadoran schoolchildren have higher weight values than Dominican schoolchildren. The most considerable differences are found while comparing the 97th percentile data of the Central American samples with the international reference. In the case of the 97th percentile, Salvadoran 5-year-old boys are already 6 kg heavier than their peers of the international reference, raising this value to 12 kg at the age of 10 years. The case of girls is quite similar, as they present 4 kg more at 5 years of age, reaching 14 kg more than the WHO reference.

It is important to note that the two Central American populations are below the international reference in height (Fig. 16.6). Regardless of the percentile or sex, the trend observed for the differences increases with age in both cases. Those differences are markedly high, so the Salvadorans are 5, 9, and 15 cm and Dominicans 15, 11, and 7 cm below the WHO reference for 3rd, 50th, and 97th percentiles, respectively. A more remarkable growth in height is reported in the Salvadoran sample

Table 16.3 Smoothed percentiles, and L, M, and S values for weight (kg) in girls

Age (years)	L	M	S	P3	P5	P10	P25	P50	P75	P90	P95	P97
5.0	1.00	18.11	0.21	14.18	14.55	15.17	16.38	18.11	20.46	23.47	25.96	28.02
5.5	1.00	19.18	0.21	14.94	15.32	15.97	17.27	19.18	21.80	25.07	27.74	29.91
6.0	1.00	20.38	0.20	15.77	16.16	16.85	18.25	20.38	23.32	26.92	29.76	32.03
6.5	1.00	21.70	0.20	16.66	17.08	17.79	19.30	21.70	25.04	29.01	32.04	34.41
7.0	1.00	23.13	0.20	17.62	18.04	18.79	20.42	23.13	26.96	31.36	34.61	37.07
7.5	1.00	24.67	0.22	18.62	19.06	19.84	21.60	24.67	29.10	34.01	37.49	40.05
8.0	1.00	26.33	0.25	19.65	20.10	20.93	22.85	26.33	31.41	36.92	40.69	43.40
8.5	1.00	28.08	0.26	20.70	21.18	22.07	24.17	28.08	33.86	40.04	44.18	47.12
9.0	1.00	29.94	0.25	21.77	22.3	23.27	25.59	29.94	36.40	43.31	47.93	51.19
9.5	1.00	31.90	0.26	22.86	23.45	24.55	27.13	31.90	38.98	46.64	51.84	55.55
10.0	1.00	33.95	0.27	23.96	24.66	25.91	28.79	33.95	41.52	49.91	55.79	60.07
10.5	1.00	36.06	0.27	25.08	25.9	27.37	30.60	36.06	43.92	52.96	59.58	64.54
11.0	1.00	38.17	0.28	26.19	27.18	28.91	32.53	38.17	46.08	55.64	63.00	68.71
11.5	1.00	40.23	0.29	27.29	28.48	30.51	34.53	40.23	47.98	57.85	65.84	72.23
12.0	1.00	42.18	0.29	28.37	29.78	32.12	36.51	42.18	49.61	59.60	68.00	74.91
12.5	1.00	43.96	0.28	29.43	31.05	33.67	38.40	43.96	51.04	60.95	69.51	76.65
13.0	1.00	45.58	0.27	30.49	32.28	35.16	40.13	45.58	52.33	62.02	70.48	77.56
13.5	1.00	47.05	0.26	31.55	33.49	36.55	41.70	47.05	53.52	62.90	71.06	77.84
14.0	1.00	48.43	0.24	32.64	34.70	37.90	43.16	48.43	54.66	63.66	71.40	77.76
14.5	1.00	49.76	0.21	33.79	35.94	39.26	44.59	49.76	55.75	64.35	71.65	77.57
15.0	1.00	51.09	0.18	34.98	37.26	40.72	46.11	51.09	56.76	64.96	71.89	77.48
15.5	1.00	52.47	0.16	36.22	38.70	42.38	47.84	52.47	57.62	65.40	72.13	77.61
16.0	1.00	53.90	0.15	37.56	40.36	44.34	49.83	53.90	58.32	65.63	72.26	77.81

than in the Dominican sample, to the point that the difference in absolute values between the two countries is reversed.

Figure 16.7 shows the differences in absolute values for BMI among the three references mentioned. In general terms, the Dominicans present the lowest BMI values at all ages, followed by those of the WHO reference and the Bajo Lempa sample. The disproportionate changes of BMI of the Salvadoran sample for the 97th percentile compared with the Dominican and WHO references is very striking. It should be noted that, although the differences in absolute values tend to attenuate, an excessive growth is observed for this variable in Salvadoran boys and girls, reaching a peak at the age of 10–11 years.

16.4 Discussion

Physical growth pattern of Salvadoran schoolchildren in the Bajo Lempa region differs from the WHO reference. Although the distance between the curves is small at the initial ages, the differences increase at 10–11 years in the male series and

Table 16.4 Smoothed percentiles, and L, M, and S values for height (cm) in boys

Age (years)	L	M	S	P3	P5	P10	P25	P50	P75	P90	P95	P97
5.0	1.00	109.57	0.05	98.03	99.90	102.44	106.05	109.57	112.97	116.22	118.36	119.88
5.5	1.00	112.73	0.04	100.96	102.87	105.46	109.14	112.73	116.21	119.52	121.72	123.28
6.0	1.00	115.67	0.04	103.68	105.62	108.26	112.01	115.67	119.20	122.59	124.83	126.42
6.5	1.00	118.44	0.05	106.25	108.22	110.90	114.71	118.44	122.03	125.48	127.77	129.39
7.0	1.00	121.19	0.05	108.80	110.81	113.53	117.40	121.19	124.85	128.35	130.69	132.34
7.5	1.00	124.02	0.05	111.44	113.48	116.24	120.18	124.02	127.74	131.32	133.69	135.38
8.0	1.00	126.79	0.05	114.02	116.09	118.89	122.89	126.79	130.57	134.20	136.62	138.33
8.5	1.00	129.32	0.05	116.40	118.49	121.33	125.37	129.32	133.15	136.83	139.28	141.02
9.0	1.00	131.66	0.05	118.62	120.73	123.59	127.67	131.66	135.53	139.25	141.73	143.50
9.5	1.00	133.91	0.05	120.76	122.89	125.78	129.89	133.91	137.81	141.56	144.07	145.86
10.0	1.00	136.15	0.05	122.93	125.07	127.97	132.11	136.15	140.08	143.87	146.41	148.21
10.5	1.00	138.49	0.04	125.19	127.34	130.26	134.42	138.49	142.45	146.27	148.82	150.64
11.0	1.00	140.97	0.04	127.60	129.76	132.70	136.88	140.97	144.95	148.80	151.37	153.21
11.5	1.00	143.65	0.05	130.21	132.39	135.33	139.54	143.65	147.65	151.53	154.12	155.97
12.0	1.00	146.63	0.05	133.13	135.31	138.27	142.49	146.63	150.66	154.56	157.17	159.04
12.5	1.00	149.97	0.05	136.40	138.59	141.57	145.81	149.97	154.02	157.95	160.59	162.47
13.0	1.00	153.51	0.04	139.88	142.08	145.07	149.33	153.51	157.59	161.54	164.20	166.10
13.5	1.00	157.01	0.04	143.34	145.55	148.54	152.81	157.01	161.10	165.07	167.74	169.66
14.0	1.00	160.13	0.04	146.48	148.69	151.67	155.94	160.13	164.22	168.20	170.87	172.79
14.5	1.00	162.58	0.04	149.03	151.22	154.18	158.42	162.58	166.65	170.61	173.27	175.19
15.0	1.00	164.32	0.04	150.93	153.09	156.02	160.20	164.32	168.34	172.26	174.90	176.80
15.5	1.00	165.36	0.04	152.21	154.33	157.21	161.32	165.36	169.32	173.18	175.79	177.66
16.0	1.00	165.82	0.03	152.95	155.02	157.84	161.86	165.82	169.70	173.49	176.05	177.89

11–12 years in the female series. From these peripubertal ages, Salvadoran boys and girls present height, clearly below that described by WHO, as seen from the percentile values. However, the weight is closer to the WHO references, although it slightly exceeds the median value and, especially, the 97th percentile one. Consequently, a lower height and higher weight are reflected in the BMI distribution of Salvadoran children, which also presents figures more elevated than the WHO references at 50th percentile and even higher at 97th.

Physical growth is a biological process with a genetic predisposition influenced by epigenetic and environmental factors. Economic factors are essential because they determine other issues such as education, housing, health care, hygiene, and food. According to the most up-to-date view, optimal nutrition, absence of disease, healthy environment, and favourable economic circumstances guaranteeing essential family support are prerequisites for successful growth regulation in children (Bogin et al., 2018). It is complex to discern to what extent the genetic composition determines short stature of Salvadorans since the analyzed sample lives under environmental conditions that are far from optimal. The Salvadoran region of Bajo

Table 16.5 Smoothed percentiles, and L, M, and S values for height (cm) in girls

Age (years)	L	M	S	P3	P5	P10	P25	P50	P75	P90	P95	P97
5.0	1.00	108.59	0.05	98.68	99.98	101.95	105.15	108.59	111.92	114.82	116.53	117.62
5.5	1.00	111.36	0.05	101.36	102.64	104.59	107.82	111.36	114.85	117.96	119.80	120.99
6.0	1.00	114.52	0.05	104.43	105.69	107.63	110.88	114.52	118.17	121.47	123.45	124.74
6.5	1.00	117.66	0.05	107.46	108.71	110.65	113.94	117.66	121.45	124.93	127.05	128.43
7.0	1.00	120.73	0.04	110.38	111.63	113.58	116.92	120.73	124.67	128.31	130.54	132.01
7.5	1.00	123.79	0.05	113.18	114.46	116.45	119.86	123.79	127.87	131.67	134.00	135.55
8.0	1.00	126.85	0.05	115.91	117.22	119.27	122.79	126.85	131.07	135.00	137.43	139.03
8.5	1.00	129.92	0.05	118.59	119.95	122.08	125.73	129.92	134.27	138.32	140.81	142.45
9.0	1.00	133.05	0.05	121.31	122.73	124.94	128.73	133.05	137.51	141.63	144.15	145.81
9.5	1.00	136.26	0.05	124.11	125.59	127.90	131.82	136.26	140.79	144.94	147.46	149.12
10.0	1.00	139.47	0.05	126.99	128.54	130.93	134.96	139.47	144.02	148.16	150.65	152.27
10.5	1.00	142.59	0.05	129.92	131.52	133.97	138.06	142.59	147.11	151.17	153.60	155.17
11.0	1.00	145.52	0.05	132.82	134.44	136.92	141.03	145.52	149.95	153.89	156.22	157.73
11.5	1.00	148.16	0.04	135.59	137.22	139.7	143.75	148.16	152.45	156.23	158.46	159.89
12.0	1.00	150.42	0.04	138.12	139.74	142.18	146.15	150.42	154.55	158.15	160.26	161.61
12.5	1.00	152.24	0.03	140.31	141.89	144.28	148.13	152.24	156.18	159.60	161.59	162.86
13.0	1.00	153.54	0.03	142.03	143.57	145.89	149.61	153.54	157.28	160.51	162.38	163.58
13.5	1.00	154.26	0.03	143.23	144.72	146.95	150.52	154.26	157.81	160.85	162.61	163.73
14.0	1.00	154.54	0.03	144.00	145.43	147.58	150.98	154.54	157.90	160.76	162.42	163.47
14.5	1.00	154.54	0.03	144.49	145.87	147.92	151.16	154.54	157.71	160.41	161.96	162.94
15.0	1.00	154.40	0.03	144.83	146.15	148.11	151.20	154.40	157.39	159.93	161.39	162.31
15.5	1.00	154.24	0.03	145.14	146.40	148.27	151.20	154.24	157.07	159.46	160.83	161.70
16.0	1.00	154.13	0.03	145.48	146.68	148.46	151.25	154.13	156.81	159.07	160.36	161.18

Lempa is recognized as a critical area in terms of environmental threat, risk and vulnerability, an aspect that negatively conditions health and food security of its inhabitants (Pedrero-Tomé et al., 2022).

Human body size shows a considerable ethnic and population variation that partly responds to the genetic component and partly to the environmental settings in which the individual grows (Roser et al., 2013). Biological anthropologists have been trying for decades to unravel the contribution of each of these components at each stage of ontogeny. This considerable variation in size supports the idea that genetic factors are involved. However, at the same time, in many cases, the tallest human groups are also the ones that enjoy the best economic conditions, while the shortest people being the poorest. Specific studies of family correlations between parent-children or twins have shown that the heritability of height and other longitudinal dimensions is significantly higher than the heritability of weight or BMI; phenotypes where the environmental component contributes to a greater extent (Jalenovic & Rebato, 2012; Poveda et al., 2012; Segal et al., 2009;). This implies that the contribution of the genetic factor is not the same for all body tissues; compared to bone tissue, more sensitive to environmental changes are muscle and fat

Table 16.6 Smoothed percentiles, and L, M, and S values for BMI (kg/m^2) in boys

Age (years)	L	M	S	P3	P5	P10	P25	P50	P75	P90	P95	P97
5.0	1.00	15.30	0.17	12.92	13.15	13.53	14.27	15.30	16.70	18.52	20.09	21.43
5.5	1.00	15.62	0.16	13.08	13.32	13.73	14.51	15.62	17.12	19.08	20.77	22.22
6.0	1.00	15.91	0.15	13.22	13.47	13.90	14.74	15.91	17.51	19.61	21.42	22.96
6.5	1.00	16.19	0.14	13.34	13.61	14.06	14.94	16.19	17.88	20.12	22.03	23.68
7.0	1.00	16.45	0.15	13.45	13.74	14.21	15.14	16.45	18.24	20.60	22.63	24.37
7.5	1.00	16.69	0.16	13.55	13.85	14.34	15.32	16.69	18.59	21.08	23.22	25.05
8.0	1.00	16.93	0.17	13.64	13.95	14.46	15.48	16.93	18.92	21.53	23.79	25.71
8.5	1.00	17.15	0.17	13.72	14.04	14.58	15.64	17.15	19.23	21.97	24.33	26.34
9.0	1.00	17.37	0.17	13.79	14.12	14.69	15.79	17.37	19.53	22.38	24.83	26.92
9.5	1.00	17.57	0.17	13.87	14.21	14.79	15.94	17.57	19.81	22.76	25.27	27.41
10.0	1.00	17.77	0.18	13.95	14.30	14.90	16.08	17.77	20.07	23.08	25.64	27.80
10.5	1.00	17.96	0.19	14.04	14.41	15.02	16.23	17.96	20.31	23.36	25.92	28.07
11.0	1.00	18.14	0.20	14.14	14.52	15.15	16.38	18.14	20.52	23.57	26.11	28.21
11.5	1.00	18.32	0.20	14.26	14.64	15.28	16.54	18.32	20.70	23.73	26.22	28.25
12.0	1.00	18.49	0.20	14.39	14.77	15.43	16.70	18.49	20.87	23.85	26.25	28.19
12.5	1.00	18.65	0.19	14.53	14.92	15.58	16.86	18.65	21.01	23.92	26.24	28.07
13.0	1.00	18.81	0.19	14.67	15.07	15.73	17.02	18.81	21.14	23.97	26.18	27.91
13.5	1.00	18.96	0.17	14.83	15.23	15.90	17.19	18.96	21.26	24.00	26.11	27.74
14.0	1.00	19.12	0.16	14.99	15.39	16.06	17.35	19.12	21.36	24.02	26.02	27.55
14.5	1.00	19.26	0.15	15.15	15.56	16.23	17.52	19.26	21.47	24.03	25.94	27.38
15.0	1.00	19.40	0.14	15.32	15.72	16.40	17.68	19.40	21.56	24.04	25.86	27.22
15.5	1.00	19.54	0.13	15.48	15.89	16.56	17.84	19.54	21.65	24.05	25.78	27.07
16.0	1.00	19.68	0.12	15.64	16.05	16.72	17.99	19.68	21.75	24.06	25.72	26.94

tissues that are influenced by diet and exercise habits, factors that can generate size differences even with a similar genetic structure (López-Ejeda et al., 2020).

Low height-for-age in childhood, also known as chronic malnutrition or stunting, has been recurrently used as an indicator of poor socioeconomic background. WHO considers that a country with a prevalence of stunting above 30% is in a very high severity situation, and it should be a priority for humanitarian action (de Onis et al., 2018). However, there are countries where these figures are markedly exceeded in almost the entire territory, as is the case of Guatemala, with a national prevalence of 46.5%, with figures reaching 70% in some regions of the country (SIINSAN, 2016).

In general, larger body size requires more energy for maintenance, and more susceptible in the contexts of deprivation due to lack of food or excess energy expenditure, as occurs when exposed to recurrent infectious diseases (Diez-Navarro et al., 2017; Solomons, 2019). After studying height of human remains from archaeological sites and historical series, Scheffler and Hermanussen (2022) found high prevalences of stunting in poor contexts as well as privileged social strata. Therefore, they propose that stunting would be the natural condition of the human species, the most adaptive response for most of our evolutionary history. Therefore, in contexts where the availability of resources and the epidemiological situation have remained stable until recent history, population selection for “small size genes” could be

Table 16.7 Smoothed percentiles, and L, M, and S values for BMI (kg/m^2) in girls

Age (years)	L	M	S	P3	P5	P10	P25	P50	P75	P90	P95	P97
5.0	1.00	15.17	0.15	12.84	13.12	13.54	14.26	15.17	16.48	18.36	20.04	21.43
5.5	1.00	15.33	0.15	12.98	13.25	13.66	14.38	15.33	16.70	18.70	20.48	21.96
6.0	1.00	15.49	0.14	13.11	13.37	13.77	14.49	15.49	16.94	19.07	20.97	22.54
6.5	1.00	15.64	0.13	13.21	13.46	13.86	14.60	15.64	17.19	19.47	21.50	23.19
7.0	1.00	15.79	0.13	13.28	13.53	13.94	14.70	15.79	17.45	19.89	22.08	23.90
7.5	1.00	15.95	0.16	13.34	13.59	14.00	14.79	15.95	17.72	20.36	22.73	24.70
8.0	1.00	16.13	0.20	13.41	13.66	14.08	14.90	16.13	18.03	20.88	23.45	25.61
8.5	1.00	16.35	0.21	13.50	13.76	14.19	15.05	16.35	18.39	21.47	24.28	26.65
9.0	1.00	16.63	0.21	13.63	13.90	14.35	15.25	16.63	18.81	22.16	25.23	27.85
9.5	1.00	16.98	0.21	13.82	14.10	14.57	15.51	16.98	19.31	22.92	26.30	29.21
10.0	1.00	17.38	0.21	14.07	14.35	14.84	15.84	17.38	19.85	23.74	27.44	30.69
10.5	1.00	17.82	0.21	14.34	14.64	15.15	16.19	17.82	20.42	24.55	28.57	32.16
11.0	1.00	18.26	0.21	14.61	14.92	15.46	16.56	18.26	20.96	25.29	29.61	33.54
11.5	1.00	18.68	0.22	14.83	15.16	15.73	16.89	18.68	21.49	25.99	30.55	34.81
12.0	1.00	19.08	0.23	14.98	15.33	15.94	17.18	19.08	22.03	26.70	31.47	36.02
12.5	1.00	19.47	0.23	15.05	15.43	16.09	17.43	19.47	22.59	27.43	32.35	37.10
13.0	1.00	19.86	0.24	15.09	15.51	16.23	17.68	19.86	23.11	27.96	32.73	37.26
13.5	1.00	20.25	0.24	15.17	15.63	16.41	17.97	20.25	23.49	27.97	32.02	35.62
14.0	1.00	20.63	0.22	15.37	15.87	16.70	18.33	20.63	23.68	27.50	30.57	33.02
14.5	1.00	21.01	0.19	15.75	16.27	17.14	18.80	21.01	23.76	26.87	29.12	30.79
15.0	1.00	21.41	0.17	16.24	16.79	17.68	19.32	21.41	23.84	26.37	28.09	29.29
15.5	1.00	21.82	0.14	16.74	17.30	18.22	19.85	21.82	24.00	26.15	27.54	28.47
16.0	1.00	22.25	0.12	17.17	17.77	18.71	20.35	22.25	24.26	26.16	27.33	28.11

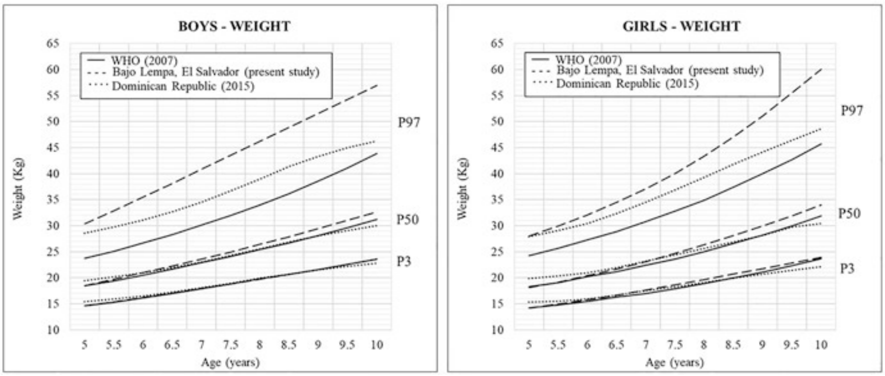

Fig. 16.2 Normalized weight (kg) of boys and girls from El Salvador and comparison with WHO growth reference and data from Dominican Republic

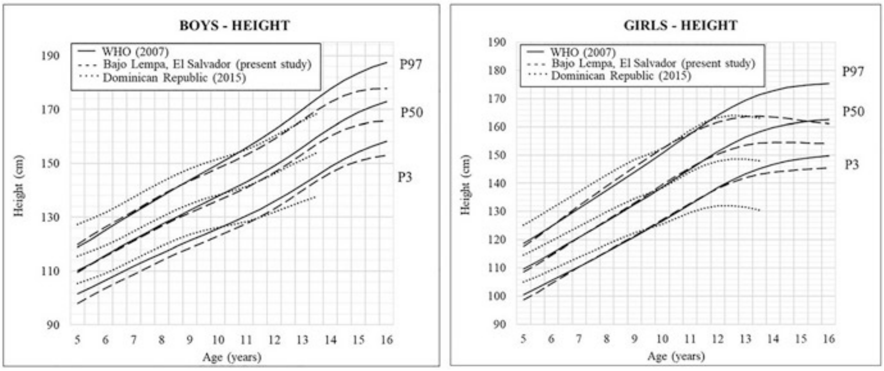

Fig. 16.3 Normalized height (cm) of boys and girls from El Salvador and comparison with WHO growth reference and data from Dominican Republic

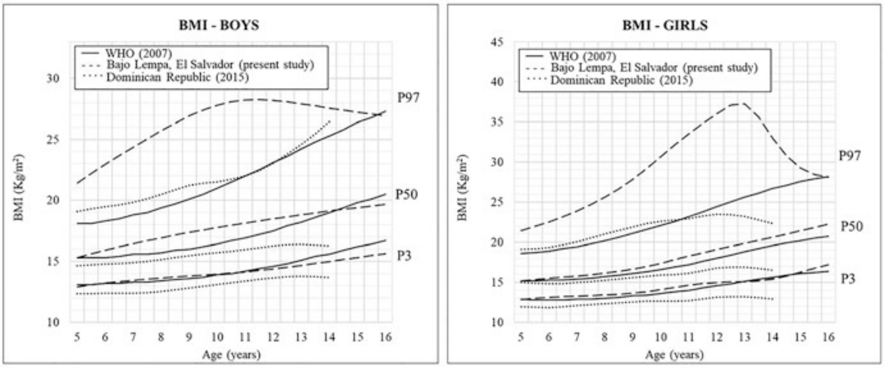

Fig. 16.4 Normalized BMI (kg/m^2) of boys and girls from El Salvador and comparison with WHO growth reference and data from Dominican Republic

considered a resource-adaptive phenomenon and not necessarily an anthropometric failure. In this context, international references are not useful for diagnosing chronic malnutrition, and the development of a specific reference would be required.

To date, Genome-Wide Association Studies have identified more than 200 Single Nucleotide Polymorphisms (SNPs) associated with height in adults with different frequencies in European, Asian, and African populations (Lango et al., 2010; Du et al., 2014; He et al., 2015). The number of SNPs associated with weight or BMI in adults, children, and adolescents is also very high and has an unequal frequency in different populations (Yilmaz, 2020; Czerwinski & Choh, 2022).

In any case, these genetic variants would explain only 10–20% of the variability in height, which, as secular studies have amply demonstrated, is a sensitive indicator of living conditions. As mentioned, social and political conditions are associated with the average height of children and adults worldwide (Bogin & Loucky, 1997; Candela-Martínez et al., 2022; Martínez-Carrión et al., 2022). In 100 years (from

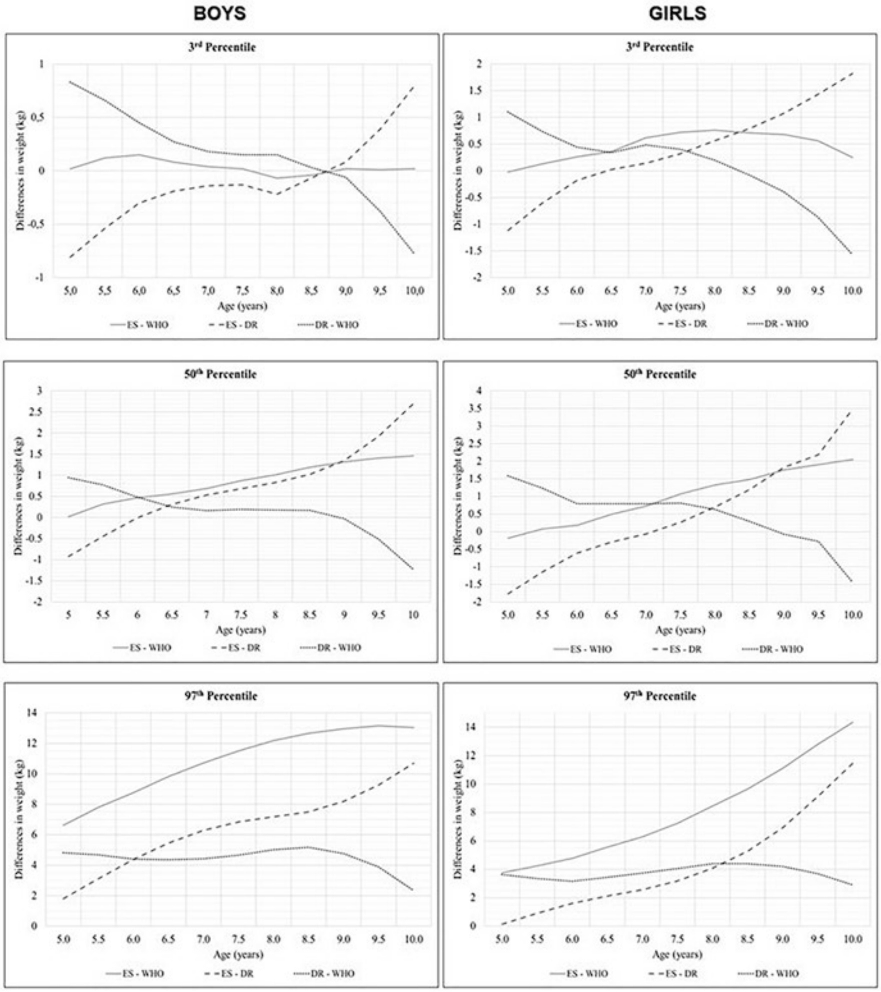

Fig. 16.5 Weight (kg) by percentile of boys and girls from El Salvador and comparison with WHO growth reference and data from Dominican Republic

1914 to 2014), height has increased up to 20 cm in specific human groups that have experienced increased social welfare (NCD Risk Factor Collaboration, 2016).

Studies of migrant populations moving to more favorable environments have demonstrated growth plasticity. Examples include Guatemalan children migrated to the United States or Bangladeshi children born and raised in London, among other cases reported by Bogin et al. (2018). Interestingly, along with this trend of height increase, a tendency of obesity is perceived in migrant children, also detected in the Tarahumara ethnic group of Mexico displaced from rural settlements to the city of Chihuahua (Benítez-Hernández et al., 2017) or Latino adolescents who migrated to Spain (Santos et al., 2009).

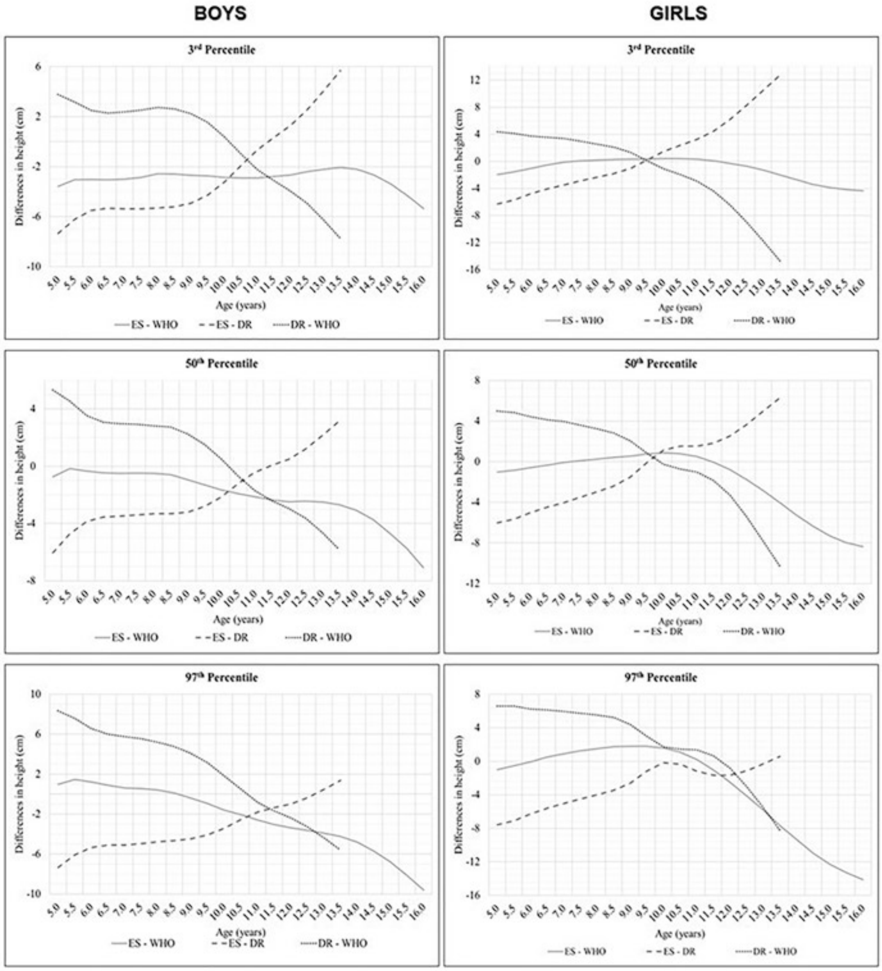

Fig. 16.6 Height (cm) by percentile of boys and girls from El Salvador and comparison with WHO growth reference and data from Dominican Republic

Dietary changes and more sedentary lifestyle that affect these transition populations negatively, influence weight gain and increase of BMI. In addition, the most satiating and inexpensive foods are usually calorie-dense but not necessarily of more excellent nutritional value. As indicated above, surveys conducted in the Bajo Lempa area by this same research team have shown that food insecurity was high, affecting almost 60% of the households (Pedrero-Tomé et al., 2022).

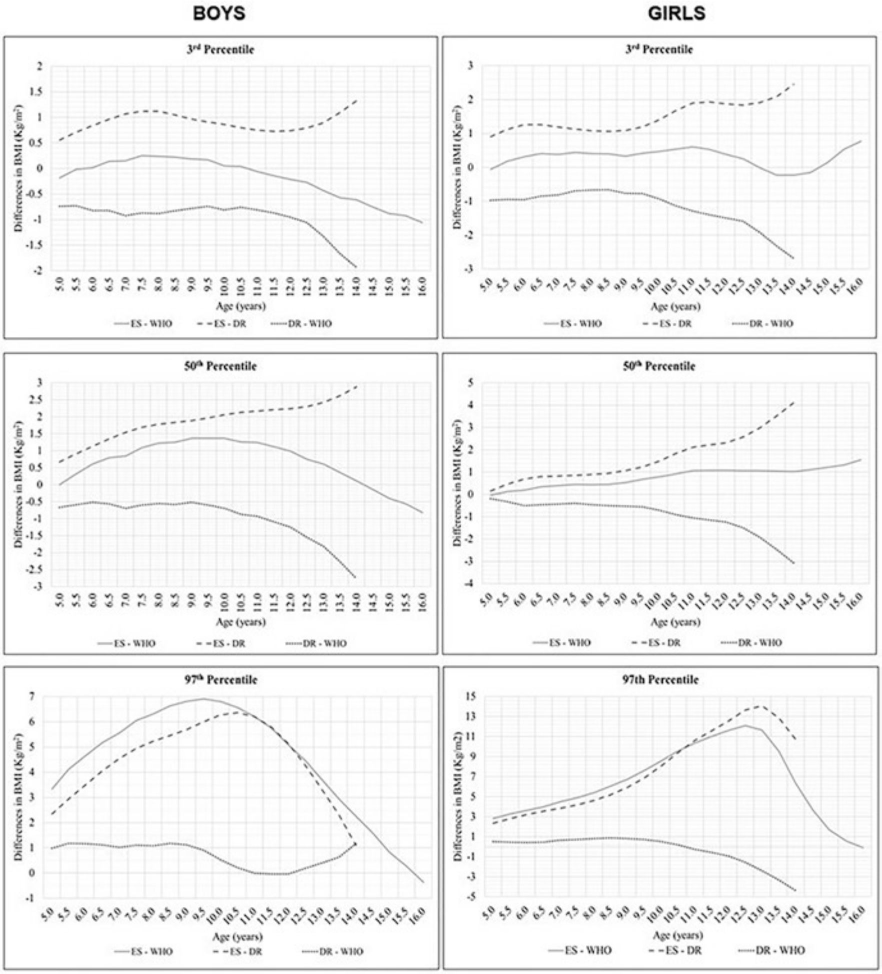

Fig. 16.7 BMI (kg/m^2) by percentile of boys and girls from El Salvador and comparison with WHO growth reference and data from Dominican Republic

16.5 Conclusions

The shorter stature of Salvadoran schoolchildren with respect to the international references, which becomes evident only after pubertal age, should not necessarily be interpreted as a problem of chronic malnutrition or generalized stunting since it is after puberty when growth curves begin to diverge from the reference, but not before. It is possible that the genetic component of the population partly limits the potential for longitudinal growth. However, the conditions of vulnerability and food insecurity that are typical of the region of study may be the factors that negatively affect height growth and favors obesity.

However, the marked predisposition to overweight reflected in the curves defining the 97th percentile for weight and BMI reveal a tendency towards obesity that may undermine the future health of these children. Follow-up studies monitoring physical growth of children and adolescents in these same communities, where a program of education, school gardens, and school canteens is now starting, will reveal the adaptive response to the expected changes.

Acknowledgments The authors would like to thank the Complutense University of Madrid for the funding received to carry out this study (Ref. 19/2017; Ref. 11/2018; Ref. 05/2021; Ref. 17/2022). We also thank the National University of El Salvador and the Asociación-Fundación para la Cooperación y el Desarrollo Comunitario de El Salvador (CORDES), Spanish Society of Dietetics and Food Science (*Sociedad Española de Dietética y Ciencias de la Alimentación, SEDCA*) and of course, the communities and all the people who participated in the study.

References

Asociación-Fundación para la Cooperación y el Desarrollo Comunal de El Salvador. (2017). Diagnóstico participativo. In *Área de desarrollo territorial*. CORDES.

Benítez-Hernández, M. L., de la Torre-Díaz, M., Cervantes-Borunda, M., Hernández-Torres, P., Cabañas, M. D., López-Ejeda, N., & Marrodán, M. D. (2017). Migration and nutritional status of Tarahumara schoolchildren from Chihuahua State (México). *American Journal of Human Biology, 29*, e2292. https://doi.org/10.1002/ajhb.22927

Bogin, B., & Loucky, J. (1997). Plasticity, political economy, and physical growth status of Guatemala Maya children living in the United States. *American Journal of Physical Anthropology, 102*, 17–32. https://doi.org/10.1002/(SICI)1096-8644(199701)102:1<17::AID-AJPA3>3.0.CO;2-A

Bogin, B., Hermanussen, M., & Scheffler, C. (2018). As tall as my peers – Similarity in body height between migrants and hosts. *Anthropologischer Anzeiger, 74/5*(Supplement), 63–374. https://doi.org/10.1127/anthranz/2018/0828

Cacciari, E., Milani, S., Balsamo, A., Dammacco, F., De Luca, F., Chiarelli, F., & Vanelli, M. (2002). Italian cross-sectional growth charts for height, weight and BMI (6-20y). *European Journal of Clinical Nutrition, 56*(2), 171–180. https://doi.org/10.1038/sj.ejcn.1601314

Candela-Martínez, B., Cámara, A. D., López-Falcón, D., & Martínez-Carrión, J. M. (2022). Growing taller unequally? Adult height and socioeconomic status in Spain (Cohorts 1940-1994). *SSM – Population Health, 101126*. https://doi.org/10.1016/j.ssmph.2022.101126

Carmenate, M., Gómez Valenzuela, V., & Prado, C. (2015). *Evaluación del estado nutricional de niños y niñas del primer ciclo de la educación básica del sistema de educación pública de la República Dominicana*. MINERD. IDEICE. Santo Domingo, D. N. República Dominicana.

Carrascosa, A., Fernandez, J. M., Fernandez, C., Ferrandez, A., Lopez-Siguero, J. P., Sanchez, E., et al. (2008). Spanish cross-sectional growth study 2008. Part II. Height, weight and body mass index values in 32,064 subjects (16,607 males and 15,457 females) from birth to adulthood. *Anales de Pediatría (Barc), 68*(6), 552–569. https://doi.org/10.1157/13123287

Chen, W., & Chang, M. H. (2010). New growth charts for Taiwanese children and adolescents based on World Health Organization standards and health-related physical fitness. *Pediatrics & Neonatology, 51*(2), 69–79. https://doi.org/10.1016/S1875-9572(10)60014-9

Cole, T. (1988). Fitting smoothed centile curves to reference data. *Journal of the Royal Statistical Society A, 151*, 385–418. https://doi.org/10.2307/2982992

Cole, T. (2022). Chapter 14: Growth references and standards. In N. Cameron & L. M. Schell (Eds.), *Human growth and development* (3rd ed., pp. 391–422). Academic Press. https://doi.org/10.1016/B978-0-12-822652-0.00012-2

Cole, T., & Green, P. (1992). Smoothing reference centile curves: The LMS method and penalized likelihood. *Statistics in Medicine, 11*, 1305–1319. https://doi.org/10.1002/sim.4780111005

Czerwinski, S., & Choh, A. C. (2022). Chapter 8: The genetic epidemiology of growth and development. In N. Cameron & L. M. Schell (Eds.), *Human growth and development* (3rd ed., pp. 203–244). Academic Press. https://doi.org/10.1016/B978-0-12-822652-0.00001-8

De Onis, M., Borghi, E., Arimond, M., Webb, P., Croft, T., Saha, K., De-Regil, L. M., Thuita, F., Heidkamp, R., Krasevec, J., Hayashi, C., & Flores-Ayala, R. (2018). Prevalence thresholds for wasting, overweight and stunting in children under 5 years. *Public Health Nutrition, 22*(1), 175–179. https://doi.org/10.1017/S1368980018002434

Diez-Navarro, A., Marrodán, M. D., Gómez, A., Rivero, E., Vargas, A., Pacheco, J. L., Sánchez-Álvarez, M., López-Ejeda, N., Moreno-Romero, S., Prado, C., Cabañas, M. D., & Martínez-Álvarez, J. R. (2017). Female eco-stability and severe malnutrition in children: Evidence from humanitarian aid interventions of Action Against Hunger in African, Asian and Latin American countries. *Nutricion Clinica y Dietética Hospitalaria, 37*(4), 127–134. https://doi.org/10.12873/374dnavarro

Du, M., Auer, P. L., Jiao, S., Haessler, J., Altshuler, D., Boerwinkle, E., et al. (2014). Whole-exome imputation of sequence variants identified two novel alleles associated with adult body height in African Americans. *Human Molecular Genetics, 15;23*(24), 6607–6615. https://doi.org/10.1093/hmg/ddu361

El-Mouzan, M. I., Al-Herbish, A. S., Al-Salloum, A. A., Qurachi, M. M., & Al-Omar, A. A. (2007). Growth charts for Saudi children and adolescents. *Saudi Medical Journal, 28*(10), 1555. https://doi.org/10.4103/0256-4947.51726

Faulhaber J (1976) *Investigación longitudinal del crecimiento*. Col. Científica. n° 26. Instituto Nacional de Antropologia e Historia. México.

Frisancho, A. R. (1990). *Anthropometric standards for the assessment of growth and nutritional status*. University of Michigan Press. https://doi.org/10.3998/mpub.12198

Garrido-Miguel, M., Cavero-Redondo, I., Álvarez-Bueno, C., Rodríguez-Artalejo, F., Moreno-Aznar, L., Ruiz, J. R., & Martínez-Vizcaíno, V. (2017). Prevalence and trends of thinness, overweight and Obesity among children and adolescents aged 3-18 years across Europe: A protocol for a systematic review and meta-analysis. *British Medical Journal, 7*, e018241. https://doi.org/10.1136/bmjopen-2017-018241

Hamill, P. V., Driz, T., Johnson, C. L., Reed, R. B., & Roche, A. F. (1977). *NCHS growth curves for children, birth-18 years United States*. Public National Center for Health Statistics. https://doi.org/10.1037/e405052004-001

He, M., Xu, M., Zhang, B., Liang, J., Chen, P., Lee, J. Y., et al. (2015). Meta-analysis of genome-wide association studies of adult height in East Asians identifies 17 novel loci. *Human Molecular Genetics, 15;24*(6), 1791–1800. https://doi.org/10.1093/hmg/ddu583

Hernández, M., Castellet, J., Narvaiza, J. L., Rincón, J. M., Ruiz, I., Sánchez, E., Sobradillo, B., & Zurimendi, A. (1988). *Curvas y tablas de crecimiento (0-18 años)*. Instituto de Investigación sobre Crecimiento y Desarrollo. Fundación Faustino Orbegozo, Bilbao. ISBN: 84-7391-177-6 1-32.

Hosseini, M., Carpenter, R. G., & Mohammad, K. (1998). Growth charts for Iran. *Annals of human biology, 25*(3), 237–247. https://doi.org/10.1080/03014469800005602

Jelenkovic, A., & Rebato, E. (2012). Association among obesity-related anthropometric phenotypes: Analyzing genetic and environmental contribution. *Human Biology, 2*, 127–137. https://doi.org/10.3378/027.084.0202

Johnston FE (1986) Reference data for physical growth in nutritional anthropology. In: Quandt SA, Ritenbaugh C (Editors) Training Manual in Nutritional Anthropology. Washington, D.C. pp. 60-65.

Jordan. (1979). *Desarrollo humano en Cuba*. Editorial Científico Médica.

Júlíusson, P. B., Roelants, M., Eide, G. E., Moster, D., Juul, A., Hauspie, R., Waaler, P. E., & Bjerknes, R. (2009). Vekstkurver for norske barn [Growth references for Norwegian children]. *Tidsskrift for den Norske Laegeforening, 12;129(4):281-6*. https://doi.org/10.4045/tidsskr.09.32473

Jureša, V., Musil, V., & Kujundžić, T. M. (2012). Growth charts for Croatian school children and secular trends in past twenty years. *Collegium Antropologicum, 36*(1), 47–57. https://doi.org/10.5671/ca.2012361s.47

Khadilkar, V. (2013). The growing controversy about growth charts: WHO or regional? International. *Journal of Pediatric Endocrinology*, (Suppl 1), O6. https://doi.org/10.1186/1687-9856-2013-S1-O6

Khadilkar, V., Yadav, S., Agrawal, K. K., et al. (2015). Revised IAP growth charts for height, weight and body mass index for 5- to 18-year-old Indian children. *Indian Pediatrics, 52*, 47–55. https://doi.org/10.1007/s13312-015-0566-5

Kim, J. H., Yun, S., Hwang, S. S., Shim, J. O., Chae, H. W., Lee, Y. J., Lee, J. H., Kim, S. C., Lim, D., Yang, S. W., Oh, K., Moon, J. S., & Committee for the Development of Growth Standards for Korean Children and Adolescents; Committee for School Health and Public Health Statistics, the Korean Pediatric Society; Division of Health and Nutrition Survey, Korea Centers for Disease Control and Prevention. (2018). The 2017 Korean National Growth Charts for children and adolescents: development, improvement, and prospects. *Korean Journal Pediatrics, 61*(5), 135–149. https://doi.org/10.3345/kjp.2018.61.5.135

Lango Allen, H., Estrada, K., Lettre, G., Berndt, S. I., Weedon, M. N., Rivadeneira, F., Willer, C. J., Jackson, A. U., Vedantam, S., & Raychaudhuri, S. (2010). Hundreds of variants clustered in genomic loci and biological pathways affect human height. *Nature, 467*, 832–838. https://doi.org/10.1038/nature09410

Lejarraga, H., & Orfila, G. (1987). Estándares de peso y estatura para niñas y niños argentinos desde el nacimiento hasta la madurez. *Archivos Argentinos de Pediatría, 85*, 209–222.

Li, H., Ji, C. Y., Zong, X. N., & Zhang, Y. Q. (2009). Height and weight standardized growth charts for Chinese children and adolescents aged 0 to 18. *Chinese Journal of Pediatrics, 47*(7), 487–492.

López-Ejeda, N., Martínez, J. R., Villarino, A., Cabañas, M. D., González Montero de Espinosa, M., López Mojares, L. M., Romero Collazos, J. F., Prado, C., Alaminos, A., & Marrodán, M. D. (2020). Physical Activity Protects Genetically Predisposed Schoolchildren from Obesity. *Kronos, 19*(2).

Martínez-Carrión, J. M., Varea, C., & Salvatore, R. (2020–2022). Biological living standards and nutritional health inequality in transition to the developed world. *International Journal of Environmental Research and Public Health*, Special Issue.

MINSAL – Ministerio de Salud de El Salvador. (2013). *Lineamientos técnicos para la evaluación del estado nutricional en el ciclo de vida y desarrollo en la niñez y adolescencia.* http://asp.salud.gob.sv/regulacion/pdf/lineamientos/lineamientos_estado_nutricional_ciclo_vida_29112013.pdf

Muggeo, V. M. R., Sciandra, M., Tomasello, A., & Calvo, S. (2013). Estimating growth charts via nonparametric quantile regression: A practical framework with application in ecology. *Environmental and Ecological Statistics, 20*(4), 519–531. https://doi.org/10.1007/s10651-012-0232-1

NCD Risk Factor Collaboration (NCD-RisC). (2016). A century of trends in adult human height. Elife 5: e13410. https://doi.org/10.7554/eLife.13410

Ohuma, E. O., & Altman, D. G. (2019). Statistical methodology for constructing gestational age-related charts using cross-sectional and longitudinal data: The INTERGROWTH-21st project as a case study. *Statistics in Medicine, 38*(19), 3507–3526. https://doi.org/10.1002/sim.8018

Onyango, A. W., & de Onís, M. (2008). *WHO child growth standards: training course on child growth assessment*. Department of Nutrition for Health and Development WHO Press. https://doi.org/10.1016/S0140-6736(08)60131-2

Pedrero-Tomé, R., Sánchez Álvarez, M., López-Ejeda, N., Herrero-Jaúregui, C., Acosta Gallo, B., & Dolores Marrodán, M. (2020). Development Cooperation in Bajo Lempa (El Salvador): Perception of the Health and Nutritional Condition. *Revista Agunkuyâa, 10*(1), 15–23.

Pedrero-Tomé, R., López-Ejeda, N., Sánchez Álvarez, M., Herrero-Jaúregui, C., Acosta Gallo, B., & Dolores Marrodán, M. (2022). Household food insecurity and nutritional status of schoolchildren in rural regions of Bajo Lampa, El Salvador (2018–2019). *Ecology of Food and Nutrition, 61*(2), 128–143. https://doi.org/10.1080/03670244.2021.1968851

Poveda, A., Jelenkovic, A., Salces, I., Ibanez, M. E., & Rebato, E. (2012). Heritability variations of body linearity and obesity indicators during growth. *Homo, 63*(4), 301–310. https://doi.org/10.1016/j.jchb.2012.03.006

R Core Team. (2022). *R: A language and environment for statistical computing*. R Foundation for Statistical Computing, Vienna, Austria. https://www.R-project.org/

Rigby, R. A., & Stasinopoulos, D. M. (2005). Generalized additive models for location, scale and shape. *Journal of the Royal Statistical Society Series C (Applied Statistics), 54*(3), 507–554. https://doi.org/10.1111/j.1467-9876.2005.00510.x

Roede, M. J., & Vieringen, V. (1985). Growth diagrams 1980. Netherlands Third Nationwide Survey. *Tijdschrift voor GezondheidsRecht, 63*(suppl), 1–34.

Roser, M., Cameron, A., & Ritchie, A. (2013). *Human height*. Published online at OurWorldInData.org. Retrieved from https://ourworldindata.org/human-height

Saari, A., Sankilampi, U., Hannila, M. L., Kiviniemi, V., Kesseli, K., & Dunkel, L. (2011). New Finnish growth references for children and adolescents aged 0 to 20 years: Length/height-for-age, weight-for-length/height, and body mass index-for-age. *Annals of Medicine, 43*(3), 235–248. https://doi.org/10.3109/07853890.2010.515603

Santos, M. G., Fernández-del Olmo, R., Prado, C., Roville-Sausse, F., Marrodán, M. D., & Carmenate, M. (2009). Composition corporelle des adolescents de la région de Madrid selon leur origine géographique. *Biométrie Humaine et Anthropologie, 27*(1-2), 37–42.

Scheffler, C., & Hermanussen, M. (2022). Stunting is the natural condition of human height. *American Journal of Human Biology, 34*(5), e23693. https://doi.org/10.1002/ajhb.23693

Segal, N. L., Feng, R., McGuire, S. A., Allison, D. B., & Miller, S. (2009). Genetic and environmental contributions to body mass index: comparative analysis of monozygotic twins, dizygotic twins and same-age unrelated siblings. *International Journal of Obesity, 33*(1), 37–41. https://doi.org/10.1038/ijo.2008.228

SIINSAN (Sistema de Información Nacional de seguridad Alimentaria y Nutricional) de Guatemala. (2016). *Encuesta Nacional de Salud Materno Infantil 2014-2015*. From https://portal.siinsan.gob.gt/ensmi/. Retreived on August 9, 2022.

Solomons, N. W. (2019). Vision of research on human linear growth. *Food and Nutrition Bulletin, 40*(4), 416–431. https://doi.org/10.1177/0379572119885475

Suwa, S., & Tachibana, K. (1993). Standard growth charts for height and weight of Japanese children from birth to 17 years based on a cross-sectional survey of national data. *Clinical Pediatric Endocrinology, 2*(2), 87–97. https://doi.org/10.1297/cpe.2.87

Waterlow, J. C., Buzina, R., Keller, W., Lane, J. M., Nichaman, M. Z., & Tanner, J. M. (1977). The presentation and use of height and weight data for comparing the nutritional status of groups of children under the age of 10 years. *Bulletin of the world Health Organization, 55*(4), 489.

Weiner, J. S., & Lourie, J. A. (1981). *Practical human biology*. Academic Press.

World Health Organization. (2006). *World Health Organization Multicentre Growth Reference Study Group. WHO Child Growth Standards: Length/height-for-age, weight-for-age, weight-forlength, weight-for-height and body mass index-for-age: Methods and development* (pp. 1–312). World Health Organization.

World Health Organization (2007) *Growtth refrence data for 5 to 19 years*. Ginebra. https://www.who.int/tools/growth-reference-data-for-5to19-years

World Medical Association. (2013). *64th general assembly. Declaration of Helsinki. Ethical principles for medical research in humans*. In 64th WMA General Assambley, Fortaleza, Brasil.

Yilmaz, B., & Gezmen, K. M. (2020). The current review of adolescent obesity: the role of genetic factors. *Journal of Pediatric Endocrinology and Metabolism, 16;34*(2), 151–162. https://doi.org/10.1515/jpem-2020-0480

Chapter 17
Measuring the Impact of Stunting on Child Growth Considering Ontogeny and Sexual Dimorphism

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17.1 Infant and Child Malnutrition in Guatemala

The terms wasting and stunting were introduced in the early 1970s by John Waterlow to differentiate underweight (low weight-for-age) children from those who were underweight for their height (wasting) and stunting (low height-for-age) (Waterlow, 1972). The term acute malnutrition is associated with wasting and chronic malnutrition with stunting. Based on clinical experience, it is considered that children suffering from wasting are at a higher risk of early mortality than stunted children, but suffering from both types together should be prioritized because they present the highest risk among all (Garenne et al., 2019; Khara et al., 2018; Waterlow, 1974).

Stunting continues to be a global problem in low- and middle-income countries (Juarez et al., 2021). This condition is the outcome of poor nutrition in utero and early childhood (UNICEF et al., 2021), causing growth deficit and relatively lower cognitive development among infants and children. Globally, 149.2 million infants and children under 5 years of age suffered from stunting in 2020 (UNICEF et al., 2021). Due to the limitations of access to the nutritionally adequate food and essential nutrition services during the COVID-19 pandemic, the number may have increased significantly, an effect that may take several years to recover.

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S. Datta Banik (ed.), *Human Growth and Nutrition in Latin American and Caribbean Countries*, https://doi.org/10.1007/978-3-031-27848-8_17

According to Food and Agriculture Organization (FAO) of the United Nations (UN) and the Pan American Health Organization (PAHO), there is a prevalence of 49.3% of childhood stunting in Guatemala, 3% higher than that recorded 2 years earlier (46.5%) by the National Maternal and Child Health Survey (MSPAS et al., 2015), and that prevalence is higher in rural areas of the country (UN-FAO & PAHO, 2017). Stunting has been recorded mainly among rural and agricultural communities, where most of the inhabitants are indigenous Maya, and the prevalence surpass national level average reaching 50% or more; people live in below poverty level (60%) and have household food insecurity (16%) (MSPAS et al., 2015). Nowadays, Guatemala registers the highest stunting rate in Latin America, and sixth place in the world ranking, with an annual rate of reduction averaged in 0.45% during the last 20 years (Juarez et al., 2021).

Undernutrition has historically been present in Guatemala in its different forms. Currently, this complex problem continues to be one of the main causes of morbidity and mortality, especially in the poor population of rural and marginal urban areas, highlighting among them children under 5 years of age, pregnant and lactating women from indigenous and rural populations (Colón et al., 2012) with little or no education. Given this situation, Government had the National Food and Nutrition Security Policy with an associated law and regulation (Política Nacional de Seguridad Alimentaria y Nutricional, 2008), in addition to the definition and implementation of several strategic and operational plans to provide a comprehensive response to the problem, given its historical, structural, and multi-causal nature. These government plans and strategies have had as their main objective to reduce chronic child undernutrition in Guatemala by 7% to 10%. However, the strategies and efforts have been focused on health actions and not on a comprehensive care approach to the unequal conditions in which Guatemalan children develop (household food insecurity, poverty, access to basic health services, water and sanitation, among others). Thus, despite intensive efforts have been made to reduce the prevalence of stunting dramatically, for example by the National Secretary of Food and Nutritional Security during 2006–2016, successful results have not yet been achieved, probably due to the complex interaction of stunting with other determinants of well-being (Juarez et al., 2021). Among them, weather, geographical isolation, poverty, food insecurity, lack of access to primary healthcare, etc. (Ballard et al., 2018; Cordon et al., 2019; Pelletier et al., 2012). Moreover, the Guatemalan population has faced a recurring period of food shortages since 2009, in which there has been a deterioration in the food and nutritional security situation, associated with the effects of irregular rainfall caused by the presence of the phenomenon of *El Niño*, which exacerbated the situation of Nutritional Food Insecurity of a large sector of the population (Colón et al., 2012). The most affected departments in Guatemala are part of the Dry Corridor region, constituting 11.8% of its geographical area: El Progreso, Zacapa, Baja Verapaz, Jutiapa, Jalapa, Santa Rosa and Chiquimula; with 163 municipalities at high (109) and severe (54) risk of household food insecurity out of 340 municipalities in the country (AAH, 2014; van der Zee et al., 2012). Moreover, in recent years, the negative effects have spread to the regions of Quiché, Huehuetenango, Sololá, San Marcos, Totonicapán and

Chimaltenango (AAH, 2014). In addition, the western region of the country has a complex geography (mountainous and with vast relief), which hinders access to health services. This situation is due to various factors such as geographical distance, quality of roads, infrastructure (often non-existent), unavailability of public transport, economic and educational limitations, gender inequality and even lack of confidence in the quality of services outside the community (Bourdon, 2017). Ministry of Health reported 296 maternal deaths in Guatemala between January and September 2021, either at hospitals (62.49%), in transit to a care center (6.42%), in health centers (7.77%) at home (20.61%) or for other reasons (2.71%), showing that the transfers were delayed and when the complications were already serious enough to save the lives of the mothers (Aroche & Cristian, 2021). The impacts of the food crisis in the Dry Corridor gave rise to an increase in cases of malnutrition. At the end of December 2020, such region accumulated 27,913 cases of total acute malnutrition (moderate and severe) in children under 5 years of age that was reported by the Guatemalan Ministry of Public Health and Social Assistance, occurring the largest proportion of cases (65%) in children from 6 months to less than 2 years, mainly in the group from 12 to 24 months (43.1%) and accounting for a 2.0–3.4% of severe wasting (Giammattei, 2021). This record corresponds to the identification of wasted children through weight-for-height z-scores (WHZ) indicator and includes those children who were attended by a health center, leaving a significant number of children undiagnosed: families that did not go to health center for various reasons, mainly their distance, and those who were diagnosed by mid-upper-arm circumference (MUAC), since Guatemalan Health Ministry does only accept those infants and children for treatment who were identified as wasted using low WHZ indicator (MSPAS, 2009, 2010). According to the study "REDAC – Relationship between wasting and stunting in Guatemala" (REDAC in Spanish *Estudio de la Relación entre Desnutrición Aguda y Desnutrición Crónica*), carried out by the Consortium of Humanitarian NGOs and led by the Action against Hunger Foundation in 2018 with a sample of 4,022 children between 0 and 60 months, it was estimated that there was an underreporting of around 30% when only stunting rate was hiding wasting, and MUAC was not used for diagnosis (Medialdea, 2018).

17.2 Challenges When Analyzing Data on Child Malnutrition

Wasting and stunting are usually addressed using the indicators proposed by the World Health Organization (WHO), based on anthropometric measurements (WHO, 2006). Thus, stunting is assessed using height (or length)-for-age z-score values (HAZ) which reflects growth retardation (low height or length-for-age). When such indicator is below −2 standard deviations (SD) from the mean of the reference population used by WHO to create its standards, the infant or child is considered as stunted; in a moderate degree if it is between −2 and −3 SD and in a severe degree if its value is under −3 SD. Such indicator is based on the assumptions that height is reduced because of a nutritional deficit that negatively affects growth.

Following the same guidelines, wasting is assessed by the WHZ indicator, which measures the effect of food shortages or deterioration and the presence of undernutrition in the immediate past (MSPAS et al., 2015). If this indicator has a value less than −2SD from the mean of the reference population, the minors are considered wasted, in a moderate (−2SD > WHZ ≥ −3 SD) or severe (WHZ < −3SD) degree. Infants over 6 months or children under 5 years old can also be considered wasted if the measurement of their MUAC is below 125 mm (moderate if it is between 125 and 115 mm and severe if MUAC <115 mm) or if they exhibit bilateral oedema (infants and children from 6 to 59 months) that are mainly observed in their limbs (Bogin & Medialdea, 2023).

The fact that WHZ and HAZ rely on the same variable (height or length) for their estimation necessarily creates an interrelationship. From a mathematical point of view, the WHZ indicator will show a higher value for a smaller infant or child with a given weight than for a taller infant or child with the same body weight. This aspect is considerably relevant in the contexts where stunting and wasting happen together in the same individual (Garenne et al., 2019; Khara et al., 2018; Roberfroid et al., 2015).

Besides, many data on infant and child malnutrition collected in rural populations from low- and middle-income countries are framed in monitoring activities carried out by the institutions from local governments or non-governmental organizations undertaking humanitarian or social interventions either at a national or international level. During these activities, a baseline data is collected to establish the starting point before the interventions are carried out. Since the territories with vulnerable populations are widespread and the funds are limited, these baseline surveys seek to identify the most vulnerable populations affected by food insecurity, malnutrition, conditions of low access to basic health services, water, sanitation, and hygiene. Some examples of methodology for conducting such data collection are provided by different NGOs (Naliaka, 2018; Schlecht & Casey, 2007). Generally, the baseline data are used to explore and identify vulnerability of the populations at risk of suffering from infant and child malnutrition, food or nutritional insecurity, or water, sanitation, and hygiene deprivation. The same variables collected in the baseline survey will be collected in the different monitoring stages of the implementation, thus allowing the compilation of longitudinal data. However, it is frequent that participants in such activities may discontinue before their conclusion, leading to have incomplete data of many participants and thereby making it difficult to acquire enough data to perform statistical analysis. This usually happens when statistical methods need data from all measurement stages are used, like repeated measures analysis of variance (ANOVA), multivariate ANOVA or change score analysis (Garcia & Marder, 2017).

In the present study, we aimed to evaluate growth and nutritional status of 0–60 month-old infants and children and to validate the use of mixed linear regression model for the correlated data, which do not necessarily have to be complete for all the measurement series.

17.3 Study Design

A sample of 4,022 boys and girls between 0 and 60 months was studied. Anthropometric measurements of weight, height and MUAC were registered, along with, age (considering the date of birth of the health cards) and sex. In addition, other variables of interest were presence of acute diarrheal disease, respiratory tract infections, and edema, as reported by the mother/caregiver.

The data examined in the present study were collected within the framework of a humanitarian project carried out by different organizations grouped into two consortia lead by the Action Against Hunger Foundation and Oxfam, respectively, and funded by the European Civil Protection and Humanitarian Aid Operations (ECHO). The common objective pursued by all institutions was to respond to the needs of families had food insecurity, surveillance of children's nutritional status and support for livelihoods. The actions carried out by the implementation involved seven departments and 17 municipalities. Data collection was carried out from May to August 2017.

Criterion to select families in the humanitarian project was having a vulnerability classification of degree three in the Integrated food security Phase Classification. This classification consists of a global harmonized system to classify the severity and magnitude of the situation of food insecurity and malnutrition in a target context and identify its key drivers (IPC, 2022). It was not mandatory that these families had or not boys or girls under 60 months of age. The first stage of this project, to which we refer in this work, consisted of data collection in the baseline and in three subsequent monthly visits. The sample of the study that we present here was made up of girls and boys belonging to the families enrolled in the project that our field teams visited to monitor in relation to the humanitarian program, along with other boys and girls from the visited community who were screened for child malnutrition as part of the nutritional surveillance actions implemented in the project (Table 17.1). Thus, the analyzed database was made up of data on boys and girls under 5 years of

Table 17.1 Sample size by number of measurements, age, and sex of the participant infants and children (n = 4,022)

Measurements	Sex	>24 months (n)	≤24 months (n)
4	F	150	125
	M	149	128
3	F	241	173
	M	244	184
2	F	187	147
	M	197	154
1	F	549	436
	M	533	425
Total	F	1,127	881
	M	1,123	891

Sex: female (F) and male (M)

age located in 17 municipalities covering almost the entire Dry Corridor area. It should be noted that the present work was not an epidemiological study, but to standardize the methodology and to evaluate the rigor of the data acquired for the generation of evidence to different degrees, such consideration has been given. More details about the normalization analysis carried out, as well as the main operational results of humanitarian interventions are available in the technical report of the project (Medialdea, 2018).

Nutritional indicators related to the recorded measurements of weight (kg), height or length (cm), MUAC (cm), and z-scores for weight-for-age (WAZ), height (or length)-for-age (HAZ), MUAC-for-age (MUACAZ) and WHZ (WHO, 2006) were calculated using the R package 'Anthro' provided by WHO (Schumacher et al., 2018/2021). A descriptive analysis of the average gain or loss for each of the anthropometric variables throughout the monitoring period was carried out, estimating it equally for the nutritional indicators. For this, the first and last measurements of each infant or child who had participated in at least three monitoring sessions were considered and the significance level was set at $p<0.05$.

Data of growth curves for weight, height, MUAC and associated nutritional indicators were calculated through a linear mixed model for the regression of correlated data. This made it possible to include all the enrolled infants and children in the model regardless of the number of measurements that had been recorded. This was possible because the model, which required a continuous outcome variable linearly related to a set of explanatory variables, extends the ordinary linear regression model by allowing the lack of independence between observations to be incorporated and more than one error term to be modeled (Cnaan et al., 1997). In our case, the effect of age, stunting and the interaction of both was evaluated in the overall sample as well as subdividing it by sex. Therefore, this regression model evaluates the behavior of each individual (taking into account each of its measurements) and predicts the value for each variable for each month of age in the populations with and without stunting. It was implemented in R software 4.0.4.

17.4 Results and Discussion

17.4.1 Nutritional Status Evaluated in Measurement Sessions

Physical growth is a fundamental aspect associated with child development. For this reason, one of the important tasks to be carried out by health professionals during this stage is to accurately monitor the physical changes that occur from birth until (desirable) the final adult size is reached. Moreover, the quantification and analysis of average variations in the anthropometric variables and derived nutritional indicators of interest allowed us to understand the impact of the actions carried out in relation to nutritional security, especially when the baseline data was compared with the last measurement of the longitudinal study. The program that framed the sample analyzed here had the objective of improving the food and nutritional security of vulnerable families. In this aspect, food assistance was delivered in the form of cash transfers according to the number of family members during the critical months of seasonal hunger. In addition, agricultural capacities of the families were strengthened with resources, inputs and technical assistance, nutritional surveillance, and counseling. Therefore, it was expected to observe substantial improvements in the nutritional status of the individuals from these families.

In this section we present and discuss the results obtained from the evaluation of average gain of each of the recorded anthropometric measurements and their associated nutritional status indicators (Table 17.2). Thus, for example, a significant gain was observed in mean values of weight when the program was completed with four measurements (0.8 kg; $p<0.05$) and when three measurements were registered (0.6 kg; $p<0.05$). Similarly, mean values of height increased significantly when four measurements were considered (3.0 cm; $p<0.05$) and when three measurements (2.4 cm; $p<0.05$) were recorded. On contrary, MUAC showed a significant decrease of mean values by 0.3 cm among those individuals who completed the program, while among those on whom three measurements were recorded, no significant differences were observed ($p>0.05$).

These results reveal that weight and height increased significantly as the program progresses, which was consistent with child growth. It would be interesting to compare whether these gains are like those reported in individuals from the same population not suffering food and nutritional limitations. It is important to point out that the intervention took place during the most critical period of the year in terms of food insecurity for the study regions. During the months of May to September there are periods of intense drought in the region that hinder not only to have direct access to an adequate variety of food but also access to other economic resources for many families that depend on agriculture for subsistence. Regarding MUAC measurement, although it remains under discussion whether its use should be complementary or a substitute for the WHZ indicator (Custodio et al., 2018; Grellety et al., 2015; Grellety & Golden, 2016; Roberfroid et al., 2015), its ability to identify children at higher risk of death due to acute malnutrition (Briend et al., 2012; Myatt et al., 2006). Therefore, it is advisable to consider the significant decrease of mean values of this indicator during the 4 months of nutritional follow-up as an alarming sign, although in the same way, attention must be given to the rest of the indicators evaluated before a conclusion to be drawn.

In relation to the nutritional indicators, only the MUACAZ indicator (MUAC-for-age z-score) presented a significant decrease of 0.37 SD on average among all the subjects studied ($p<0.05$) for 4 months and of 0.10 SD for those followed up for 3 months. Even though no other indicator showed significant differences between the first and last measurements carried out, it is possible to extract very interesting information from their values. For example, it was observed that the study population started from a situation at risk of malnutrition due to low weight ($WAZ < -1SD$). On one hand, this information indicates that the analyzed sample was in a vulnerable situation for not only food (considering that it was selected according to food insecurity criteria), but also nutrition deficit. On the other hand, it is important to

Table 17.2 Average gain in anthropometric variables and nutritional status indicators when three or four measurements were carried out

Number of measurements		Weight (kg)	Height (cm)	MUAC (cm)	WAZ (SD)	HAZ (SD)	WHZ (SD)	MUACAZ (SD)
4	Sample size	(n = 552)	(n = 552)	(n = 490)	(n = 552)	(n = 552)	(n = 552)	(n = 490)
	First (mean ± SD)	10.0 ± 2.8	78.2 ± 11.7	14.8 ± 1.3	−1.60 ± 1.09	−2.60 ± 1.24	−0.12 ± 1.22	−0.48 ± 1.06
	Last (mean ± SD)	10.8 ± 2.7	81.2 ± 10.8	14.5 ± 1.1	−1.53 ± 1.00	−2.61 ± 1.11	−0.05 ± 1.02	−0.85 ± 0.80
	Gain (mean ± SD)	0.8* ± 0.9	3.0* ± 2.2	−0.3* ± 0.9	0.08 ± 0.72	−0.01 ± 0.64	0.07 ± 1.10	−0.37* ± 0.76
3	Sample size	(n = 842)	(n = 842)	(n = 767)	(n = 842)	(n = 842)	(n = 842)	(n = 767)
	First (mean ± SD)	10.2 ± 2.9	79.1 ± 12.2	14.4 ± 1.2	−1.55 ± 1.08	−2.48 ± 1.16	−0.16 ± 1.07	−0.83 ± 1.06
	Last (mean ± SD)	10.8 ± 2.8	81.4 ± 11.2	14.4 ± 1.2	−1.54 ± 1.01	−2.54 ± 1.10	−0.13 ± 1.06	−0.93 ± 0.91
	Gain (mean ± SD)	0.6* ± 0.8	2.4* ± 2.3	0.0 ± 0.8	0.01 ± 0.65	−0.06 ± 0.61	0.03 ± 0.96	−0.10* ± 0.70
Total	Sample size	(n = 1394)	(n = 1394)	(n = 1257)	(n = 1394)	(n = 1394)	(n = 1394)	(n = 1257)
	Gain (mean ± SD)	0.7 ± 0.8	2.6 ± 2.3	−0.1 ± 0.9	0.03 ± 0.68	−0.04 ± 0.63	0.05 ± 1.02	−0.21 ± 0.74

SD Standard Deviation

Due to not normal distribution for the majority of comparisons, Kruskall Wallis test is used at a significance level (*) $p<0.05$

mention that the sample was also consisted of individuals belonging to the communities surveyed in the NGO's programs. In this background, on average, the sample of children was at risk of malnutrition due to low weight-for-age, showed the need to pay attention to these communities, if not to provide support to all members of the communities in terms of nutritional security, and at least regularly monitor the situation to understand its seriousness. Another very alarming evidence revealed by the registered data was high prevalence of stunting. In this case, the HAZ indicator reveals that on average, the analyzed sample was in a situation of chronic malnutrition to a moderate degree since the baseline information showed mean HAZ < -2 SD. Together with the values already observed for the WAZ indicator, it was evident that the population studied was in a critical situation of nutritional vulnerability.

Once this fact was evidenced, it was necessary to continue deepening the analysis to know how certain relevant factors in the population were interacting with growth pattern of children. In our study, these factors were age, sex, and given the high prevalence previously known for this context and evidenced by the first analysis, the presence or absence of stunting was considered. In the next section, we will approach this analysis through a statistical model that is still little known in certain areas of physical anthropology and nutritional assessment but really practical in those longitudinal studies in which the subjects voluntarily participated and also left in case of inconvenience.

17.4.2 Effect of Stunting on Growth

The statistical model used for the longitudinal data analysis, the mixed linear regression model considers all the cases and all the measurements recorded, taking into consideration, participation and discontinuation of the participants, which allows maximizing the sample size for the subsequent statistical analysis. In the present work, we have applied the statistical model to boys and girls independently and in general (Table 17.3). Growth curves considering the whole sample and the sample by sex, have also been created to evaluate each of the variables of interest in presence and absence of stunting, including a line in 24 months of age to visually consider the grouping by age as recommended by WHO.

In order to properly interpret the mixed linear regression model, it was first necessary to consider the effect of each of the contrasted factors alone to subsequently examine the combined effect of both, in our case, age, and stunting. Thus, when we analyzed the effect of age on the anthropometric parameters and nutritional status indicators, all of them changed significantly with age ($p<0.05$), both in the total sample and each sex (Table 17.3). These results revealed, on the one hand, that the variables of weight, height and MUAC were positively related to child growth (Bogin & Medialdea, 2023), and on the other hand, that the population studied shows a clear nutritional deficiency during growth, reflected in the fact that the value of the nutritional status indicators decreases with age. Similarly, when the effect of the presence of stunting in the sample is evaluated, all variables appear to

Table 17.3 Effect of age, stunting and their interaction in anthropometric variables and nutritional indicators for girls and boys

Sex	Factor	Weight (kg)	Height (cm)	MUAC (cm)	WAZ (SD)	HAZ (SD)	WHZ (SD)	MUACAZ (SD)
Girls	Age	2.7**	11.8**	0.9**	−0.2**	−0.1**	−0.3**	−0.3**
	Stunting	−0.8**	−4.0**	−1.1**	−0.8**	−1.7**	0.6**	−0.7**
	Age*stunting	0.0	0.2	0.2*	0.0	0.1**	−0.1**	0.1
Boys	Age	2.8**	12.0**	0.8**	−0.1**	−0.1**	−0.2**	−0.1*
	Stunting	−0.7**	−4.7**	−1.0**	−0.8**	−1.8**	0.6**	−0.8**
	Age*stunting	−0.1	0.4**	0.1*	−0.0	0.1**	−0.2**	0.1*
Total	Age	2.8**	11.9**	0.9**	−0.1**	−0.1**	−0.2**	−0.2**
	Stunting	−0.7**	−4.3**	−1.0**	−0.8**	−1.7**	0.6**	−0.8**
	Age*stunting	−0.0	0.3*	0.2**	0.0	0.1**	−0.2**	0.1*

The model shows the mean differences for the study variables based on the following hypotheses: (a) oldest = youngest and (b) stunted subjects = non-stunted subjects

SD Standard Deviation

Significance level (*) $p<0.05$; (**) $p<0.01$

be significantly affected by the factor ($p<0.05$), both in the total sample and each sex (Table 17.3). All anthropometric measurements and z-score values increased in non-stunted infants and children except for WHZ which shows higher values in stunted individuals.

The interaction between the presence of stunting and the effect of age on the anthropometric and nutritional status indicators turned out to be significant for all of them except for weight and WAZ when data of entire sample was analyzed. This means that for all variables except for weight and WAZ, the data generated two non-parallel lines with different ordinates at the origin for the stunting factor (Fig. 17.1b–d), indicating differential growth trends between subjects with and without stunting from the start of their growth record. Particularly, stunted infants and children had significantly ($p<0.01$) lower values for height (4.3 cm less), MUAC (1.0 cm less), HAZ (1.7SD less) and MUACAZ (0.8 SD less), together with higher WHZ (0.6 SD more) from the starting point of their growth compared to the non-stunted peers. At the same time, their growth evolved differently, showing for the anthropometric variables of height and MUAC, a significant increase with age and a significantly better performance (positive and stepper slope) for stunted subjects. For the HAZ and MUACAZ indicators, the trend was to decrease the value with age, showing stunted infants and children having a significantly less steeped slope. However, despite changes of these variables becomes better in stunted individuals at more advanced ages (60 months), the accumulated differences during approximately the first 30 months of life cannot be corrected.

Besides, WHZ indicator worsens with age (Fig. 17.1d), starting from the sample of stunted boys and girls, a higher average value, but their negative trend is significantly more pronounced (WHZ decreases faster with age for the stunted group than for infants and children without stunting), so that at older ages, stunted individuals may have lower WHZ values (the lines intersect). At this point, it raises an issue that

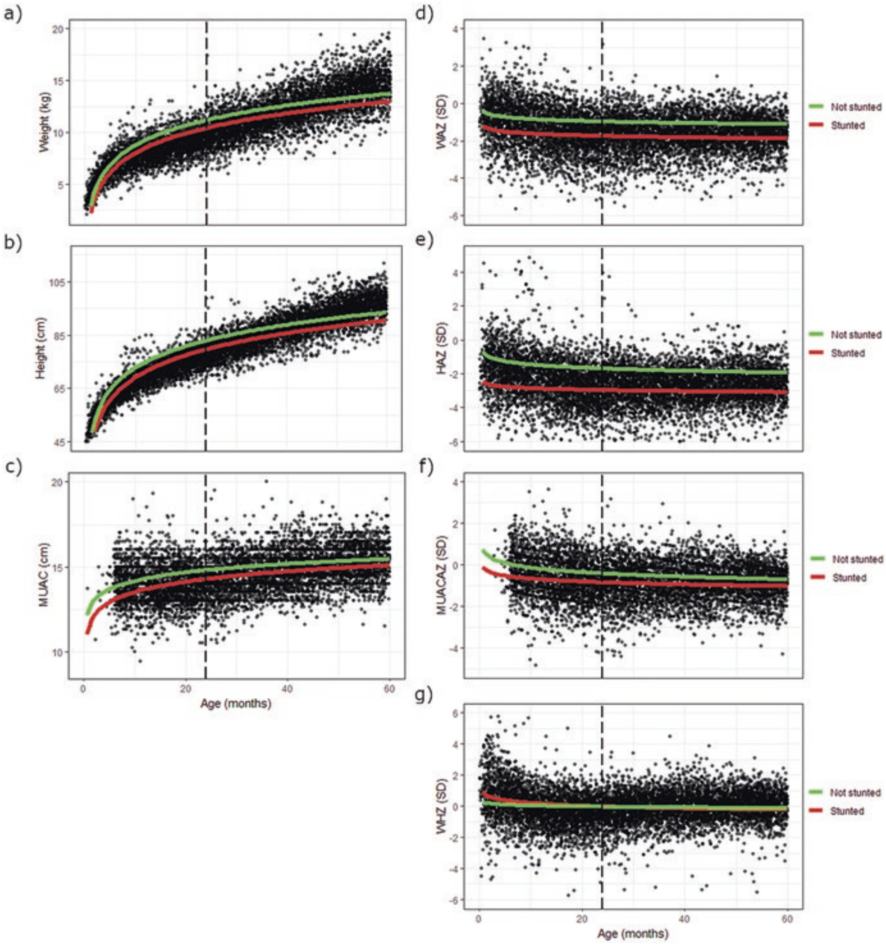

Fig. 17.1 Growth curve for the nutritional status indicators of weight-for-age (WAZ), height-for-age (HAZ), MUAC-for-age (MUACAZ) and weight-for-height (WHZ) among infants and children between 0 and 60 months of age with stunting (red line) and without stunting (green line). Individuals: black dots. Age 24 months marked with dashed black line

deserves a few lines of reflection. The WHZ indicator appears to be significantly favored for the stunted population, compared to the non-stunted, at least in the first years of life. This fact can generate confusion, since observed in an isolated way it could imply that the stunted children maintain a better nutritional status than the non-stunted peers, since a more positive weight/height ratio is found. If we consider that, mathematically, the lower the height or length, the higher this ratio will be, the presence of stunting will prevent this indicator from reaching negative values. This could also make it difficult to find subjects with acute malnutrition identified by this indicator, as has already been stated by several authors (Grellety & Golden, 2016; Hermanussen et al., 2016; Roberfroid et al., 2015). Therefore, it is necessary to consider the rest of the nutritional status indicators when evaluating the nutritional status of infants and children.

Weight and WAZ, however, present a different growth model, since in these cases, no significant interaction is found between the effect of stunting and age (Fig. 17.1a). This means samples of stunted and non-stunted boys and girls present different starting points, (stunted infants and children have 0.7 kg and 0.8 SD less in average compared to non-stunted, p<0.05) but without evidence of different growth patterns, meaning that the curves are parallel. These marked differences in growth patterns observed between stunted and non-stunted subjects are usually associated with genetic but also environmental factors like poverty and household food insecurity, among others (Scheffler et al., 2020).

The observed growth patterns persist with respect to the entire sample and for the boys and girls separately, for all variables except for height and MUACAZ in girls (Figs. 17.2 and 17.3). For both indicators, results do not show growth trends that are significantly more favorable to the stunted girls, indicating that, unlike stunted boys who showed an improvement in their growth rate compared to that of non-stunted,

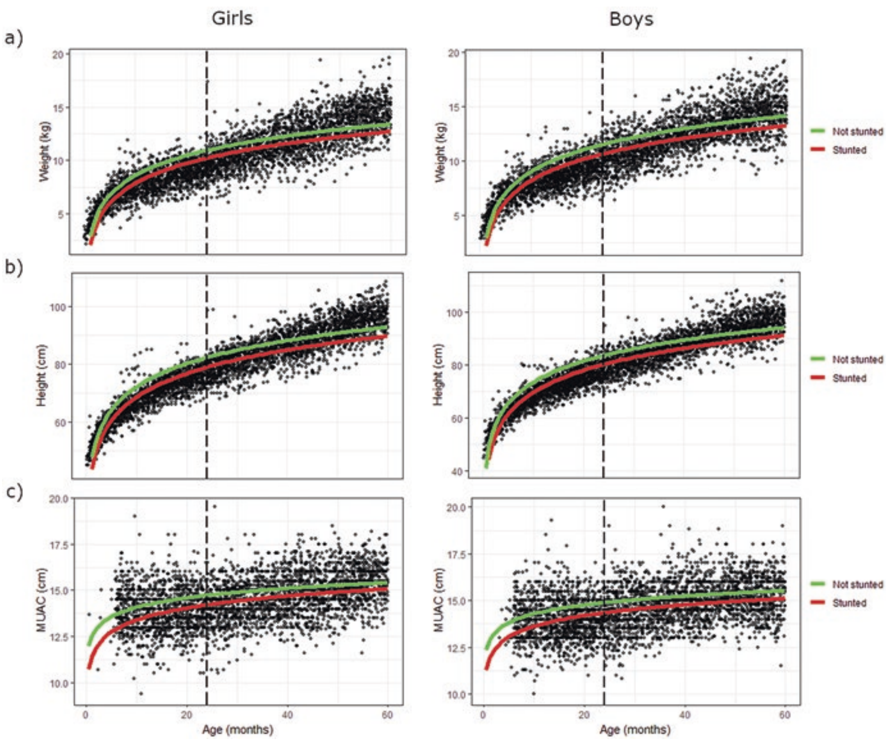

Fig. 17.2 Growth curves of weight, height and MUAC in boys (right) and girls (left) between 0 and 60 months of age with stunting (red line) and without stunting (green line). Individuals: black dots. Age 24 months marked with dashed black line

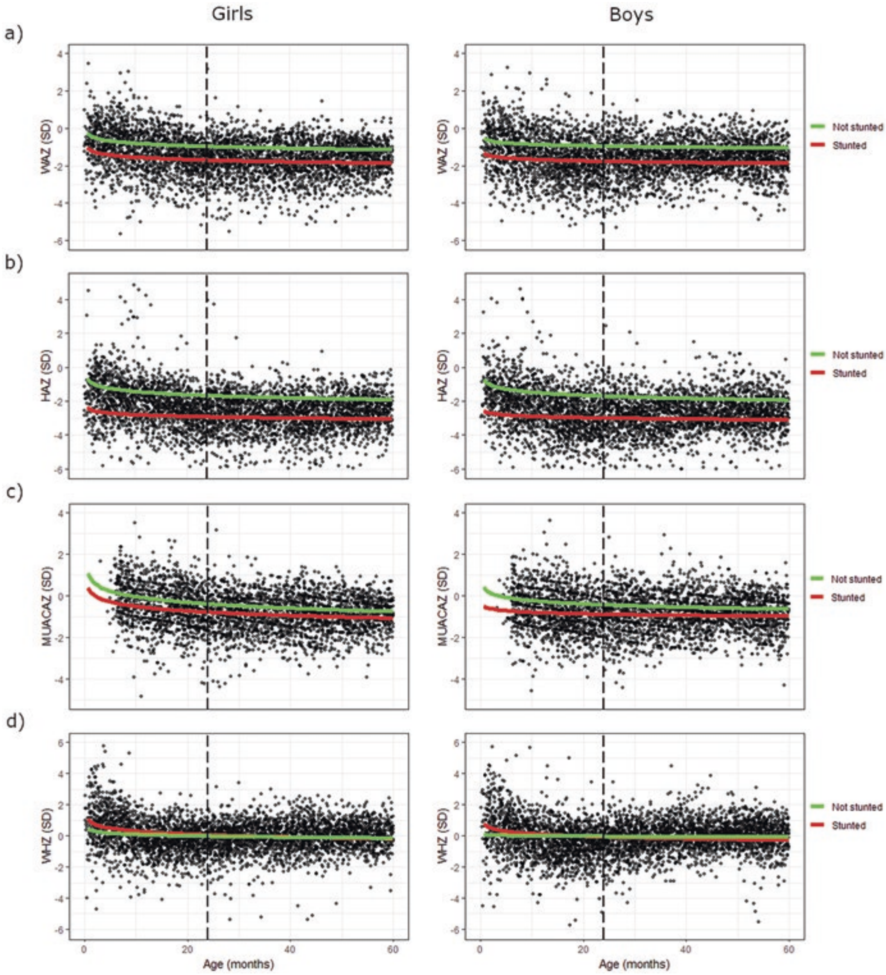

Fig. 17.3 Growth curves of weight-for-age (WAZ), height-for-age (HAZ), MUAC-for-age (MUACAZ) and weight-for-height (WHZ) in boys (right) and girls (left) between 0 and 60 months of age with stunting (red line) and without stunting (green line). Individuals: black dots. Age 24 months marked with dashed black line

stunted girls progressed at the same rate as non-stunted girls in their height growth (Fig. 17.2) and MUACAZ (Fig. 17.3). It has been thus evidenced the sexual dimorphism of growth patterns. It would be interesting to delve into the study of the causality of this pattern to try to discern between a possible genetic, epigenetic effects associated with certain environmental factors or possible gender bias due to other sociocultural factors.

17.5 Conclusions

In this chapter it has been evidenced that stunting had a negative effect on growth that was observed in weight, height and MUAC from the beginning of life, emphasizing the first few months. In the case of weight and WAZ, the negative trend seems to stop with age for stunted children. For height, MUAC, HAZ and MUACAZ, growth pattern in stunted children evolved positively with age. However, the accumulated differences during the first months of life could not be corrected for any variable and in no case, it was possible to recover the growth pattern of non-stunted individuals.

The WHZ indicator began to express better values in stunted infants but evolved worse with age. This finding makes sense if we consider that this indicator results from a mathematical interrelationship between weight and height. If height was significantly lower in stunted cases, it was rational that this indicator appeared to be increased with stunting. Thus, when height grows positively in stunted children (although the effect of chronic malnutrition is not reversed), WHZ changes negatively. Consequently, the indicator reflects negative patterns of growth since it is approximately after 24 months of age when growth trends of stunted and non-stunted children appear to be reversed. Therefore, it is not advisable to follow the WHZ indicator alone to describe growth of stunted children, since its interpretation could lead to the confusing conclusions, especially in the first months of life.

It has been shown that stunting has a negative effect on the development and on anthropometric variables, not only height but also weight and MUAC, as well as their associated nutritional status indicators. It is, therefore, necessary to consider stunted infants and children as a vulnerable group and more susceptible to suffering from acute malnutrition, especially at an early age. In the presence of stunting, it is advisable to evaluate MUAC, as well as its associated nutritional status indicator MUACAZ. Given that among stunted individuals, this measure significantly decreases its value with respect to WHZ, not affected by height, and also identifies a growth trend that is significantly worse in stunted than among non-stunted subjects, coinciding with the rest of the nutritional status indicators and therefore, reflecting in a more appropriate way the nutritional status of this group. This indicator is more appropriate for monitoring nutritional status and physical growth in stunted infants and children than WHZ.

Acknowledgements We would like to make a special mention to all the people who participated in the programs of our organization. We hope that we could make a positive impact on their lives. We also wish to thank the funding agencies of the program in which this publication is framed: European Civil Protection and Humanitarian Aid Operations (ECHO). Our warmest thanks to the partners of the consortia: *Trocaire, Grupo de Voluntariado Civil* (GVC), *Médicos del Mundo* (MDM) *Arbeiter-Samariter-Bund Deutschland* (ASB), Telecoms Sans Frontieres (TSF), OXFAM, *Cooperazione Internazionale* (COOPI*), Asociación de Servicios y Desarrollo Socioeconómico de Chiquimula* (ASEDECHI) and *Corazón del Maíz*. Finally, a special mention goes to our colleagues from the Guatemala and Madrid offices, including all the people from the technical team in health and nutrition area who participated in the training, screening, distribution and other activities of the project in the field, those involved in the coordination with our stakeholders, as well as those in charge of logistic and administrative divisions.

References

Action Against Hunger Foundation (AAH). (2014). *The drought in the Central American dry corridor: Vulnerable situation and proposals for intervention using the experience accumulated in previous crises*. Action Against Hunger Foundation.

Aroche, S., & Cristian, M. (2021). *Situación Epidemiológica de muerte materna de enero a septiembre de 2021 Guatemala*. Ministerio de Salud Pública y Asistencia Social de Guatemala. http://epidemiologia.mspas.gob.gt/files/2021/salas-situacionales/desnutricion-aguda/ss-mm-sep-2021.pdf. Retrieved on November, 16, 2022.

Ballard, M., Bonds, M., Burey, B. A., et al. (2018). *Community health worker assessment and improvement matrix (CHW AIM)*. Updated Program Functionality Matrix for Optimizing Community Health Programs. https://doi.org/10.13140/RG.2.2.27361.76644. Retrieved on November, 16, 2022.

Bogin, B., & Medialdea, L. (2023). Anthropometric assesment. In C. Geissler & H. Powers (Eds.), *Human nutrition* (14th ed.). Oxford University Press. (in press).

Bourdon, B. (2017). Bourdon, B. (2017). *Marco teorico: Las distintas formas de distancia y sus impactos sobre las comunidades rurales de Guatemala*. Action Against Hunger Foundation. https://www.accioncontraelhambre.org/sites/default/files/documents/ach_2017_marco_teorico_distancia_salud.pdf. Retrieved on November, 16, 2022.

Briend, A., Maire, B., Fontaine, O., et al. (2012). Mid-upper arm circumference and weight-for-height to identify high-risk malnourished under-five children: Identifying high-risk malnourished children. *Maternal & Child Nutrition, 8*(1), 130–133. https://doi.org/10.1111/j.1740-8709.2011.00340.x

Cnaan, A., Laird, N. M., & Slasor, P. (1997). Using the general linear mixed model to analyse unbalanced repeated measures and longitudinal data. *Statistics in Medicine, 16*(20), 2349–2380. https://doi.org/10.1002/(SICI)1097-0258(19971030)16:20. 2349::AID-SIM6673.0.CO;2-E.

Colón, J. P., Cardona, J. F., Marroquín, M. J., et al. (2012). *Situación nutricional y riesgos de inseguridad alimentaria en niños de áreas rurales y urbanas de la República de Guatemala*. MSc thesis, Universidad San Carlos de Guatemala, Guatemala. http://biblioteca.usac.edu.gt/tesis/05/05_8844.pdf. Retrieved on November, 16, 2022.

Cordon, A., Asturias, G., De Vries, T., et al. (2019). Advancing child nutrition science in the scaling up nutrition era: A systematic scoping review of stunting research in Guatemala. *British Medical Journal Paediatrics Open, 3*(1), e000571. https://doi.org/10.1136/bmjpo-2019-000571

Custodio, E., Martin-Cañavate, R., Di Marcantonio, F., et al. (2018). MUAC-for-age more useful than absolute MUAC for nutritional surveillance in Somalia: Results from nineteen cross-sectional surveys (2007–2016). *BioMed Central Nutrition, 4*(1), 8. https://doi.org/10.1186/s40795-018-0213-3

Food and Agriculture Organization of the United Nations (UN-FAO), Pan American Health Organization (PAHO). (2017). *América Latina y el Caribe – Panorama de la seguridad alimentaria y nutricional 2016: Sistemas alimentarios sostenibles para poner fin al hambre y la malnutrición.* FAO and PAHO. https://iris.paho.org/bitstream/handle/10665.2/33680/9789253096084-spa.pdf?sequence=1&isAllowed=y. Retrieved on November, 23, 2022.

Garcia, T. P., & Marder, K. (2017). Statistical approaches to longitudinal data analysis in neurodegenerative diseases: Huntington's disease as a model. *Current Neurology and Neuroscience Reports, 17*(2), 14. https://doi.org/10.1007/s11910-017-0723-4

Garenne, M., Myatt, M., Khara, T., et al. (2019). Concurrent wasting and stunting among under-five children in Niakhar, Senegal. *Matern Child Nutr, 15*(2), e12736. https://doi.org/10.1111/mcn.12736

Giammattei, A. (2021). *Situación de la Desnutrición Aguda en niños menores de 5 años.* Ministerio de Salud Pública y Asistencia Social de Guatemala. http://epidemiologia.mspas.gob.gt/files/2021/salas-situacionales/desnutricion-aguda/DA-SE-8-2021.pdf. Retrieved on 16 November 2022.

Grellety, E., & Golden, M. H. (2016). Weight-for-height and mid-upper-arm circumference should be used independently to diagnose acute malnutrition: Policy implications. *BioMed Central Nutrition, 2*(10). https://doi.org/10.1186/s40795-016-0049-7

Grellety, E., Krause, L. K., Shams Eldin, M., et al. (2015). Comparison of weight-for-height and mid-upper arm circumference (MUAC) in a therapeutic feeding programme in South Sudan: Is MUAC alone a sufficient criterion for admission of children at high risk of mortality? *Public Health Nutrition, 18*(14), 2575–2581. https://doi.org/10.1017/S1368980015000737

Hermanussen, M., Ipsen, J., Mumm, R., et al. (2016). Stunted growth. Proceedings of the 23rd Aschauer Soiree, held at Aschauhof, Germany, November 7th 2015. *Pediatric Endocrinology Reviews: PER, 13*(4), 756–767.

Integrated Food Security Phase Classification. (2022). *IPC overview and classification system*. IPC Global Platform. https://www.ipcinfo.org/ipcinfo-website/ipc-overview-and-classification-system/en/. Retrieved on November, 16, 2022

Juarez, M., Dionicio, C., Sacuj, N., et al. (2021). Community-based interventions to reduce child stunting in rural Guatemala: A quality improvement model. *International Journal of Environmental Research and Public Health, 18*(2), 773. https://doi.org/10.3390/ijerph18020773

Khara, T., Mwangome, M., Ngari, M., et al. (2018). Children concurrently wasted and stunted: A meta-analysis of prevalence data of children 6-59 months from 84 countries. *Maternal & Child Nutrition, 14*(2), e12516. https://doi.org/10.1111/mcn.12516

Medialdea, L. (2018). *Estudio REDAC. Relación entre desnutrición aguda y crónica. Haciendo visible lo invisible* (Health & Nutrition series technical report). Action Against Hunger Foundation. https://www.accioncontraelhambre.org/sites/default/files/documents/estudio_relacion_entre_desnutricion_aguda_y_cronica696_0.pdf. Retrieved on November, 16, 2022.

Ministerio de Salud Pública y Asistencia Social (MSPAS). (2009). *Protocolo para el tratamiento ambulatorio de la desnutrición aguda severa.* Ministerio de Salud Pública y Asistencia Social de Guatemala. http://www.siinsan.gob.gt/siinsan/wp-content/uploads/cedesan/PROTOCOLO%20PARA%20EL%20TRATAMIENTO%20AMBULATORIO%20DA%20SEVERA.pdf. Retrieved on November, 16, 2022.

MSPAS. (2010). *Protocolo para el tratamiento ambulatorio de la desnutrición aguda moderada.* Ministerio de Salud Pública y Asistencia Social de Guatemala. http://www.siinsan.gob.gt/siinsan/wp-content/uploads/cedesan2/libros/Protocolo-Tratamiento-ambulatorio-DA-MODERADA.pdf. Retrieved on November, 16, 2022.

MSPAS, INE, & ICF Internacional. (2015). *VI Encuesta Nacional de Salud Materno Infantil 2014–2015*. Final report. MSPAS/INE/ICF. https://www.ine.gob.gt/images/2017/encuestas/ensmi2014_2015.pdf. Retrieved on November, 16, 2022.

Myatt, M., Khara, T., & Collins, S. (2006). A review of methods to detect cases of severely malnourished children in the community for their admission into community-based therapeutic care programs. *Food and Nutrition Bulletin, 27*(3_suppl3), S7–S23. https://doi.org/10.1177/15648265060273S302

Naliaka, B. (2018). *Needs assessment and baseline surveys for WASH in emergencies*. Humanitarian Library. https://www.humanitarianlibrary.org/collection/needs-assessment-and-baseline-surveys-wash-emergencies. Retrieved on November, 16, 2022.

Pelletier, D. L., Frongillo, E. A., Gervais, S., et al. (2012). Nutrition agenda setting, policy formulation and implementation: Lessons from the mainstreaming nutrition initiative. *Health Policy and Planning, 27*(1), 19–31. https://doi.org/10.1093/heapol/czr011

Roberfroid, D., Huybregts, L., Lachat, C., et al. (2015). Inconsistent diagnosis of acute malnutrition by weight-for-height and mid-upper arm circumference: Contributors in 16 cross-sectional surveys from South Sudan, The Philippines, Chad, and Bangladesh. *Nutrition Journal, 14*(1), 86. https://doi.org/10.1186/s12937-015-0074-4

Scheffler, C., Hermanussen, M., Bogin, B., et al. (2020). Stunting is not a synonym of malnutrition. *European Journal of Clinical Nutrition, 74*(3), 377–386. https://doi.org/10.1038/s41430-019-0439-4

Schlecht, J., & Casey, S. (2007). Challenges of collecting baseline data in emergency settings. *Forced Migration Review, 29*, 6–70.

Schumacher, D., Borghi, E., & Polonsky, J. (2021). *Anthro: Computation of the WHO child growth standards [R]*. World Health Organization. https://github.com/WorldHealthOrganization/anthro. Original work published 2018, Retrieved on November, 16, 2022.

Secretaría de Seguridad Alimentaria y Nutricional. (2008). *Política Nacional de Seguridad Alimentaria y Nutricional, 32-2005 y 75-2006*. http://www.siinsan.gob.gt/siinsan/wp-content/uploads/Politica-SAN.pdf. Retrieved on November, 16, 2022.

UNICEF, World Health Organization (WHO), & World Bank Group. (2021). *Levels and trends in child malnutrition. Joint Child Malnutrition Estimates: Key findings of the 2021 edition*. World Health Organization.

van der Zee, A., van der Zee, J., & Meyrat, A. et al. (2012). *Tomo I Estudio de Caracterización Corredor Seco Centroamericano (Países CA-4)* (Vol I). FAO.

Waterlow, J. C. (1972). Classification and definition of proteincalorie malnutrition. *British medical journal, 3*, 566–569.

Waterlow, J. C. (1974). Some aspects of childhood malnutrition as a public health problem. *British Medical Journal, 4*, 88–90.

WHO. (2006). *WHO child growth standards: Length/height-for-age, weight-for-age, weight-for-length, weight-for-height and body mass index-for-age: Methods and development*. World Health Organization Press.

Chapter 18
Consequences of Increased Dependence on Store Foods on Seasonal Macronutrient Intake and Gut Microbiota in Maya Mothers and Their 12- to 36-Month-Old Children

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18.1 Introduction

The persistence of childhood undernutrition in rural areas and the appearance of metabolic syndrome in adolescents and adults during this century are not independent and may be the result of agriculturalist's inability to provide pregnant women and children access to a balanced diet (Golden et al., 2019; Gurri, 2015; Hirvonen et al., 2015; Lachat et al., 2018; M'Kaibi et al., 2015). Poor nutritional environments in utero followed by a high carbohydrate diet during the first 3 years of life will lead to the development of a thrifty phenotype (Hales & Barker, 2001, 2013; Wells, 2011). Affected children will have lower metabolic capacity and greater metabolic load (Wells, 2011). They will be shorter and less efficient in the oxidation of body fat (Frisancho, 2009). These children will tend to accumulate fat, will become overweight easier than children growing under better conditions, and will tend to develop metabolic syndrome when exposed to obesogenic environments (Hoffman et al., 2000).

Diet quality in the early years is also a key factor in the conformation of a healthy microbiota structure that will positively affect body composition (Fung et al., 2015; Davis et al., 2021), and reduce metabolic disorders in adults (Milani et al., 2017). Modern diets with increased processed sugar and saturated fat intake will contribute to dysbiosis as the microbiota Firmicutes/Bacteroidetes ratio increases (Maskarinec

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S. Datta Banik (ed.), *Human Growth and Nutrition in Latin American and Caribbean Countries*, https://doi.org/10.1007/978-3-031-27848-8_18

et al., 2019, 2021). This may lead to the development of metabolic syndrome (Chen et al., 2020).

Unbalanced diets result from limited dietary diversity (Fanzo et al., 2013; Mahmudiono et al., 2017; Nithya & Bhavani, 2017), which during every agricultural cycle responds to seasonal changes in the number of food items available in their environment (Bacon et al., 2014; Golden et al., 2019; Gurri et al., 2021; Hirvonen et al., 2015; Khandker, 2012; Madan et al., 2018; Sibhatu & Qaim, 2017). Although enthusiastically promoted as a solution, rural grocery stores provide limited food diversity emphasizing processed sugary products of low nutritional value (Abay & Hirvonen, 2017; Biing-Hwan et al., 2014; Bustillos et al., 2009; Hirvonen et al., 2017; Gurri, 2020; Leatherman & Goodman, 2005; Liese et al., 2007; Otero et al., 2017; Sharkey et al., 2012, 2013). Unfortunately, their proliferation has been accompanied by the abandoning of subsistence production for other cash generating activities making the diet of rural populations increasingly dependent on the foods that can be purchased in these stores (Otero et al., 2017; Gurri et al., 2021).

In this chapter we explore if increased dependency on grocery store products has had any effects on the seasonal macronutrient intake and gut microbiota structure of a rural Maya population from the Yucatan Peninsula, Mexico, by comparing those who belong to the households that depend mostly on store-bought foods to those who produce what they consume. We focus on children from 12 to 36 months and their mothers as proxy of their nutritional environment in utero. It is during pregnancy and the first 3 years of life that the metabolic characteristics that will follow the individual throughout his or her life will develop. Any macronutrient imbalance or microbiota changes produced by the type of foods consumed at this time are likely to have important consequences in the frequency of metabolic syndrome in adults from these populations.

18.2 Background

The "*milpa*" has been the staple-base system in the Yucatan Peninsula since precolonial times. It is a diversified maize (*Zea mays*) polyculture that includes different types of beans (*Phaseolus* sp.), squash (Cucurbita sp.), chili peppers (*Capsicum* sp.) and other cultigens that vary locally. Diet is based on its cultigens and backyard farming, which are supplemented by harvesting fallow fields, hunting, and gathering in the forest. In addition to food, forest management provides firewood, building materials, medicinal plants, and fodder (Atran et al., 1993; Lope-Alzina, 2017; Terán & Rasmussen, 2009).

Local traditional technology is slash-and-burn shifting agriculture. Its cycles are determined by the rains, which regulate all aspects of Maya life including most community and family rituals and provide a background for most religious beliefs (Tuz, 2013). During the dry season, between February and May, fruits and vegetables from their home gardens become available. The burning of fields takes place in April and early May. Corn is planted in late May and early June, depending upon the first rain that brings water to *milpas*, and grows in the field until October. The green corn is harvested to be consumed fresh as "*atole nuevo*" and "*pibipollos*" during the festivities of all Saints Day "*día de muertos*". When the dry season starts in October, the maize stalks are folded over and the ears of corn are left to dry in the fields. The dried corn is harvested in December (Gates, 1993; Sohn et al., 1999).

The cycle implies that every year the Maya must face a scarcity season. This one will coincide with the rains between June and September when fruits stop producing and stores from the previous harvest are low. The abundance season, between October and May, may be divided in two: when the harvest has recently come in and grains and legumes are abundant, and from February to May when all different kind of fruits become available in the local back yards (Gurri et al., 2021) (Fig. 18.1).

18.3 Regional Transformation

In the late 1960s and early 1970s, a modern road connected the central area of the state of Yucatan to the urban centers of Merida and Cancun. This road increased the number of peasants seeking salaried work in the cities, transforming the region's subsistence economy into a mixed economy (Re Cruz, 1996; Villanueva, 1994). By the 1980s, peasant households began placing more emphasis on wage labor and participation in the cash economy without abandoning slash-and-burn agriculture in their borne communities (Gurri & Balam, 1992). Continued improvement of the original communication network has transformed many of the larger towns into semi-suburbs where workers leave early in the morning and come back at night or leave early Monday and come back Fridays (Azcorra et al., 2015; Otero et al., 2017). In addition, the most communicated towns have developed agricultural industries that hire residents and since the late 1980s, permanent irrigated plots to grow commercial crops have been increasing.

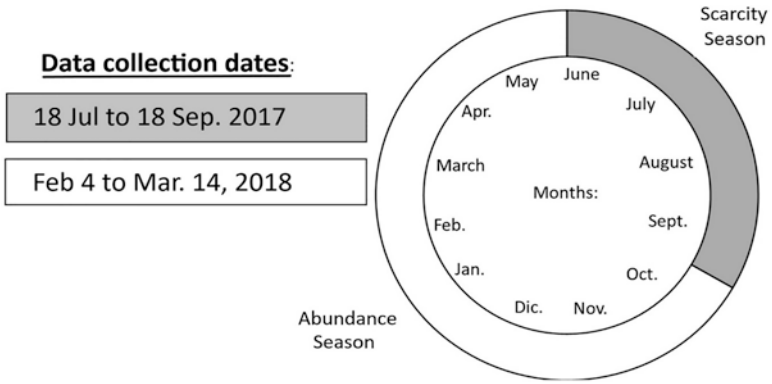

Fig. 18.1 Seasons of abundance and scarcity in the Maize Region of the State of Yucatan, and dates when samples were collected

Development in the area, however, has not been uniform. While some towns have grown in population and size, developed local industry, improved communication to markets and labor centers in the cities and increased their number of grocery stores for their population to purchase food, others remained small, with poor communication networks making access to local labor and other markets difficult, they offer limited if any local-salaried labor opportunities and have few food grocery stores. In addition, As many as 36% of the farmers refused to abandon their traditional livelihood (Gurri, 2010; Gurri et al., 2021). These were significantly more predominant in small, less developed communities than in the large ones where households that reorient family labor to focus on new economic opportunities at the expense of subsistence activities were the norm (Gurri et al., 2021).

While dependence on cash generating activities does not necessarily imply the abandonment of staple-based subsistence production (Anderzén et al., 2020; García et al., 2008), in the Maize region as many as 47.5% of those who favor generating cash over subsistence in large towns and 16.2% in the small ones abandoned *milpa* maize production altogether (Otero et al., 2017). Gurri et al. (2021) and Otero et al. (2017) showed that dependence on store foods was greater in these transformed households than in those that still depended on subsistence agriculture. Dependence on store-bought foods, however, was always greater in households that favored cash generation regardless of town size.

All families in both types of communities were affected by a seasonal reduction in the number of food items consumed in every food group. To replace the variability lost during the scarcity season, transformed households, especially in large communities, maintained or increased their sugar intake (Gurri et al., 2021). Arguably then, the increased supply of food stores, and the substitution of subsistence effort for cash generating activities has increased the amount of food consumed by rural populations year-round but has been unable to provide agriculturalists with a balanced diet during the scarcity season (Golden et al., 2019; Hirvonen et al., 2015; Lachat et al., 2018; M'Kaibi et al., 2015).

18.4 Materials and Methods

Mother infant pairs were chosen from a sample of rural households surveyed in a project designed to study the interaction between seasonality and the substitution of subsistence effort for cash generating activities in the maize producing region of the state of Yucatan, Mexico. Households were grouped into 'traditional', which were those that focused on subsistence production, and 'modern, which were those that emphasized cash generating activities and had a greater dependence on store-bought foods (See Gurri et al., 2021 for survey details as well as household classification procedure).

The sample consisted of mother infant pairs from both productive strategies measured once during the scarcity and once during the abundance seasons of 2017–18 agricultural cycle. Children (n=12) were between 12 and 36 months old, without any intestinal or respiratory diseases and who had not recently been vaccinated; 16 mothers participated in the study. They were under mother's direct care, and the latter was present where the team could observe and record her activities and food intake both during the scarcity and the abundance periods. If anyone happened to be ill or unavailable during any of the team's visits, he or she was excluded from further analysis. Sample size was limited by the number of households the team could visit in 15 working days (between Monday and Friday) during one season.

A Food Portions study (FAO, 1962; Ortega et al., 2015; Pinheiro & Atalah, 2005) was carried out twice in the same individual, once during the scarcity and a follow-up during the abundance season of the 2017–18 agricultural cycle to estimate daily macronutrient intake in kilocalories. Food intake was recorded during day-long observation periods where all food and drink consumed by the children and their mothers from their first meal of the day to their last before going to sleep. Within the house, all ingredients used for the preparation of the day's meals were quantified and weighed. Food served was weighed and measured before it was eaten. Any leftovers were also measured. When the mothers or the children left the house, a team member accompanied them and recorded any food eaten. An OHAUS 3000 XTREME digital scale capacity 6000 g., precision 1 g was used to weigh food consumed and household measures such as cups, spoons, and glasses were standardized into grams using local food and crockery before field work.

All food eaten was broken down into 100-gram portions of carbohydrates, protein and lipids using the Nutritional Value tables for the foods consumed in the state of Yucatan (Gurri et al., 2019; Muñoz, 2010). Foods not found in the latter were analyzed for their content in the bromatology laboratory of *El Colegio de la Frontera Sur*. Macronutrient portions per dish were transformed into grams consumed per macronutrient. Grams of each macronutrient consumed during a meal were added and summed to obtain macronutrient intake for a 24-hour period. Daily totals were then transformed into kilocalories per macronutrient using the Atwater system (Atwater & Bryant, 1900).

A multivariate repeated measures analysis of variance was performed comparing seasonal kcal intake for proteins, carbohydrates, and lipids. Age group, mothers, and children, and the two productive strategies, traditional and modern, where used as fixed factors. The model's marginal means were used for the univariate comparisons.

To estimate nutritional adequacy, participants' physical activity levels (PAL) and anthropometric measurements were obtained. PAL was estimated using the four categories suggested by FAO/WHO/UNU (2005). These are sedentary, light activity, moderate and intense. Participants were measured in the morning before breakfast. Mothers were weighed without shoes and light clothing using a Tanita BC-577 Fitscan, capacity 150 kg, precision 0.1 kg., bathroom scale. Their children were weighed in their mother's arms and their weight estimated by subtraction. Height in adult women was measured to the nearest 0.1 cm using a Martin type anthropometer and recumbent length in children under 36 months was measured with an infantometer (Frisancho, 1990). Diet quality was evaluated according to the recommendations of Suverza (2010).

Microbiota DNA was obtained from stool samples. Each participant family received a collection kit including a Coprotainer® stool sample fecal specimen sterile cup of 60 ml, a disposable sanitized spoon, and a hermetic Ziplock plastic bag. For infants, a sanitized, plastic potty chair was also provided. The instruction given to participants were as follows: To collect a small sample of solid feces (5 g) and put it into the cup. For babies the sample was taken directly from the diaper trying to exclude urine. Obtained samples were kept under refrigeration. As soon as samples were received, they were opened under aseptic conditions and 500 mg were transferred to a sterile microcentrifuge tube containing 500 μL of RNAlater® Stabilization Solution (Cat. R0901, Sigma, St. Louis, MO, USA), vortex-homogeneized and maintained at 4 °C until DNA extraction. The rest of each fecal sample was maintained at 4 °C and delivered to the nearest commercial clinical laboratory for general stool examination (GST). Those samples under normal parameters without any sign of disease were considered for DNA extraction.

Environmental DNA (eDNA) was extracted using the commercial kit QIAamp® Power Fecal®DNA (Cat. 51804, QIAGEN; Hilden, Germany) following manufacturer's instructions. Purified samples were analyzed to verify its integrity, purity (Abs.$^{260}/_{280}$) and pooled by evaluated condition, taking 5 ng of total eDNA per individual. Pooled DNA samples were sent to Research and Testing Laboratories (RTL Genomics, www.rtlgenomic.com) for amplicon-based 16S sequencing in an Illumina MiSeq® 2000 platform employing the Fw 5′-CAGAGTTTGATC CTGGCTCAG-3′ and Rv 5′-AAGGAGGTGATCCAGCC-3′ set of primers.

The raw *.Fastq files received, were processed in QIIME2 2020.8 (Caporaso et al., 2010) following the pipeline reported by Becerra et al. (2021). Taxonomical designations were assigned to obtained Operational Taxonomic Units (OTUs) with the Greengenes database (version 13–8) as a reference. Venn diagrams were plotted using Venny 2.1 (Oliveros, 2007–2015).

18.5 Results

Figure 18.2 locates the communities where the sample was collected. Table 18.1 shows sample size per strategy (traditional and modern) of mother and child, and Fig. 18.1 demonstrates dates and seasons when the households were visited. A total of 12 children and 16 mothers were evaluated. The children of four of the mothers included in the analysis were excluded for different reasons. The data from the mothers in both seasons was acceptable, however, it was decided to keep them in the order to boost sample size.

Mean kcal and the sum of kcals consumed per macronutrient by children and mothers from traditional and modern households during the scarcity and the abundance seasons are presented in Table 18.2. Table 18.3 shows the results of the multivariate repeated measures analysis of variance comparing the means presented in

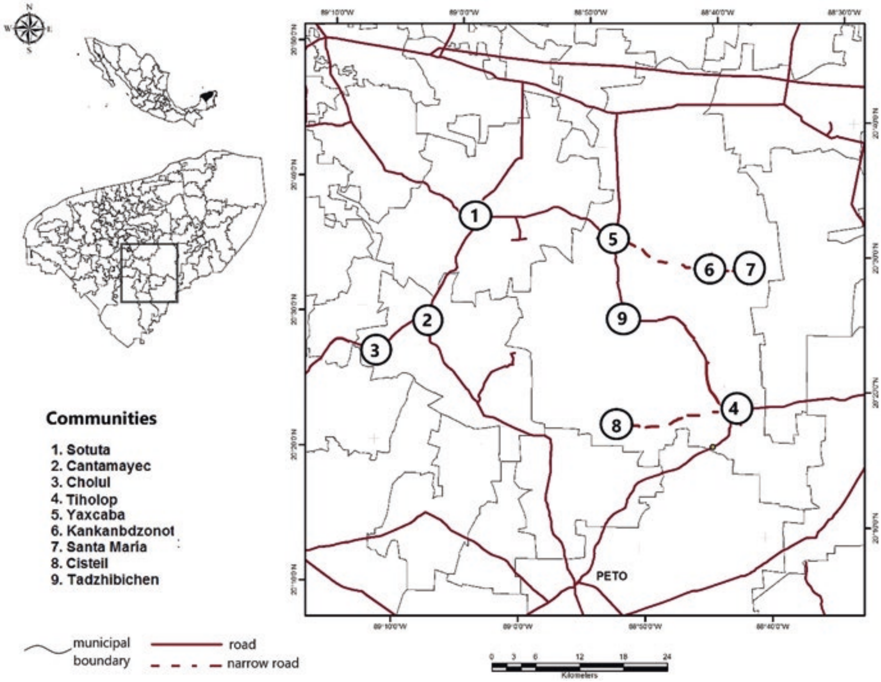

Fig. 18.2 Map of localities studied in Yucatan

Table 18.1 Sample size by age group and productive strategy

Strategy	Children 12–36 months	Mothers	Total
Traditional	6	8	14
Modern	6	8	14
Total	12	16	28

Table 18.2, controlling for any possible interaction effects for age group and strategy. Mothers consume significantly more kcal than their children, and it appears they all consume significantly more macronutrients during the abundance than during the scarcity season. There are no significant interaction effects. Children and their mothers from both productive strategies (traditional and modern) reduce macronutrient intake during the scarcity season, and strategy does not seem to have an overall effect on macronutrient consumption.

Univariate comparisons per macronutrient are presented in Table 18.4. Kcal reductions during the scarcity season are significant for all three macronutrients. As in the multivariate model, there are no significant differences observed between strategies and no interaction effects found.

Not only do absolute kcal per macronutrient change seasonally, so does the kcal proportion each macronutrient contributes to the diet. Table 18.5 compares average relative contribution to the diet in kcal for each macronutrient during the scarcity

Table 18.2 Mean kcal consumed per macronutrient by age group and productive strategy during the scarcity and abundance seasons of the 2017–18 agricultural cycle

Macronutrients	Season	Mean kcal consumed						Total (n = 28)
		Children between 12 and 36 months of age			Mothers			
		Productive strategy		Total children (n = 12)	Productive strategy		Total mothers (n = 16)	
		Traditional (n = 6)	Modern (n = 6)		Traditional (8)	Modern (n = 8)		
Protein	Scarcity	170.51	208.99	189.75	320.76	265.17	300.58	248.73
	S.D.	44.10	51.11	49.75	59.85	56.46	68.70	76.99
	Abundance	212.94	250.33	231.64	357.67	326.67	332.04	294.80
	S.D.	58.65	52.60	56.59	56.58	45.39	65.48	76.90
Carbohydrates	Scarcity	885.68	987.92	936.80	1362.05	1170.76	1290.29	1125.15
	S.D.	147.95	123.69	140.55	214.17	176.91	272.94	247.11
	Abundance	983.83	1059.52	1021.68	1431.38	1309.64	1340.68	1221.01
	S.D.	187.45	146.94	165.37	206.34	230.95	246.58	262.88
Lipids	Scarcity	322.78	491.04	406.90	404.35	398.15	466.08	403.67
	S.D.	129.84	154.12	161.81	162.73	168.01	286.08	157.70
	Abundance	422.42	572.96	497.69	475.38	498.59	475.38	491.57
	S.D.	143.88	111.39	145.71	165.53	179.65	159.28	155.66
Total kcal	Scarcity	1378.96	1687.95	1533.46	2087.17	1834.08	1960.62	1777.55
	S.D.	247.82	289.94	303.59	278.27	313.32	314.69	372.70
	Abundance	1619.19	1882.82	1751.00	300.65	2134.91	2199.67	2007.39
	S.D.	328.45	267.30	316.97	300.65	383.10	339.33	395.00

S.D. Standard deviation

Table 18.3 Multivariate repeated measures analysis of variance comparing seasonal consumption of protein, carbohydrates and lipid kcal with age group and strategy as inter subject factors

Effect		λ	F[a]	α
Inter subjects	Intersection	0.02	365.774	<0.001
	Age group	0.369	12.555	<0.001
	Strategy	0.887	0.935	0.44
	Age group by strategy	0.828	1.52	0.237
Intra subjects	Season	0.141	44.571	<0.001
	Season by age group	0.964	0.272	0.845
	Season by strategy	0.933	0.528	0.668
	Season by age group by strategy	0.843	1.368	0.278

Design: Intersection + age group + strategy + age group × strategy
Intra-subjects design: Season
Wilky's λ
[a]d.f. = 3/22

and abundance season. There is a significant proportional increase in carbohydrate intake during the scarcity season.

Most individuals had unbalanced diets year-round, especially the mothers (Table 18.6). This was clearly due to a deficient lipid intake (Table 18.6). They all

Table 18.4 Univariate repeated measures analysis of variance comparing seasonal kcal consumption per macronutrient with strategy and age group as inter subject factors[a]

Macronutrient:	Effect: Season	
	F[b]	α[c]
Protein	75.936	<0.001
Carbohydrates	39.188	<0.001
Lipids	38.026	<0.001

[a]Only seasonal Fs are shown. Interaction effects were not significant.
[b]d.f = 1 for all Fs.
[c]Greenhouse-Geisser correction was used to adjust α

Table 18.5 Seasonal change in macronutrient contribution to the diet of both mothers and children (n = 28) expressed in % contribution. Paired t tests per macronutrient

Macronutrients	Season		Dif	Paired t*	α
	Scarcity	Abundance			
Protein	13.86	14.61	−0.76	−2.50	$\alpha = 0.019;\ _{27d.f}$
S.D.	2.54	2.31	1.61		
Carbohydrate	63.55	60.86	2.69	4.72	$\alpha < 0.001,_{27d.f.}$
S.D.	7.88	5.22	3.01		
Lipids	22.59	24.52	−1.93	−3.36	$\alpha = 0.002,_{27d.f.}$
S.D.	8.39	6.19	3.04		

*$p < 0.05$

had an adequate protein intake in both seasons. Lipid and carbohydrate intakes, however, were not independent. During the scarcity season, 65% of the individuals with a deficient lipid intake also consumed carbohydrates in excess, while all those with an adequate lipid intake had also an adequate carbohydrate intake. During the abundance season, there were fewer individuals with low lipid intake than during the scarcity season. Nevertheless, as many as 24% of those with low lipid intake, consumed excess carbohydrates while none of those with an adequate lipid intake did.

Table 18.7 shows energy intake per season and overall, for children and their mothers. Half of the children have hypercaloric diets during the scarcity season and three with isocaloric diets increase their caloric intake to hypercaloric ones during the abundance season. Unlike their children, mothers have a hypocaloric diet specially during the scarcity season. Four with hypocaloric diets increase caloric intake to an isocaloric diet during the abundance season, but only one with adequate caloric intake increases it to hypercaloric.

Table 18.6 Individual's diet adequacy evaluation: overall and per macronutrient for children and their mothers

Overall diet evaluation and by macronutrient			Relative frequency in % Children (n = 12)	Mothers (n = 16)	Total (n = 28)
Unbalanced diets	Scarcity	Unbalanced	58.30%	81.30%	71.40%
	Abundance	Unbalanced	41.70%	75%	60.70%
Protein	Scarcity	Deficient	–	–	–
		Adequate	100.00%	100.00%	100.00%
		Excess	–	–	–
	Abundance	Deficient	–	–	–
		Adequate	100.00%	100.00%	100.00%
		Excess	–	–	–
Carbohydrates	Scarcity	Deficient	–	–	–
		Adequate	58.30%	50.00%	53.60%
		Excess	41.70%	50.00%	46.40%
	Abundance	Deficient	–	–	–
		Adequate	75.00%	100.00%	85.70%
		Excess	25.00%	–	14.30%
Lipids	Scarcity	Deficient	58.30%	81.30%	71.40%
		Adequate	41.70%	18.80%	28.60%
		Excess	–	–	–
	Abundance	Deficient	41.70%	75.00%	60.70%
		Adequate	58.30%	25.00%	39.30%
		Excess	–	–	–

Table 18.7 Caloric adequacy by age group

	Children (n = 12)		Mothers (n = 16)		Total (n = 28)	
Adequacy	Scarcity	Abundance	Scarcity	Abundance	Scarcity	Abundance
Hypocaloric	8.30%	8.30%	68.80%	43.80%	42.90%	28.60%
Isocaloric	41.70%	16.70%	25.00%	43.80%	32.10%	32.10%
Hypercaloric	50.00%	75.00%	6.30%	12.50%	25.00%	39.30%

18.5.1 Microbiota Analysis

A total of 326,036 quality 16S sequences derived from composite samples from five individuals were analyzed by plotting rarefaction curves. In all samples the expected representability was reached (Fig. 18.3a). Microbial structure by age (infants and mothers), strategy (traditional and modern) and season (abundance and scarcity) were analyzed to determine alpha diversity, which resulted in statistically significant differences between infants and mothers in both seasons and strategies (Fig. 18.3b) but were larger between mothers and infants from modern families. Faith's phylogenetic diversity also shows significant differences between infants

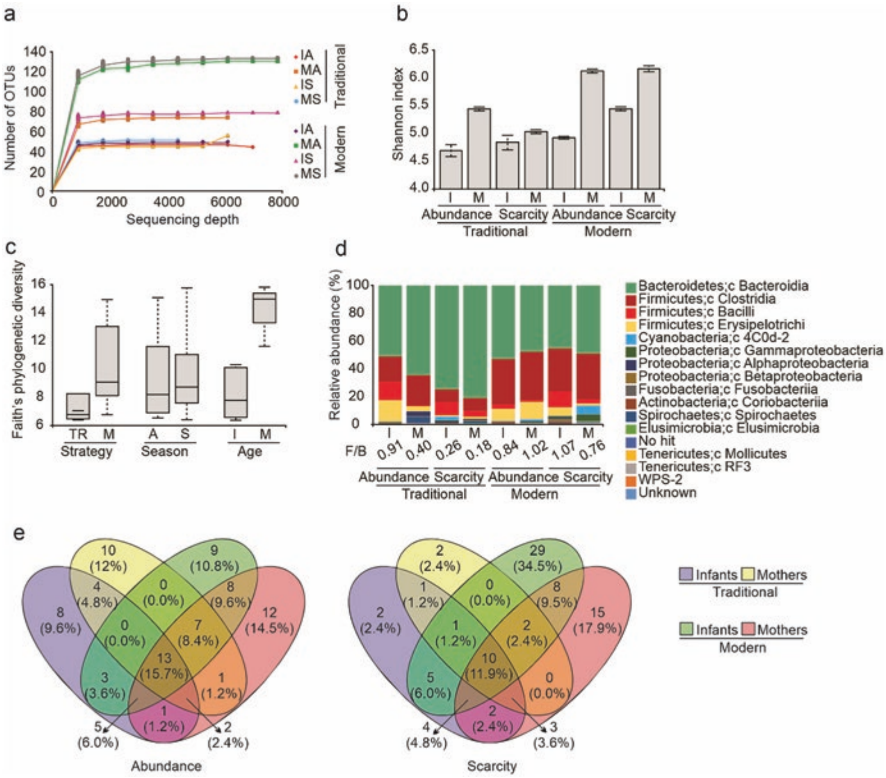

Fig. 18.3 Microbiota structure analysis. Panel (**a**) correspond to rarefaction curves from samples showing dots for 10 iterations per sampling sequence depth; (**b**) Alpha diversity per sample calculated by Shannon index. Error bars correspond to Standard Deviation of 10 iterations; (**c**) Faith's phylogenetic diversity plot as an expression of beta diversity; (**d**) relative abundance of dominant taxa at phylum or class (**c**) taxonomic level; (**e**) Venn diagrams showing taxa frequency by evaluated condition. (*I* Infants, *M* Mothers, *TR* Traditional, *TF* Transformed, *F/B* Firmicutes/Bacteroidetes ratio by absolute frequency per phylum)

and mothers (Fig. 18.3c). Species richness and relative abundance in evaluated samples showed differences between all analyzed conditions, however, strategy showed the greatest differences (Fig. 18.3d). Taxonomic assignment resulted in the identification of 108 species belonging to 75 genera, 38 families, 18 orders, 15 classes and 10 phyla of bacteria.

When Firmicutes/Bacteroidetes (F/B) ratio was calculated per sample, significant differences were found between strategies. Traditional samples had a value 0.518 in average while those from modern households averaged 0.958. In all samples, the bacterial community was dominated by the representatives of Bacteroidia class, particularly *Prevotella* sp., followed by Clostridia class, represented by Lachnospiraceae, and Ruminococcaceae family members. Venn plots show strong differences in exclusive bacteria species in each analyzed group (Fig. 18.3e), being the most significant the high number of exclusive species found in modern infants during the scarcity season (21 species belong to Firmicutes, 7 to Bacteroidetes and 1 to Proteobacteria Phyla), representing a F/B index of 3.92.

Finally, a Unifrac PCA analysis was run against protein, carbohydrate, and lipid intake. Because macronutrient intake was significantly different per season, cocktails from the same individuals but from different seasons were taken as independent samples. The results for each macronutrient are shown in Fig. 18.4a. Only lipids formed separate bacterial population clusters (Fig. 18.4b).

18.6 Discussion

Seasonal nutrient deficiencies are and most likely have been the norm amongst dry agriculturalists around the world. Unlike what has been proposed as a solution, abandonment of subsistence agriculture and increase dependence on store-bought foods has not solved the problem (Cantor et al., 2018; Gurri, 2020, 2015; Guthman, 2011; Kraft et al., 2018; Leatherman & Goodman, 2005; Leatherman et al., 2020; Little et al., 2016; Popkin, 2014). It appears that in the maize region of the state of Yucatan, transformation of subsistence agriculturalists has not had the desired effect

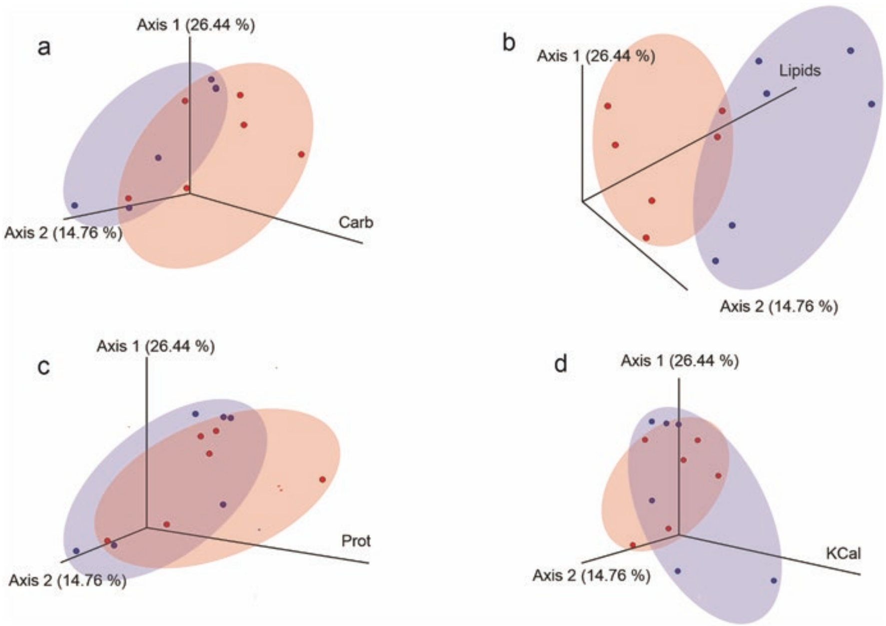

Fig. 18.4 Unifrac analysis. Principal Components Plot grouping samples by observed diversity plotted in relation to (**a**) carbohydrates; (**b**) lipids; (**c**) protein; or (**d**) Kcal intake. The seasonal samples were treated as independent

either. There are significant seasonal kcal intake differences between all individuals tested in the maize region. Significantly fewer protein, carbohydrate and lipids are consumed during the scarcity season. As expected, mothers consume more of each macronutrient in both seasons than their infants but there aren't any significant differences between productive strategies.

The sample used for this portions study was obtained from a larger number of households selected and classified by Gurri et al. (2021) a year earlier. In that sample, significant reductions in food diversity were found during the scarcity season in both modern and traditional households. While the effect was significantly more noticeable in modern households, all of them increased store-bought sugary product intake to make up for the lack of other food types during the scarcity season. The proportional increase in carbohydrate contribution to the diet during the scarcity season observed in this sample was likely the direct effect of this behavior.

Most diets were unbalanced particularly during the scarcity season. Protein intake was not a problem. Most individuals, however, had lipid deficient diets which they compensated with an excess in carbohydrate intake. Lipids play a central role in the building of metabolic capacity during growth in utero and during the first 36 months as they buffer the energy demands of the brain, confer immune function, secrete a variety of growth factors and facilitate the deposition of lean mass (Wells, 2010). Children from this sample would have been energy stressed and lipid deprived in utero as most of their mothers had hypocaloric diets year-round and more so during the scarcity season.

Nutritionally challenged fetuses are likely to be underweight babies and will experience catch-up growth during their first 24–36 months. During catch-up growth, unbalanced diets with excess carbohydrate intake will increase metabolic load favoring a thrifty phenotype (Wells, 2011). In the maize region of Yucatan, it seems, excess carbohydrate consumption is responsible for most of the children's hypercaloric diet, and this is particularly noticeable during the scarcity season when the perennial lipid deficiency worsens and is compensated by an increase in carbohydrate consumption.

In general, all samples had a highly diverse bacterial microbiota according to the Shannon Index (Spellerberg & Fedor, 2003). As expected, however, mother's greater macronutrient intake led to more diverse communities with more relative abundance of the taxa belonging to the phylum Firmicutes than their children. Firmicutes' diversity is significantly greater in mothers from modern households who consumed more processed carbohydrates than those from subsistence households. Higher abundance of Firmicutes has been related to obesogenic disorders (Ignacio et al., 2016). In these samples, significant differences found at the Class and Species levels between all categories contributed to larger F/B ratios in cocktails from modern households particularly during the scarcity season. For example, out of 29 unique species present in children with modern diet during the scarcity season, as many as 27 were Firmicutes.

Apparently, lipid intake contributed the most to the formation of separate bacterial population clusters. This is not surprising considering that more mothers were more lipid intake deprived than children and significant seasonal and age group differences in F/B ratios suggest that interrelationships between macronutrient composition and microbiota structure do exist. This, however, does not explain why both mother and child cocktails from different strategies should show different bacterial variability when there aren't any significant differences in macronutrient consumption between strategies. Maskarinec et al. (2019, 2021) suggested that food processing could play an important role in the gut microbiota composition of western populations consuming industrially processed foods and traditional communities who harvest and process their own. While these samples come from the same towns, compared to traditional households a larger proportion of the foods consumed by modern ones was purchased in grocery stores (Gurri et al., 2021). It is likely, therefore, that gut microbiota differences may also be responding to other environmental factors associated with food processing year-round rather than just macronutrient composition.

Lipid deficiency affects mothers and their children in the maize region, and this problem is exacerbated during the scarcity season. Increased dependence on store-bought foods has not solved the problem as mothers make up for their lack of lipids by purchasing cheap carbohydrate rich products leading to excess carbohydrate intake and hypocaloric diets in children. In addition to lipid deficiency, increased dependence on store-bought foods may have modified the structure and composition of their gut microbiota by substituting the intake of locally harvested food with industrialized and packaged consumables. In both cases, increase dependence on store-bought foods does not solve the nutritional deficiencies of agriculturalist mothers and their children but they do promote the conditions that lead to the selection of individuals with thrifty phenotypes amongst these Maya agriculturalist populations.

Acknowledgements The authors wish to thank the families that put up with this extremely intrusive type of study. They allowed us to visit their households more than once and did it always with a smile on their faces. We can only hope that our results will eventually help them and other members of their communities. We also wish to thank our field team Elizabeth Mena Fuentes, Lourdes Hernández Félix, Elma Heredia Campos, David Otero Prevost, Gabriela Ehuan Noh, and Verónica May Canul, Mónica Arcila Sánchez and Mónica Bustamante Cruz from our laboratory teams. Without them, this could never have been accomplished. Finally, the data was collected thanks to grant CB-CONACYT-240697 sanctioned by CONACYT, Mexico. The contents of this chapter are the exclusive responsibility of the authors.

References

Abay, K., & Hirvonen, K. (2017). Does market access mitigate the impact of seasonality on child growth? Panel data evidence from northern Ethiopia. *Journal of Development Studies, 53*(9), 1414–1429. https://doi.org/10.1080/00220388.2016.1251586

Anderzén, J., Guzmán Luna, A., Luna-González, D. V., Merrill, S. C., Caswell, M., Méndez, V. E., Hernández Jonapá, R., & Mier y Terán Giménez Cacho, M. (2020). Effects of on-farm diversification strategies on smallholder coffee farmer food security and income sufficiency in Chiapas, Mexico. *Journal of Rural Studies, 77*(1), 33–46. https://doi.org/10.1016/j.jrurstud.2020.04.001

Atran, S., Chase, A., Fedick, S., Knapp, G., McKillop, S., Marcus, J., Schwartz, N., & Webb, M. (1993). Itza maya tropical agro-forestry. *Current Anthropology, 34*(5), 633–700. https://doi.org/10.1086/204212

Atwater, W. O., & Bryant, A. P. (1900). *The availability and fuel value of food materials*. Experimental Station 12th Annual Report (pp. 73–110). US Government Printing Office.

Azcorra, H., Rodríguez, L., Varela-Silva, M. I., Datta Banik, S., & Dickinson, F. (2015). Intergenerational changes in knee height among Maya mothers and their adult daughters from Merida, Mexico. *American Journal of Human Biology, 27*(6), 792–797. https://doi.org/10.1002/ajhb.22752

Bacon, C. M., Sundstrom, W. A., Flores Gómez, M. E., Ernesto Méndez, V., Santos, R., Goldoftas, B., & Dougherty, I. (2014). Explaining the "hungry farmer paradox": Smallholders and fair trade cooperatives navigate seasonality and change in Nicaragua's corn and coffee markets. *Global Environmental Change, 25*(1), 133–149. https://doi.org/10.1016/j.gloenvcha.2014.02.005

Becerra-Lucio, A. A., Labrín-Sotomayor, N. Y., Becerra-Lucio, P. A., Trujillo-Elisea, F. I., Chávez-Bárcenas, A. T., Machkour-M'Rabet, S., & Peña-Ramírez, Y. J. (2021). Diversity and interactomics of bacterial communities associated with dominant trees during tropical forest recovery. *Current Microbiology, 78*(9), 3417–3429. https://doi.org/10.1007/s00284-021-02603-9

Biing-Hwan, L., Ver Ploeg, M., Kasteridis, P., & Yen, S. T. (2014). The roles of food prices and food access in determining food purchases of low-income households. *Journal of Policy Modeling, 36*(5), 938–952. https://doi.org/10.1016/j.jpolmod.2014.07.002

Bustillos, B., Sharkey, J. R., Anding, J., & McIntosh, A. (2009). Availability of more healthful food alternatives in traditional, convenience, and nontraditional types of food stores in two rural Texas counties. *Journal of the American Dietetic Association, 109*(5), 883–889. https://doi.org/10.1016/j.jada.2009.02.011

Cantor, A. R., Chan, I., & Baines, K. (2018). From the chacra to the tienda: Dietary delocalization in the Peruvian Andes. *Food and Foodways, 26*(3), 198–222. https://doi.org/10.1080/07409710.2018.1490376

Caporaso, J. G., Kuczynski, J., Stombaugh, J., Bittinger, K., Bushman, F. D., Costello, E. K., Fierer, N., Peña, A. G., Goodrich, J. K., Gordon, J. I., Huttley, G. A., Kelley, S. T., Knights, D., Koenig, J. E., Ley, R. E., Lozupone, C. A., McDonald, D., Muegge, B. D., Pirrung, M., Reeder, J., Sevinsky, J., Turnbaugh, P., Walters, W., Widmann, J., Zaneveld, J., & Knight, R. (2010). QIIME allows analysis of high-throughput community sequencing data. *Nature Methods, 7*(5), 335–336. https://doi.org/10.1038/nmeth.f.303

Chen, Z., Radjabzadeh, D., Ikram, A., Uitterlinden, A., Kraaij, R., & Voortman, T. (2020). Dietary patterns and gut microbiome composition in a large population-based cohort. *Current Developments in Nutrition, 4*(Supplement_2), S514–S514. https://doi.org/10.1093/cdn/nzaa046_014

Davis, J. A., Collier, F., Pasco JA, M. M., Shivappa, N., Hébert, J. R., Jacka, F. N., & Loughman, A. (2021). The associations of butyrate-producing bacteria of the gut microbiome with diet quality and muscle health. *Gut Microbiome, 2*(2), 1–18. https://doi.org/10.1017/gmb.2021.2

Fanzo, J., Hunter, D., Borelli, T., & Mattei, F. (2013). Introduction: Agricultural biodiversity, diverse diets and improving nutrition. In J. Fanzo, D. Hunter, T. Borelli, & F. Mattei (Eds.), *Diversifying food and diets: Using agricultural biodiversity to improve nutrition and health* (pp. 1–14). Routledge.

FAO (Food and Agriculture Organization). (1962). *El Estado Mundial de la Agricultura y la Alimentación*. ONU.

FAO (Food and Agriculture Organization). (2005). Human energy requirements. Scientific background papers from the Joint FAO/WHO/UNU Expert Consultation. October 17–24, 2001. *Public health nutrition, 8*(7A), 929–1228. https://doi.org/10.1079/phn2005778

Frisancho, A. R. (1990). *Anthropometric standards for the assessment of growth and nutritional status*. University of Michigan Press.

Frisancho, A. R. (2009). Developmental adaptation: Where we go from here. *American Journal of Human Biology, 21*(5), 694–703. https://doi.org/10.1002/ajhb.20891

Fung, H. Y. J., Fu, S.-C., Brautigam, C. A., & Chook, Y. M. (2015). Structural determinants of nuclear export signal orientation in binding to exportin CRM1. *eLife, 4*, E10034. https://doi.org/10.7554/eLife.10034.001

García-Frapolli, E., Toledo, V. M., & Martinez-Alier, J. (2008). Adaptations of a yucatec Maya multiple-use ecological management strategy to ecotourism. *Ecology and Society, 13*(2), 31. https://doi.org/10.5751/ES-02627-130231

Gates, M. (1993). *In default: Peasants, the debt crisis, and the agricultural challenge in Mexico*. Routledge.

Golden, C. D., Vaitla, B., Ravaoliny, L., Vonona, M. A., Anjaranirina, E. J. G., Randriamady, H. J., Glahn, R. P., Guth, S. E., Fernald, L. C. H., & Myers, S. S. (2019). Seasonal trends of nutrient intake in rainforest communities of North-Eastern Madagascar. *Public Health Nutrition, 22*(12), 1–10. https://doi.org/10.1017/s1368980019001083

Gurri, F. D. (2010). Smallholder land use in the southern Yucatan: How culture and history matter. *Regional Environmental Change, 10*(3), 219–231. https://doi.org/10.1007/s10113-010-0114-8

Gurri, F. D. (2015). The disruption of subsistence agricultural systems in rural Yucatan, Mexico may have contributed to the coexistence of stunting in children with adult overweight and obesity. *Collegium Antropologicum, 39*(4), 847–854. PMID: 26987151.

Gurri, F. D. (2020). Agricultural transformation and ontogeny in rural populations from the Yucatan peninsula at the turn of the century: Studying Linear Enamel Hypoplasias and Body Composition in Adolescents. In H. Azcorra & F. Dickinson (Eds.), *Culture, Environment and Health in the Yucatan Peninsula: A Human Ecology Perspective* (pp. 137–158). Springer. https://doi.org/10.1007/978-3-030-27001-8_8

Gurri, F. D., & Balam, G. (1992). Regional integration and changes in nutritional status in the central region of Yucatan, Mexico: A study of dental eneamel hypoplasia and anthropometry. *Journal of Human Ecology, 3*(2), 417–432.

Gurri, F. D., Ruiz-García, W., Aragón-Medina, K. G., Vallejo-Nieto, M. I., & Molina-Rosales, D. O. (2019). *Tabla de Valor Nutrimental de los Alimentos Consumidos en la Zona Maicera de Yucatán* (p. 17). CONACYT- ECOSUR.

Gurri, F. D., Ruiz-García, W., Vallejo-Nieto, M. I., & Molina-Rosales, D. O. (2021). Effect of seasonality on food access in subsistence and cash dependent Maya households in large and small rural communities in Yucatan, Mexico. *Agroecology and Sustainable Food Systems, 46*, 1–26. https://doi.org/10.1080/21683565.2021.1930623

Guthman, J. (2011). *Weighing in obesity, food justice, and the limits of capitalism*. University of California Press.

Hales, C. N., & Barker, D. J. P. (2001). The thrifty phenotype hypothesis: Type 2 diabetes. *British Medical Bulletin, 60*(1), 5–20. https://doi.org/10.1093/bmb/60.1.5

Hales, C. N., & Barker, D. J. P. (2013). Type 2 (non-insulin-dependent) diabetes mellitus: The thrifty phenotype hypothesis. *International Journal of Epidemiology, 42*(5), 1215–1222. https://doi.org/10.1093/ije/dyt133

Hirvonen, K., Taffesse, A. S., & Hassen, W. I. (2015). Seasonality and household diets in Ethiopia. *Public Health Nutrition, 13*, 1–8. https://doi.org/10.1017/S1368980015003237

Hirvonen, K., Hoddinott, J., Minten, B., & Stifel, D. (2017). Children's diets, nutrition knowledge, and access to markets. *World Development, 95*, 303–315. https://doi.org/10.1016/j.worlddev.2017.02.031

Hoffman, J., Sawaya, A., Verreschi, I., Tucker, K., & Roberts, S. (2000). Why are nutritionally stunted children at increased risk of obesity? Studies of metabolic rate and fat oxidation in shantytown children from Sao Paulo, Brazil. *American Journal of Clinical Nutrition, 72*(3), 702–707. https://doi.org/10.1093/ajcn/72.3.702

Ignacio, A., Fernandes, M. R., Rodrigues, V. A. A., Groppo, F. C., Cardoso, A. L., Ávila-Campos, M. J., & Nakano, V. (2016). Correlation between body mass index and faecal microbiota from children. *Clinical Microbiology and Infection, 22*(3), 258–258.e8. https://doi.org/10.1016/j.cmi.2015.10.031

Khandker, S. R. (2012). Seasonality of income and poverty in Bangladesh. *Journal of Development Economics, 97*(2), 244–256. https://doi.org/10.1016/j.jdeveco.2011.05.001

Kraft, T. S., Stieglitz, J., Trumble, B. C., Martin, M., Kaplan, H., & Gurven, M. (2018). Nutrition transition in 2 lowland Bolivian subsistence populations. *American Journal of Clinical Nutrition, 108*(6), 1183–1195. https://doi.org/10.1093/ajcn/nqy250

Lachat, C., Raneri, J. E., Smith, K. W., Kolsteren, P., van Damme, P., Verzelen, K., Penafiel, D., Vanhove, W., Kennedy, G., Hunter, D., Odhiambo, F. O., Ntandou-Bouzitou, G., de Baets, B., Ratnasekera, D., Ky, H. T., Remans, R., & Termote, C. (2018). Dietary species richness as a measure of food biodiversity and nutritional quality of diets. *Proceedings of the National Academy of Sciences of the United States of America, 115*(1), 127–132. https://doi.org/10.1073/pnas.1709194115

Leatherman, T. L., & Goodman, A. (2005). Coca-colonization of diets in the Yucatan. *Social Science & Medicine, 61*(4), 833–846. https://doi.org/10.1016/j.socscimed.2004.08.047

Leatherman, T., Goodman, A. H., & Stillman, J. T. (2020). A critical biocultural perspective on tourism and the nutrition transition in the Yucatan. In H. Azcorra & F. Dickinson (Eds.), *Culture, environment and health in the Yucatan Peninsula*. Springer.

Liese, A. D., Weis, K. E., Pluto, D., Smith, E., & Lawson, A. (2007). Food stores types, availability, and cost of foods in a rural environment. *Journal of American Dietetic Association, 107*(11), 1916–1923. https://doi.org/10.1016/j.jada.2007.08.012

Little, M., Humphries, S., Patel, K., & Dewey, C. (2016). Decoding the type 2 diabetes epidemic in rural India. *Medical Anthropology, 36*(2), 96–110. https://doi.org/10.1080/01459740.2016.1231676

Lope-Alzina, D. G. (2017). Cuatro décadas de estudio en huertos familiares maya- yucatecos: Hacia la comprensión de su variación y complejidad. *Gaia Scientia, 11*(3), 160–184. https://doi.org/10.21707/gs.v11.n03a013

Madan, E. M., Haas, J. D., Menon, P., & Gillespie, S. (2018). Seasonal variation in the proximal determinants of undernutrition during the first 1000 days of life in rural South Asia: A comprehensive review. *Global Food Security, 19*(3), 11–23. https://doi.org/10.1016/j.gfs.2018.08.008

Mahmudiono, T., Sumarmi, S., & Rosenkranz, R. R. (2017). Household dietary diversity and child stunting in East Java, Indonesia. *Asia Pacific Journal of Clinical Nutrition, 26*(2), 317–325. https://doi.org/10.6133/apjcn.012016.01

Maskarinec, G., Hullar, M. A. J., Monroe, K. R., Shepherd, J. A., Hunt, J., Randolph, T. W., Wilkens, L. R., Boushey, C. J., Le Marchand, L., Lim, U., & Lampe, J. W. (2019). Fecal microbial diversity and structure are associated with diet quality in the multiethnic cohort adiposity phenotype study. *The Journal of Nutrition, 149*(9), 1575–1584. https://doi.org/10.1093/jn/nxz065

Maskarinec, G., Raquinio, P., Kristal, B. S., Setiawan, V. W., Wilkens, L. R., Franke, A. A., Lim, U., Marchand, L. L., Randolph, T. W., Lampe, J. W., & Hullar, M. A. J. (2021). The gut microbiome and type 2 diabetes status in the multiethnic cohort. *PLoS One, 16*(6), e0250855. https://doi.org/10.1371/journal.pone.0250855

Milani, C., Duranti, S., Bottacini, F., Casey, E., Turroni, F., Mahony, J., Belzer, C., Delgado Palacio, S., Montes, S. A., Mancabelli, L., Lugli, G. A., Rodriguez, J. M., Bode, L., de Vos, W., Gueimonde, M., Margolles, A., van Sinderen, D., & Ventura, M. (2017). The first microbial colonizers of the human gut: Composition, activities, and health implications of the infant gut microbiota. *Microbiology and Molecular Biology Reviews, 81*(4), 1–67. https://doi.org/10.1128/MMBR

M'Kaibi, F. K., Steyn, N. P., Ochola, S., & Du Plessis, L. (2015). Effects of agricultural biodiversity and seasonal rain on dietary adequacy and household food security in rural areas of Kenya. *BMC Public Health, 15*(1), 422. https://doi.org/10.1186/s12889-015-1755-9

Muñoz de Chávez M (2010) Composición de Alimentos. In *Valor Nutritivo de los Alimentos de Mayor Consumo* (p. 420). McGraw-Hill.

Nithya, D. J., & Bhavani, R. V. (2017). Dietary diversity and its relationship with nutritional status among adolescents and adults in rural India. *Journal of Biosocial Science, 50*(3), 397–413. https://doi.org/10.1017/S0021932017000463

Oliveros, J. C. (2007–2015). *Venny*. An Interactive Tool for Comparing Lists with Venn's Diagrams. https://bioinfogp.cnb.csic.es/tools/venny/index.html

Ortega, R. M., Pérez-Rodrigo, C., & López-Sobaler, A. M. (2015). Métodos de evaluación de la ingesta actual: Registro o diario dietético. *Revista Española de Nutrición Comunitaria, 21*(Supl. 1), S34–S41. https://doi.org/10.3305/nh.2015.31.sup3.8749

Otero Prevost, D. E., Gurri, F. D., Mariaca Méndez, R., & Guízar Vázquez, F. (2017). La incorporación y el aumento de oferta de alimentos industrializados en las dietas de las unidades domésticas y su relación con el abandono del sistema de subsistencia propio en las comunidades rurales mayas de Yucatán, México. *Cuadernos de Desarrollo Rural, 14*(80), 1–16. https://doi.org/10.11144/javeriana.cdr14-80.iaoa

Pinheiro, F. A., & Atalah, E. (2005). Propuesta de una metodología de análisis de la calidad global de la alimentación. *Revista Medica De Chile – REV MED CHILE*, 133, 175–182. https://doi.org/10.4067/S0034-98872005000200004

Popkin, B. M. (2014). Nutrition, agriculture and the global food system in low and middle income countries. *Food Policy, 47*, 91–96. https://doi.org/10.1016/j.foodpol.2014.05.001

Re Cruz, A. (1996). The two Milpas of Chan Kom: A study of socioeconomic and political transformations in a maya community. *State University of New York Press., 100*, 230–231. https://doi.org/10.1525/aa.1998.100.1.230

Sharkey, J. R., Dean, W. R., & Nalty, C. (2012). Convenience stores and the marketing of foods and beverages through product assortment. *American Journal of Preventive Medicine, 43*(3), S109–S115. https://doi.org/10.1016/j.amepre.2012.05.012

Sharkey, J. R., Dean, W. R., Nalty, C., & Xu, J. (2013). Convenience stores are the key food environment influence on nutrients available from household food supplies in Texas Border Colonias. *Public Health, 13*(45), 1–8. https://doi.org/10.1186/1471-2458-13-45

Sibhatu, K. T., & Qaim, M. (2017). Rural food security, subsistence agriculture, and seasonality. *PLoS One, 12*(10), 1–15. https://doi.org/10.1371/journal.pone.0186406

Sohn, Y., Moran, E., & Gurri, F. D. (1999). Deforestation in North-Central Yucatan (1985–1995): Mapping secondary succession of forest and agricultural land use in Sotuta using the cosine of the angle concept. *Photogrammetric Engineering and Remote Sensing, 65*(8), 947–958.

Spellerberg, I. F., & Fedor, P. J. (2003). A tribute to Claude Shannon (1916–2001) and a plea for more rigorous use of species richness, species diversity and the "Shannon-Wiener" Index. *Global Ecology and Biogeography, 12*(3), 177–179. https://doi.org/10.1046/j.1466-822X.2003.00015.x

Suverza, A. (2010). *El ABCD de la Evaluación del Estado de Nutrición* (p. 349). McGRAW-HILL Interamericana Editores.

Terán, S., & Rasmussen, C. H. (2009). *La Milpa de los Mayas: La Agricultura de los Mayas Prehispánicos y Actuales en el Noroeste de Yucatán* (p. 396). UNAM.

Tuz Chi, L. H. (2013). *Aj balam yúumtsilo'ob: Cosmovisión e Identidad en los Rituales Agrícolas de los Mayas Peninsulares* (p. 337). Secretaría de Educación del Gobierno del Estado de Yucatán.

Villanueva, E. M. (1994). *La Formación de las Regiones en la Agricultura: El caso de Yucatán* (p. 275). Maldonado Editores.

Wells, J. C. K. (2010). *The evolutionary biology of human body fatness: Thrift and control* (pp. 179–187). Cambridge University Press. https://doi.org/10.1017/CBO9780511691843

Wells, J. C. K. (2011). The thrifty phenotype: An adaptation in growth or metabolism? *American Journal of Human Biology: The Official Journal of the Human Biology Council, 23*(1), 65–75. https://doi.org/10.1002/ajhb.21100

Chapter 19
Parasitic Infection, Obesity, and Micronutrient Deficiencies in School-Aged Children in Mexico

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19.1 Introduction

Intestinal parasitic infections (PI) are a global health concern, particularly in children. The PI are among the most common infectious diseases in humans worldwide, and combined with obesity and micronutrient deficiencies, account for more than 10% of the global disability-adjusted-life-years (DALY's) (Black et al., 2013; Ng et al., 2014).

Intestinal PI are known to cause micronutrient deficiencies because of their effect on nutrient absorption, dysbiosis, anorexia and nutrient loss (Katona & Katona, 2008). Micronutrient deficiencies are also known to increase the risk of infections, thus, creating a cycle that affects millions of children around the world (Bhaskaram,

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S. Datta Banik (ed.), *Human Growth and Nutrition in Latin American and Caribbean Countries*, https://doi.org/10.1007/978-3-031-27848-8_19

2002; Katona & Katona, 2008; Stephenson et al., 2000). It is well recognized that PI is strongly related with high rates of undernutrition, particularly in children from low- and middle-income countries with limited access to health services. The most common micronutrients studied in relation to PI have been zinc, iron and vitamin A (de Gier et al., 2014), and little is known of the relationship of PI with other micronutrients, such as vitamins C, D or E that are important to maintain an adequate immune response (Maggini et al., 2007).

There is little information available on the effects of intestinal PI in populations with high prevalence of overweight and obesity. Also, there is limited information regarding the effect of PI in populations that in addition have micronutrient deficiencies. Like many countries in Latin America, Mexico has a high prevalence of micronutrient deficiencies and of PI. In addition, it has one of the highest rates of obesity in the world. Thus, coexistence of these three conditions is not only probable, but also a reality, and its consequences remain to be confirmed.

In this chapter, the epidemiology of PI, micronutrient deficiencies and obesity in rural Mexico is described. The relationship of PI and micronutrients in a population with high rates of obesity is also discussed.

19.2 Epidemiology of PI, Micronutrient Deficiencies and Obesity

Intestinal PI have been among the leading causes of morbidity and mortality in the world, and highly prevalent in populations around the world. They affect mainly children living in low- and middle-income countries, with tropical and subtropical weather. The intestinal PI are caused by soil transmitted helminths (STHs) and intestinal protozoan. The main intestinal parasites that cause infections in humans are shown in Table 19.1.

In Mexico, between 30% and 70% of the children have intestinal PI (Diaz et al., 2003; Morales et al., 2003; Quihui et al., 2006). The highest prevalence has been observed in the southern regions of the country. In Querétaro, a state in the plateau region in Mexico, the overall reported prevalence of PI in school-aged children from rural communities was reported to be 61% (Zavala et al., 2016). In these communities, STHs infection was 19%, and *A. lumbricoides* had the highest prevalence with 16%. A total of 47% had a protozoan infection, and the two most common were *Entamoeba coli* (20%) and *Endolimax nana* (16%). The prevalence of *E. histolytica*

Table 19.1 Main intestinal parasites that cause infections in humans

Soil transmitted helminths	Intestinal protozoan
Ascaris lumbricoides (roundworm)	*Giardia lamblia*
Trichuris trichuria (whipworm)	*Entamoeba histolytica/dispar*
Necator americanus and *Ancycostoma duodenale* (hookworm)	

Source: World Health Organization (WHO, 2013) and *Giardia lamblia* was <6%. Thus, the main protozoan infections among these children were from non-pathogenic protozoans.

In addition to the high prevalence of intestinal PI, the prevalence of micronutrient deficiencies among children in Mexico is still present. The prevalence of anemia in 5–11 years old children is 19%, and among 1–4 years old children is almost 30%. At least one micronutrient deficiency is associated with anemia in approximately 19% and 13% of preschoolers and school-aged children, respectively (De la Cruz-Góngora et al., 2021).

One of the major public health concerns in Mexico, and other countries in Latin America, is the rapid increase in childhood obesity. According to the latest national data, prevalence of overweight among <5-year-old children is 6.8%, and the combined prevalence of overweight and obesity of school-aged children is 35.5% (Shamah-Levy et al., 2020). Obesity is higher among school-aged boys (20.1%) compared to school-aged girls (15%) and are of the highest in the world. In rural areas, the prevalence of obesity among boys and girls has increased in the past years, but the prevalence of overweight has increased more in girls compared to boys (Shamah-Levy et al., 2020). In Queretaro, more than 50% of school-aged children have been reported to have high body fat (Zavala et al., 2018).

The co-existence of obesity, PI and micronutrient deficiencies represent a burden on the health care system in Mexico. It is important to consider that 46% of the Mexican population is living in poverty, which increases the risk of these conditions (CONEVAL, 2020). In addition, living with obesity, micronutrient deficiencies and PI are related with low-grade systemic inflammation, impaired growth and development, and both short- and long-term metabolic consequences (Barrera et al., 2016; Zavala et al., 2013).

19.3 Parasitic Infections, Obesity and Food Intake

The studies of PI have focused on their effects on children's growth and nutrition, mainly due to anorexia, nutrient malabsorption, increased blood loss, nutrient competition and lately, it has also been attributed to the altered composition of the gut microbiota or dysbiosis (Duedu et al., 2015; Nguyen et al., 2012; Oriá et al., 2016; Schaible & Stefan, 2007). For instance, *A. lumbricoides* has consistently been associated with lower BMI z-score (BMIz) and growth impairment (Hall et al., 2008; Papier et al., 2014). There is also evidence of the effect of giardiasis on stunting and impaired psychomotor development in children (Prado et al., 2005; Simsek et al., 2004).

It has been observed that infections with some virus and bacteria may also increase the risk of overweight and obesity (Atkinson, 2008; Yang et al., 2013). Recently, it was found that school-aged children from rural Mexico that had moderate/heavy infection with the "non-pathogenic" *Entamoeba coli* (*E. coli*) had increased body fat (Zavala et al., 2016). There are several mechanisms that may explain this association. As mentioned before, *E. coli*, as other protozoan, may cause alterations in the composition of the gut microbiome, which in turn, cause gut permeability (Oriá et al., 2016). Dysbiosis has been reported to increase energy intake, and thus, increase the risk of obesity (Gangarapu et al., 2014; Sánchez et al., 2014). In addition, gut permeability increases both intestinal and systemic inflammation, which may increase the risk of other non-communicable diseases such as diabetes and hypertension (Cox et al., 2015).

It is well documented that intestinal PI reduce food intake because it may cause reduced appetite and anorexia (Schaible & Stefan, 2007). However, evidence on the effect that PI may cause food intake in populations with a high prevalence of obesity is scarce. In rural Mexico, infection with *E. coli* was associated with higher food intake in children (Zavala et al., 2017). The dysbiosis caused by intestinal PI, specifically *E. coli*, may increase food intake and may even change food preferences, possibly caused by the effect that gut microbiota has on appetite regulation (Byrne et al., 2015; Sánchez et al., 2014). Also, the inflammation observed during PI infections may be another mechanism that increases food intake mainly due to its effect on appetite (Cani et al., 2009). The mechanisms involving the role of *E. coli* in the development of obesity and increased food intake should be studied further.

19.4 Parasitic Infections and Micronutrients

Most of the evidence in Mexico of the relationship between micronutrients and intestinal PI have focused on undernourished populations and only a few micronutrients have been studied, such as iron, zinc, and vitamin A (Rosado et al., 2009; Vazquez-Garibay et al., 2002). For instance, in Mexico, low vitamin A concentrations have been observed in children infected with *G. lamblia* (Quihui-Cota et al., 2008). In both the northwest and the central Pacific coast of Mexico, *T. trichuria* infection has been related to low iron concentrations (Quihui-Cota et al., 2010a, Gutierrez-Rodríguez et al., 2007). Also in the northwest, school-aged children infected with *G. lamblia* were considered at risk of zinc deficiency (Quihui et al., 2010b).

The effect that PI have on vitamins and mineral status is well documented and may be attributed to several mechanisms. Intestinal PI decrease appetite, decrease micronutrient absorption by increasing gut permeability, increase both intestinal and systemic inflammation, and increase blood losses (Hesham et al., 2004; Toro et al., 2019; Zavala et al., 2018). The effect on the human host may vary according to the parasite. For instance, infection with *G. lamblia* or with *A. lumbricoides* have been observed to decrease vitamin A absorption (Astiazaran-García et al., 2010; Strunz et al., 2016). In case of iron, STH and protozoa infections have been observed to interfere with iron metabolism, increase blood loss, decrease iron absorption and increase the risk of iron deficiency anemia in children (Shaw & Friedman, 2011).

It is important to consider that micronutrient deficiencies also increase the risk of intestinal PI (Katona & Katona-Apte, 2008). It is well recognized that malnutrition, including micronutrient deficiencies, impair the immune response and thus, the risk of infection is higher. The PI, in turn, increases the risk of malnutrition and micronutrient deficiencies, causing a vicious cycle that affects growth, cognitive development and overall health outcomes in children.

There is limited information regarding other micronutrients and PI. In a rural population of central Mexico, our research group found higher iron and B12 concentration in school-aged children infected with *E. coli* and *E. nana*, compared to non-infected children, probably due to a higher reported intake of foods, mainly animal food sources (data not published). More research is needed to explore how PI affect the status of other micronutrients.

19.5 Parasitic Infections and Micronutrients, Obesity

Elevated body fat, PI, and micronutrient deficiencies were present in approximately 14% of school-aged children living in rural Mexico. A total of 20% of the children with obesity and 12% of children with micronutrient deficiencies had PI with at least one parasite. In this population, the association between intestinal parasites and micronutrients, specifically zinc and vitamin A, differed between children with normal body weight and obesity, suggesting a complex relationship between these three public health problems.

It is important to consider that all three of these conditions, obesity, intestinal PI and micronutrient deficiency, have a direct effect on local (intestine) and systemic inflammatory processes in the body. Alterations in the immune response and increased concentration of pro-inflammatory markers may induce obesity and as mentioned before, other non-communicable diseases such as type II diabetes and hypertension (Esser et al., 2014). This is true for both pathogenic and non-pathogenic parasites. *E. coli*, for instance, has been associated with gut inflammation in children, even when it is considered a non-pathogenic parasite, and may cause health problems in the future, particularly in populations with a high prevalence of obesity (Zavala et al., 2018). Further research is needed to explore the relationship and possible mechanisms of the coexistence of micronutrient deficiencies, parasites and obesity.

19.6 Policy and Public Health Implications

Approximately 60% of school-aged children in rural areas from central Mexico are infected with IP, and more than 70% have some type of malnutrition (i.e.: micronutrient deficiencies or obesity). According to recent information, some IP may be contributing to the rapid increase in the prevalence of obesity. Thus, policy makers should consider, that not only undernourished but also populations with obesity may be affected by intestinal PI, and the consequences of this infection may vary with specific parasites. The same may be occurring in other countries of Latin America, where intestinal PI, obesity and micronutrient deficiencies are highly prevalent. Public health programs are urgently needed to address these three conditions, not as separate health problems, but as one. In order to address these health problems, a multidisciplinary approach will be needed to reduce the burden of PI, reduce the rates of obesity and decrease the prevalence of micronutrient deficiency in rural Mexico and other low- and middle-income countries.

Also, public health programs and policy makers should consider that the environment is key to the development of these three conditions: PI, obesity and micronutrient deficiency. Nutrition transition in Mexico and other countries because of globalization, has changed food systems and food patterns (Cuevas García-Dorado et al., 2019). The food environment has been related to obesity in rural Mexico due to the increased intake of high energy affordable foods with low nutritional quality (Zavala et al., 2021). Thus, effective public health programs and policies should include improvement in food environments, living conditions (hygiene, access to water), mass anti-parasitic treatment and education (Asaolu & Ofoeri, 2003; Davis et al., 2007).

19.7 Conclusions

In Mexico, as in other parts of Latin America, the prevalence of obesity, intestinal PI and micronutrient deficiencies are high. Some PI, such as infections with *E. coli*, may be increasing the risk of obesity and increased food intake in school-aged children living in rural Mexico. Also, the relationship of micronutrients deficiencies and PI may change depending on body fat content. Coexistence of obesity, PI and micronutrient deficiencies may occur in children living in rural areas with poor hygiene, limited access to health services, and with a diet high in calories and low in micronutrients. More studies are needed to explore the consequences of PI in populations with high prevalence of obesity and micronutrient deficiencies. Also, studies should also evaluate the coexistence of obesity, micronutrient deficiencies and PI in different contexts and different communities in Mexico and other countries in Latin America. The existence of these three conditions should be considered when planning health and community development programs to reduce the burden of PI, obesity and micronutrient deficiencies.

Acknowledgements The authors would like to aknowledge the participants of the studies conducted in rural Mexico.

References

Asaolu, S., & Ofoezie, I. (2003). The role of health education and sanitation in the control of helminth infections. *Acta Tropica, 86*(2), 283–294. https://doi.org/10.1016/S0001-706X(03)00060-3

Astiazaran-Garcia, H., Lopez-Teros, V., Valencia, M. E., Vazquez-Ortiz, F., Sotelo-Cruz, N., & Quihui-Cota, L. (2010). Giardia lamblia infection and its implications for vitamin A liver stores in school children. *Annals of Nutrition and Metabolism, 57*, 228–233. https://doi.org/10.1159/000321682

Atkinson, R. L. (2008). Could viruses contribute to the worldwide epidemic of obesity? *International Journal of Pediatric Obesity*, *3*(Suppl 1), 37–43. https://informahealthcare.com/doi/abs/10.1080/17477160801896754

Barrera, L. H., Rothenberg, S. J., Barquera, S., & Cifuentes, E. (2016). The toxic food environment around elementary schools and childhood obesity in Mexican cities. *American Journal of Preventive Medicine, 51*, 264–270. https://doi.org/10.1016/j.amepre.2016.02.021

Bhaskaram, P. (2002). Micronutrient malnutrition, infection, and immunity: An overview. *Nutrition Reviews, 60*, S40–S45. https://doi.org/10.1301/00296640260130722

Black, R. E., Victora, C. G., Walker, S. P., Butta, Z. A., Christian, P., De Onis, M., Ezzti, M., Grantham-McGregor, S., Katz, J., Martorell, R., Uauy, R., & Maternal and Child Nutrition Study Group. (2013). Maternal and child undernutrition and overweight in low-income and middle-income countries. *The Lancet, 382*, 427–451. https://doi.org/10.1016/S0140-6736(13)60937-X

Byrne, C. S., Chambers, E. S., Morrison, D. J., & Frost, G. (2015). The role of short chain fatty acids in appetite regulation and energy homeostasis. *International Journal of Obesity, 39*(9), 1331. https://doi.org/10.1038/ijo.2015.84

Cani, P. D., Lecourt, E., Dewulf, E. M., Sohet, F. M., Pachikian, B. D., Naslain, D., De Backer, F., Neyrinck, A. M., & Delzenne, N. M. (2009). Gut microbiota fermentation of prebiotics increases satietogenic and incretin gut peptide production with consequences for appetite sensation and glucose response after a meal. *American Journal of Clinical Nutrition, 90*(5), 1236–1243. https://doi.org/10.3945/ajcn.2009.28095

CONEVAL. (2020). *Resultados de pobreza en México 2020 a nivel nacional y por entidades federativas*. Consejo Nacional de Evaluación de la Política de Desarrollo Social, México. Retrieved January 3, 2022, from https://www.coneval.org.mx/Medicion/Paginas/PobrezaInicio.aspx

Cox, A. J., West, N. P., & Cripps, A. W. (2015). Obesity, inflammation, and the gut microbiota. *Lancet Diabetes Endocrinology, 3*(3), 207–215. https://doi.org/10.1016/S2213-8587(14)70134-2

Cuevas García-Dorado, S., Cornselsen, L., Smith, R., & Walls, H. (2019). Economic globalization, nutrition and health: A review of quantitative evidence. *Globalization and Health, 15*, 15. https://doi.org/10.1186/s12992-019-0456-z

Davis, M. M., Gance-Cleveland, B., Hassink, S., Johnson, R., Paradis, G., & Resnicow, K. (2007). Recommendations for prevention of childhood obesity. *Pediatrics, 120*(Supplement 4), S229–S253. https://doi.org/10.1542/peds.2007-2329E

de Gier, B., Campos-Ponce, M., van de Bor, M., Doak, C. M., & Polman, K. (2014). Helminth infections and micronutrients in school-age children: A systematic review and meta-analysis. *American Journal of Clinical Nutrition, 99*, 1499–1509. https://doi.org/10.3945/ajcn.113.069955

De la Cruz-Góngora, V., Martínez-Tapia, B., Shamah-Levy, T., & Villalpando, S. (2021). Nutritional status of iron, vitamin B12, vitamin A and anemia in Mexican children: Results from the Ensanut 2018–19. *Salud Publica de Mexico, 63*, 359–370. https://doi.org/10.21149/12158

Diaz, E., Mondragon, J., Ramirez, E., & Bernal, R. (2003). Epidemiology and control of intestinal parasites with nitazoxanide in children in Mexico. *American Journal of Tropical Medicine Hygiene, 68*, 384–385. https://doi.org/10.4269/ajtmh.2003.68.384

Duedu, K. O., Peprah, E., Anim-Baidoo, I., & Ayeh-Kumi, P. F. (2015). Prevalence of intestinal parasites and association with malnutrition at a Ghanaian orphanage. *Human Parasitic*

Diseases, *7*, 5. https://link.gale.com/apps/doc/A443010967/AONE?u=anon~e3d37704&sid=googleScholar&xid=7074a8f0

Esser, N., Legrand-Poels, S., Piette, J., Scheen, A. J., & Paquot, N. (2014). Inflammation as a link between obesity, metabolic syndrome and type 2 diabetes. *Diabetes Research and Clinical Practice, 105*(2), 141–150. https://doi.org/10.1016/j.diabres.2014.04.006

Gangarapu, V., Yildiz, K., Ince, A. T., & Baysal, B. (2014). Role of gut microbiota: Obesity and NAFLD. *The Turkish Journal of Gastroenterology, 25*(2), 133–140. https://doi.org/10.5152/tjg.2014.7886

Gutiérrez-Rodríguez, C., Trujillo-Hernández, B., Martínez-Contreras, A., Pineda-Lucatero, A., & Millán-Guerrero, R. O. (2007). Frequency of intestinal helminthiasis and its association with iron deficiency and malnutrition in children from western Mexico. *Gaceta Medica de Mexico, 143*(4), 297–300.

Hall, A., Hewitt, G., Tuffrey, V., & de Silva, N. (2008). A review and meta-analysis of the impact of intestinal worms on child growth and nutrition. *Maternal & Child Nutrition, 4*(Suppl 1), 118–236. https://doi.org/10.1111/j.1740-8709.2007.00127.x

Hesham, M. S., Edariah, A. B., & Norhayati, M. (2004). Intestinal parasitic infections and micronutrient deficiency: A review. *Medical Journal of Malaysia*, *59*(2), 284–293. http://www.e-mjm.org/2004/v59n2/Intestinal_Parasitic_Infections.pdf

Katona, P., & Katona-Apte, J. (2008). The interaction between nutrition and infection. *Clinical Infectious Diseases, 46*, 1582–1588. https://doi.org/10.1086/587658

Maggini, S., Wintergerst, E. S., Beveridge, S., & Hornig, D. H. (2007). Selected vitamins and trace elements support immune function by strengthening epithelial barriers and cellular and humoral immune responses. *British Journal of Nutrition, 98*, S29–S35. https://doi.org/10.1017/S0007114507832971

Morales-Espinoza, E. M., Sánchez-Pérez, H. J., García-Gil, M. M., Vargas-Morales, G., Méndez-Sánchez, J. D., & Pérez-Ramírez, M. (2003). Intestinal parasites in children, in highly deprived areas in the border region of Chiapas, Mexico. *Salud Publica de Mexico, 45*, 379–388. https://doi.org/10.1590/s0036-36342003000500008

Ng, M., Fleming, T., Robinson, M., et al. (2014). Global, regional, and national prevalence of overweight and obesity in children and adults during 1980–2013: A systematic analysis for the Global Burden of Disease Study 2013. *The Lancet, 384*, 766–781. https://doi.org/10.1016/S0140-6736(14)60460-8

Nguyen, N. L., Gelaye, B., Aboset, N., Kumie, A., Williams, M. A., & Berhane, Y. (2012). Intestinal parasitic infection and nutritional status among school children in Angolela, Ethiopia. *Journal of Preventive Medicine and Hygiene*, *53*(3), 157. https://www.ncbi.nlm.nih.gov/pmc/articles/PMC3587130/

Oriá, R. B., Murray-Kolb, L. E., Scharf, R. J., Pendergast, L. L., Lang, D. R., Kolling, G. L., & Guerrant, R. L. (2016). Early-life enteric infections: Relation between chronic systemic inflammation and poor cognition in children. *Nutrition Reviews, 74*(6), 374–386. https://doi.org/10.1093/nutrit/nuw008

Papier, K., Williams, G. M., Luceres-Catubig, R., Ahmed, F., Olveda, R. M., McManus, D. P., Chy, D., Chau, T. N. P., Gray, D. J., & Ross, A. G. P. (2014). Childhood malnutrition and parasitic helminth interactions. *Clinical Infectious Diseases, 59*(2), 234–243. https://doi.org/10.1093/cid/ciu211

Prado, M., Cairncross, S., Strina, A., Barreto, M., Oliveira-Assis, A., & Rego, S. (2005). Asymptomatic giardiasis and growth in young children; A longitudinal study in Salvador, Brazil. *Parasitology, 131*(1), 51–56. https://doi.org/10.1017/S0031182005007353

Quihui, L., Valencia, M. E., Crompton, D. W., Phillips, S., Hagan, P., Morales, G., & Díaz-Camacho, S. P. (2006). Role of the employment status and education of mothers in the prevalence of intestinal parasitic infections in Mexican rural schoolchildren. *BMC Public Health, 6*, 1. https://doi.org/10.1186/1471-2458-6-225

Quihui-Cota, L., Morales-Figueroa, G. G., Esparza-Romero, J., Valencia, M. E., Astiazarán-García, H., Méndez, R. O., Pacheco-Moreno, B. I., Crompton, D. W. T., & Diaz-Camacho, S. P. (2010a). Trichuriasis and low-iron status in schoolchildren from Northwest Mexico. *European Journal of Clinical Nutrition, 64*(10), 1108–1115. https://doi.org/10.1038/ejcn.2010.146

Quihui, L., Morales, G. G., Méndez, R. O., Leyva, J. G., Esparza, J., & Valencia, M. E. (2010b). Could giardiasis be a risk factor for low zinc status in schoolchildren from northwestern Mexico? A cross-sectional study with longitudinal follow-up. *BMC Public Health, 10*(1), 85. https://doi.org/10.1186/1471-2458-10-85

Quihui-Cota, L., Astiazarán-García, H., Valencia, M. E., Morales-Figueroa, G. G., Lopez-Mata, M. A., & Vazquez Ortiz, F. (2008). Impact of Giardia intestinalis on vitamin A status in schoolchildren from Northwest Mexico. *International Journal of Vitamin and Nutrition Research, 78*(2), 51–56. https://doi.org/10.1024/0300-9831.78.2.51

Rosado, J., Caamaño, M., Montoya, Y., de Lourdes, S. M., Santos, J., & Long, K. (2009). Interaction of zinc or vitamin A supplementation and specific parasite infections on Mexican infants' growth: A randomized clinical trial. *European Journal of Clinical Nutrition, 63*(10), 1176–1184. https://doi.org/10.1038/ejcn.2009.53

Sanchez, M., Panahi, S., & Tremblay, A. (2014). Childhood obesity: A role for gut microbiota? *International Journal of Environmental Research and Public Health, 12*(1), 162–175. https://doi.org/10.3390/ijerph120100162

Schaible, U. E., & Stefan, H. (2007). Malnutrition and infection: Complex mechanisms and global impacts. *PLoS Medicine, 4*(5), e115. https://doi.org/10.1371/journal.pmed.0040115

Shamah-Levy, T., Vielma-Orozco, E., Heredia-Hernández, O., Romero-Martínez, M., Mojica-Cuevas, J., Cuevas-Nasu, L., Santaella-Castell, J. A., & Rivera-Dommarco, J. (2020). *Encuesta Nacional de Salud y Nutrición 2018–19: Resultados Nacionales.* Instituto Nacional de Salud Pública. https://ensanut.insp.mx/encuestas/ensanut2018/doctos/informes/ensanut_2018_informe_final.pdf

Shaw, J. G., & Friedman, J. F. (2011). Iron deficiency anemia: Focus on infectious diseases in lesser developed countries. *Anemia, 2011*, 260380. https://doi.org/10.1155/2011/260380

Simsek, Z., Zeyrek, F. Y., & Kurcer, M. A. (2004). Effect of Giardia infection on growth and psychomotor development of children aged 0–5 years. *Journal of Tropical Pediatrics, 50*(2), 90–93. https://doi.org/10.1093/tropej/50.2.90

Stephenson, L. S., Latham, M. C., & Ottesen, E. (2000). Malnutrition and parasitic helminth infections. *Parasitology, 121*, S23–S38. https://doi.org/10.1017/S0031182000006491

Strunz, E. C., Suchdev, P. S., & Addiss, D. G. (2016). Soil-transmitted helminthiasis and vitamin A deficiency: Two problems, one policy. *Trends in Parasitology, 32*(1), 10–18. https://doi.org/10.1016/j.pt.2015.11.007

Toro-Londono, M. A., Bedoya-Urrego, K., Garcia-Montoya, G. M., Galvan-Diaz, A. L., & Alzate, J. F. (2019). Intestinal parasitic infection alters bacterial gut microbiota in children. *PeerJ, 7*, e6200. https://doi.org/10.7717/peerj.6200

Vásquez-Garibay, E. M., Romero-Velarde, E., Nápoles-Rodríguez, F., Nuño-Cosío, M. E., Trujillo-Contreras, F., & Sánchez-Mercado, O. (2002). Prevalencia de deficiencia de hierro y yodo, y parasitosis en niños de Arandas, Jalisco, México. *Salud Publica de México*, *44*, 195–200. https://www.saludpublica.mx/index.php/spm/article/view/6385

WHO. (2013). *Soil-transmitted helminths infections factsheet*. World Health Organization. Retrieved January 4, 2022, from https://www.paho.org/en/topics/soil-transmitted-helminthiasis

Yang, Z., Grinchuk, V., Smith, A., Qin, B., Bohl, J. A., Sun, R., Notari, L., Zhang, Z., Sesaki, H., Urban, J. F., Shea-Donohue, T., & Zhao, A. (2013). Parasitic nematode-induced modulation of body weight and associated metabolic dysfunction in mouse models of obesity. *Infection and Immunity, 81*(6), 1905–1914. https://doi.org/10.1128/IAI.00053-13

Zavala, G., Long, K. Z., Garcia, O. P., Caamano, M. C., Aguilar, T., Salgado, L. M., & Rosado, J. L. (2013). Specific micronutrient concentrations are associated with inflammatory cytokines in a rural population of Mexican women with a high prevalence of obesity. *British Journal of Nutrition, 109*, 686–694. https://doi.org/10.1017/S0007114512001912

Zavala, G. A., García, O. P., Campos-Ponce, M., Ronquillo, D., Caamaño, M. C., Doak, C. M., & Rosado, J. L. (2016). Children with moderate-high infection with *Entamoeba coli* have higher percentage of body and abdominal fat than non-infected children. *Pediatric Obesity, 116*, 443–449. https://doi.org/10.1111/ijpo.12085

Zavala, G. A., Rosado, J. L., Doak, C. M., Caamaño, M. C., Campos-Ponce, M., Ronquillo, D., Polman, K., & García, O. P. (2017). Energy and food intake are associated with specific intestinal parasitic infections in children of rural Mexico. *Parasitology International, 66*(6), 831–836. https://doi.org/10.1016/j.parint.2017.07.005

Zavala, G. A., García, O. P., Camacho, M., Ronquillo, D., Campos-Ponce, M., Doak, C., Polman, K., & Rosado, J. L. (2018). Intestinal parasites: Associations with intestinal and systemic inflammation. *Parasite Immunology, 40*(4), e12518. https://doi.org/10.1111/pim.12518

Zavala, G. A., Tenorio-Palos, Y., Campos-Ponce, M., Elton-Puente, J. E., López-González, C. A., Doak, C. M., Rosado, J. L., & García, O. P. (2021). Proximity and high density of convenience stores was associated with obesity in children of a rural community of Mexico; using a Geographic Information System (GIS) approach. *Food and Nutrition Bulletin, 42*, 490–501. https://doi.org/10.1177/0379572121103314

Chapter 20
Biological and Ecological Impacts on Recovery from Anemia Among Peri-Urban Peruvian Children

Achsah Dorsey

20.1 Introduction

Before the nineteenth century, when people observed fatigue, weakness, and pale skin, they attributed these symptoms to unrequited passion. Artists and playwrights explored these romantic connections in their work by invoking pallor and lethargy to represent unreciprocated devotion. Shakespeare, for example, described characters that had been disappointed by love as "smitten with green sickness" (Farley & Foland, 1990). With the advent of modern medicine in the twentieth century, health researchers discovered that these symptoms were due to anemia, a condition caused by low levels of hemoglobin, a protein vital to the transportation and storage of oxygen in blood. Since this discovery, investigators have identified a variety of risk factors for this common blood disorder, including physiological (age and sex), nutritional (low iron consumption), and pathological (blood loss, inflammation, and malabsorption) conditions (Lopez et al., 2016).

Despite the identification of proximate and distal causes, however, anemia remains a widespread public health problem. Anemia affects an astounding 1.62 billion people, almost 25% of the world's population, with reproductive-age women and pre-school-age children carrying a disproportionate amount of the burden (World Health Organization [WHO], 2009). Severe anemia is both a direct and indirect contributing factor to morbidity and mortality (Bothwell & Charlton, 1981; Macgregor, 1963; Scholl & Hediger, 1994). Childhood anemia can cause delayed and decreased cognitive and physical development and function (Beard, 2001; Stoltzfus et al., 2004). The consequences of these symptoms are associated with loss of productivity, including reduced work capacity, cognitive impairment, and increased susceptibility to infection (Balarajan et al., 2011).

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S. Datta Banik (ed.), *Human Growth and Nutrition in Latin American and Caribbean Countries*, https://doi.org/10.1007/978-3-031-27848-8_20

Due to anemia's negative impacts on child development, global health institutions recommend iron supplementation and fortification for all children living in areas with high anemia rates (Sazawal et al., 2006; Stoltzfus & Dreyfuss, 1998; WHO, 2002). Supplementation and fortification have proven to be effective public health interventions to reduce anemia rates (Baltussen et al., 2004; Thompson et al., 2013; Zimmermann & Hurrell, 2007). A comprehensive review of the efficacy of iron supplementation concluded that many randomized-control-trials investigating the effectiveness of iron supplementation in children report significant increases in hemoglobin concentration and other iron status indicators as well as reduced anemia prevalence (Iannotti et al., 2006). Where iron supplementation has not been effective in reducing anemia individually, experts suggest investigating poor compliance (Galloway & McGuire, 1994) and malabsorption (Lopez et al., 2016).

However, despite the reported benefits of iron supplementation, public health officials have raised concerns about the risks associated with iron supplementation among preschoolers. Recent systematic reviews of randomized, controlled trials of iron supplementation conclude that supplementation moderately increases the risk of diarrheal disease (Gera & Sachdev, 2002) and malaria (Oppenheimer, 2001). Since 2002, more studies have documented an association between iron fortification and increased diarrhea prevalence (Chang et al., 2010; Richard et al., 2006; Soofi et al., 2013; Zlotkin et al., 2013). Additional studies report an association between iron level and infection caused by malarial parasites with (Sazawal et al., 2006) and without (Nyakeriga et al., 2004) iron supplementation. These results demonstrate the importance of considering rates of infection and disease patterns when designing anemia intervention programs.

20.2 Anemia in Peru

Peru provides an important setting to study anemia and iron supplementation. This South American nation suffers from high anemia rates, similar to those found in many sub-Saharan African countries, where anemia prevalence tends to be highest (Alcázar, 2013). The WHO (2009) continues to categorize Peru as having 'severe' anemia prevalence and estimates that roughly half of all pre-school age children, pregnant women, and non-pregnant women of reproductive age suffer from anemia. The prevalence of anemia in children under five is higher than the prevalence of malnutrition and has remained constant despite decreases in both stunting and poverty rates (Marini et al., 2017). The high rates of anemia in Peru have received considerable governmental and non-governmental attention and several initiatives have aimed to reduce levels of anemia among children 5 years and younger, including the most recent campaign *Plan Nacional para la Reducción de la Anemia* 2017–2021 (National Plan to Reduce Anemia). Despite these repeated interventions for reducing anemia and malnutrition more broadly, however, anemia continues to represent a distinct challenge, even for those living near large cities who have greater access to urban infrastructure.

With a population of roughly nine million people, Lima is the largest city in Peru, and the third largest city in the Americas. The capital city, located on Peru's coastal plain, has been the political and financial center of the country since it's foundation by Spanish *conquistadors* in the sixteenth Century. This continues to result in substantial internal migration to Lima, contributing to an annual urban growth rate of 1.57% (INEI, 2014). One outcome of Lima's ever-growing population is the expansion of peri-urban communities. These communities are characterized by informal or poor-quality housing, unhealthy living conditions, and poverty, resulting in greater exposure to risk factors and negative health outcomes. San Juan de Lurigancho, a peri-urban district in the north-east quadrant of Lima, has been the site of numerous anemia interventions to date. In 2013, 35.7% of children under five living in this district were diagnosed with anemia; in 2014, despite the efforts of the Ministry of Health and community-based organizations, that percentage had increased to 41.9% (Ministerio de Salud, 2015). Paradoxically, San Juan de Lurigancho also has the highest rates of chronic undernutrition (8.6%) and overweight (11.0%) in pre-school-aged children compared to other low-income districts around Lima (Navarrete Mejía et al., 2016). San Juan de Lurigancho therefore, provides an ideal context to investigate iron supplementation due to its stubbornly high rates of anemia, lack of success with programs that seek to combat it, and the widespread anxiety about anemia expressed by community members.

20.3 Study Overview

Between November 2017 and July 2018, I collected data from 102 children (50 girls and 52 boys), aged 2–5 years, and their caregivers. The purpose of this study was to contribute to current literature on childhood anemia and iron supplementation through a context-specific investigation of pre-school-aged children living in San Juan de Lurigancho. I conducted this study in collaboration with researchers at the *Instituto de Investigación Nutricional* (IIN), a private, non-profit institution dedicated to interdisciplinary research on health and nutrition in Peru. This study received both University of North Carolina at Chapel Hill IRB (Study #17-0404) and IIN Ethics Board approval (Project #373-2017) for this project.

I employed a developmental microniche framework (Worthman, 2010, 1994) to explore how individual anemia status and efficacy of iron supplementation can be linked to national campaigns. Thus, the first goal of this study was to explore the overall prevalence of anemia and response to iron supplementation in our sample. The second, related goal, was to investigate the efficacy of iron supplementation within this context. I predicted that immune activation will be associated with a lack of response to supplementation. Due to previous reports suggesting that anemia status is based on an allostatic system (Dorsey et al., 2018; Hadley & DeCaro, 2015; Wander et al., 2009), I hypothesized that high immune activation before treatment would not be predictive of response to anemia treatment but rather that high immune activation at the end of treatment would be associated with lack of response.

Additionally, because of the recent development of obesogenic environments, current efforts to combat anemia and high exposure to disease, unplanned urban communities in Peru provided a prime setting to explore the dual burden of malnutrition from an evolutionary medicine perspective. For this portion of the study, I predicted that variation in body fat stores would moderate the association between immune function and response to treatment. I expected a reduced probability of response to iron supplementation in children with immune activation and high adiposity when compared to children with immune activation and low adiposity.

To test these hypotheses, I, along with my field coordinator, Gisella Barbagelatta, recruited participants through door-to-door and "snowball" sampling. After discussing the study, answering questions, and receiving informed consent from the caregiver, all maternal-child dyads participated in an initial interview in a private room at the local health center, provided by the IIN. This interview included an extensive demographic survey, morbidity symptom report, and anthropometric measurements. At the end of the interview, I assessed the child's anemia status and collected drops of capillary blood on filter paper to analyze a marker of immune activation (C-reactive protein [CRP]).

I used Hb concentration, the most common hematological assessment method to measure anemia (Chaparro & Suchdev, 2019), as an objective measure of anemia status in this study. I tested participants for anemia before and after treatment via a minimally invasive finger prick and a portable photometer Hemocue machine (Hemocue Hb 201+, HemoCue America, California). I cleaned the child's finger with alcohol and used a sterile disposable microlancet to deliver a controlled puncture. After a drop of blood formed, I placed it directly onto the Hemocue cuvette and inserted it into the Hemocue machine within 30 s of collection. I categorized anemia as a dichotomous variable (not-anemic ≥11.0 g/dL and anemic <11.0 g/dL based on WHO recommendations (2011)).

If a child was not anemic, we thanked them for participating and excluded them from further interviews. If a child was anemic, they visited the health center pediatrician who prescribed ferrous-sulfate syrup, a treatment with a high concentration of iron. Treatment included consuming a tablespoon of this syrup twice a day for 4 weeks (28 days). The pediatrician instructed the mother to give the syrup once in the morning and once in the afternoon at least 30 min before a meal. This treatment followed the anemia intervention guidelines provided by the Peruvian Ministry of Health (Ministerio de Salud, 2015). In the initial sample of 102 pre-school aged children, half were anemic. Of the anemic children, 63% suffered from mild anemia (Hb: 10.0–10.9 g/dL), and 37% experienced moderate anemia (Hb: 7.0–9.9 g/dL).

A follow-up interview took place at the local health center after 4 weeks of treatment. This interview included a morbidity symptom report, open-ended questions about experiences with and compliance to the treatment protocol, a final Hb assessment, and additional blood spot collection to assess inflammation after treatment. Like anemia status, I categorized response to iron supplementation as a dichotomous variable (responder and non-responder). Children who were no longer anemic (≥11.0 g/dL) after 1 month of treatment were categorized as responders while children whose Hb level remained below 11.0 g/dL at the final test were categorized as non-responders.

Of the 50 children diagnosed with anemia at the beginning of this study (one family was lost to follow up due to moving out of the neighborhood), only 25 responded to iron supplementation treatment and adherence was not associated with response. This result runs counter to the findings described in a meta-analysis of 21 data sets from randomized-control-trials (RCTs) exploring iron supplementation in children 0–12 years-of-age (Ramakrishnan et al., 2004) where overall Hb concentrations changed significantly between treatment and control groups. Similarly, a comprehensive review of the efficacy of iron supplementation concluded that the majority of RCTs investigating the effectiveness of iron treatment in children report significant increases in Hb concentration and other iron status indicators and reduced anemia prevalence (Iannotti et al., 2006). The differences between this study's results and those of previous studies may be due to differences in the participants' age, the overall study design, and factors associated with the developmental microniche of our participants, particularly differences in baseline disease ecology and household provisioning practices associated with the peri-urban context.

20.4 Developmental Microniche of Child Anemia

Factors that affect child nutritional status involve the complex interplay of political, ecological, social, and biological factors. The concept of the developmental microniche (Super & Harkness, 2002; Worthman, 1994) is a useful model for exploring the relationship between socioecological context and health. The niche is defined as the variable, individual context of each child and includes the social as well as physical settings in which each child develops (Harkness & Super, 1994; Worthman, 2010). The niche provides a level of analysis and explanation between the more proximate (physiological) and distal (social) aspects of biology, and a framework to organize and explore relationships between children's biology and their socio-ecological context (e.g., Brewis, 2003). The developmental microniche, therefore, serves as a useful guide for methods and analyses to explore how individual efficacy of iron supplementation can be linked to national campaigns.

20.5 Statistical Methods to Test Predictors of Treatment Response

To test predictors of response to iron supplementation within this particular context, I used stepped logistic regression models to test the relationship between aspects of the child's microniche and whether a child responded to iron supplementation or did not respond to treatment. The general analytic strategy was to first explore the bivariate relationship between hypothesized predictor variables and response to iron supplementation using logistic regression models. Following these analyses, I identified variables that had a p-value <0.20, due to the small sample size and exploratory nature of the analysis and included these variables in multivariate logistic models. I built a final model that incorporated each of the predictor variables that had a p-value <0.20 in multivariate models. In all multivariate models, child age and sex were included as covariates and robust standard errors were used to account for clustering by mother. This process adjusts for siblings included in the sample and provides a more conservative estimate of variance within the models. For brevity, only predictive variables in the final model are explored here, additional information is not shown (Dorsey & Thompson, 2020).

20.6 Predictors of Response to Iron Supplementation

Of the 50 anemic children in our sample, 50% remained anemic after 4 weeks of iron supplementation treatment (Table 20.1). Adherence to treatment was high, 52% of mothers reported adhering to treatment for 22 days or more of the prescribed 28 days. Awareness of nutritional issues among mothers in this sample was also

Table 20.1 Descriptive characteristics by response to treatment[a] (mean and [SD] for continuous variables, n and (%) for categorical variables)

Variable	Responders (n = 25)	Non-responders (n = 25)
Hemoglobin after 1 month of treatment (g/dL)	11.60 [0.5]	10.14 [0.63]
Female	11 (44.0)	12 (48.0)
Age (years)	3.04 [1.17]	2.96 [1.02]
Season (summer)[b]	12 (48.0)	22 (88.0) **
Adherence (# of days)[c]	19.4 [7.48]	21.84 [6.20]
Maternal education (completed high school)	13 (54.17)	19 (76.0) **
Persons per bedroom	2.55 (1.46)	3.40 (1.19) **
Food frequency iron rich: Heme (never)	2 (8.0)	8 (32.0) **
Consumption of dirt	11 (44.0)	5 (20.0) **
Elevated CRP (final)[d]	5 (20.0)	10 (40.0) *
Weight-for-age z-score[e]	0.02 (1.12)	−0.67 (0.96) ***
Body mass Index (BMI)-for-age z-score (>1.0)	9 (36.0)	5 (20.0) *
Waist-to-height Ratio (>0.5)[f]	23 (92.00)	18 (72.00) **

*p-value <0.10, **p-value <0.05, ***p-value <0.01 in bivariate logistic regression models
[a]Response to iron supplementation (categorical) = >11.0g/dL at final interview
[b]Dichotomous variable based on the month in which the initial interview took place, summer (December–April) and winter (May–November)
[c]28 possible days of treatment
[d]C-reactive protein levels were dichotomized (>2.2 mg/dL = Elevated)
[e]All z-scores were calculated using WHO growth standards (de Onis et al., 2006)
[f]Participant's waist circumference in cm divided by height in cm and dichotomized

high: 92% mothers reported knowing about the cause and/or health effects of anemia. The relationship between diet and health is well known within this sample, and caregivers repeatedly linked inadequate (the most common examples included: not having enough food and poor appetite) and unhealthy food (such as fried foods and sweets) to disease and illness.

In bivariate modeling, Hb concentration at the initial interview was not a significant predictor of whether the participant responded to treatment (OR: 1.22, CI: 0.56–2.56, p = 0.62). Responders included children with both mild and moderate anemia. Higher weight-for-age z-score (WAZ) was associated with greater odds of responding to iron supplementation (OR: 1.91, CI: 1.08–3.38, p = 0.03). While CRP, an inflammatory acute-phase protein commonly used as a marker of systemic inflammation, at the initial interview was not significantly associated with response to treatment, children with elevated CRP levels at the final interview were less likely to respond to treatment (OR:0.29, CI:0.08–1.07, p = 0.06). Consuming heme sources of iron at any point in the past 6 months (OR:5.41, CI:1.02–27.71, p = 0.05) and observed geophagy (OR:3.14, CI:0.85–11.63, p = 0.09) increased a child's odds of responding to treatment; however, these predictors were excluded from subsequent models due to small sample size. Season was a significant predictor for response to iron supplementation in bivariate models (OR:0.13, CI:0.03–0.53, p = 0.01).

In the final multivariate model, WAZ, CRP at the final interview, and season all remained significant predictors of responding to iron supplementation (Table 20.2). As WAZ increased, the probability of responding to treatment also increased. Participants with elevated CRP at the final interview were less likely to respond to

Table 20.2 Final multivariate logistic regression model predicting response to iron supplementation[a]

Variables categorized by level	Final model OR (CI)
Weight-for-age z-score[b]	2.08 (1.08–4.02)***
Elevated CRP[c] (final)	0.07 (0.01–0.67)***
Maternal Education (completed high school)	0.46 (0.05–5.18)
Persons-per-bedroom	0.70 (0.36–1.36)
Season[d] (summer)	0.04 (0.00–0.37)***

OR Odds Ratio, *CI* Confidence Interval
***p-value <0.05
[a]Response to iron supplementation (categorical) = >11.0g/dL at final interview
[b]Z-scores were calculated using WHO growth standards (de Onis et al., 2006)
[c]C-reactive protein levels were dichotomized (>2.2 mg/dL = Elevated)
[d]Dichotomous variable based on the month in which the initial interview took place, summer (December–April) and winter (May–November)

supplementation than those who did not have elevated CRP. If a child was treated for anemia during the summer, the probability of the child responding to treatment decreased by 92%.

20.7 Reflections on Developmental Microniche and Anemia

While anemia is a global problem, effective strategies for anemia reduction require an understanding of local and household-level causes to design interventions that address predictors effectively. In this study, season was a strong environmental predictor of response to treatment. The summer season (December–April) was associated with more negative nutritional status. Children enrolled in the study during the summer season were less likely to respond to iron supplementation. Seasonal variation in anemia rates has been documented by several authors (Rogerson et al., 2000; Senn et al., 2010), however, these studies link Hb fluctuations to increased rates of malaria during the rainy season in Papua New Guinea and Malawi, respectively. Not only is there a lack of precipitation year-round, but malarial parasites are not found in the peri-urban areas of Lima and therefore not the cause of the seasonal patterns documented in this study. Seasonal distribution of rotavirus, a virus linked to severe gastroenteritis and a potential cause of anemia, has been documented in the District of *Independencia*, but the prevalence of rotavirus peaked during the winter months in this peri-urban community within Lima and rates of this virus have decreased since the introduction of the rotavirus vaccine (Chang et al., 2015). Additional investigation is needed to determine if the driving force of the seasonal variation observed in this study is due to disease ecology.

Fluctuations in diet may also contribute to the differences observed in response to iron supplementation between the winter and summer months. While seasonal variation in diet has been documented in highland Peru, children experienced little seasonal change in energy intake (Leonard & Thomas, 1989). A study investigating child (0–35 months) nutritional status in Pampas de San Juan de Miraflores from 1987–1993, report seasonal variation, the mean weight-for-height was an estimated 0.38 z-score higher in the winter than in the summer (Marin et al., 1996). The negative outcomes associated with the summer season (non-response to supplementation) in this study may be linked to significant variation in nutritional status.

In addition to season, CRP also remained a predictor for response to iron supplementation. I proposed that high immune activation before treatment would not be predictive of response to supplementation but that high immune activation at the end of treatment would be associated with efficacy of treatment due to the allostatic nature of iron regulation. These findings supported this hypothesis, as elevated CRP at the final interview was associated with a reduced likelihood of a child responding to treatment while initial CRP concentrations were not. These results demonstrate an interesting relationship between levels of inflammation and anemia status.

Weight-for-age serves as a marker of acute nutritional status. In our study, children with higher WAZ were more likely to respond to iron supplementation. Results from research investigating the relationship between weight and anemia status are mixed, but this may be due to differences in the adiposity measures used. Some studies report that high body mass index (BMI) results in an increased risk for iron deficiency and anemia among children and adolescents in both high income and transitioning settings (Aeberli et al., 2009; Eftekhari et al., 2009; Nead et al., 2004; Zimmermann et al., 2008). Conversely, other studies have observed lower rates of anemia in women and children experiencing overnutrition (Eckhardt et al., 2008; Kroker-Lobos et al., 2014). Zimmerman et al. (2008) investigated the relationship between weight and anemia status and iron fortification. They report that increased adiposity in women and children results in lower anemia prevalence and a reduced response to iron fortification. In a study examining the efficacy of iron supplementation, Baumgartner et al. (2013) reported that South African children with high BMI-for-age z-scores had a greater risk for remaining iron-deficient after iron supplementation for 8.5 months when compared to children with low BMI-for-age z-scores. Our results are contradictory to the findings on weight and iron supplementation presented by Zimmerman et al. (2008) and Baumgartner et al. (2013). This contradiction may be due to differences in the measures used, WAZ vs. BMI, and/or the complex set of variables that include differences in disease exposure and immune activation caused by specific environmental, economic, and cultural contexts.

20.8 Immune Activation and Anemia Status

20.8.1 Evolutionary Medicine

One explanation for the predictive nature of elevated CRP, which is used as a marker of systemic inflammation levels, for lack of response to iron supplementation comes from the field of evolutionary medicine, which proposes that some manifestations of disease may act as adaptive defenses against other types of illness (Ewald, 1994; Williams & Nesse, 1991). Infection with common pathogens has been linked to higher CRP levels in children (Dowd et al., 2010) and adults (Nazmi et al., 2010; Zhu et al., 2000), with greater risk of inflammation seen with increasing pathogen burden. Inflammation is one of the first responses of the immune system to infection and signals biological systems to sequester iron, reduce iron absorption, and decrease erythropoiesis (the production of red blood cells) which causes a decrease in serum hemoglobin, resulting in anemia (Weinberg, 1992). Decreasing the amount of circulating iron and iron absorption restricts the availability of iron to pathogens, thereby inhibiting pathogen growth, proliferation, and virulence (Nemeth & Ganz, 2006).

20.8.2 The Optimal Iron Hypothesis

The Optimal Iron Hypothesis (OIH) states that an individual's optimal iron status is contingent on local disease ecology. In environments with high levels of endemic infectious disease, restricted iron intake may protect against infection (Wander et al., 2009). This hypothesis builds on previous evolutionary medicine theory to explain the relationship between iron and infection, arguing that anemia may not always be pathological and may instead act as an adaptive defense against infection. In this case, while childhood anemia impairs growth and cognitive development, in areas with high disease ecology, anemia may be beneficial as it reduces both bacterial proliferation and virulence.

In the same paper that proposed the OIH, Wander et al. (2009) examined the association between infection (CRP) and iron status (serum transferrin receptor [sTfR] and zinc protoporphyrin to heme ratio) among 270 school-age children in Kenya. When controlling for age and triceps skinfold thickness, the authors found evidence that an iron replete condition increased an individual's odds of infection, and that clinical iron deficiency may, therefore, protect against infection. The authors did not find evidence that the odds of infection change with the degree of iron deficiency. This study showed support for their proposed hypothesis, but the small sample size and cross-sectional design were not ideal for showing causation.

Hadley and DeCaro (2015) tested the predictions of the OIH using a nationally representative sample of 1164 Tanzanian children aged 6–59 months living in both rural and urban settings using levels of CRP as a marker for infection and measurements of sTfR and hemoglobin to assess iron levels. The authors reported that non-anemic low iron levels (normal hemoglobin, but below normal sTfR) were not associated with a lower likelihood of infection compared to iron replete children. These findings do not support the OIH as it was initially formulated and Hadley and DeCaro have proposed that it may be more fruitful to investigate iron regulation as an allostatic system that responds to infection adaptively as opposed to expecting an optimal pre-infection value.

Dorsey et al. (2018) reported additional support for this claim through secondary data analysis of the association between hemoglobin levels and morbidity among children living in Canto Grande, a peri-urban community located on the outskirts of Lima, Peru. The authors used risk ratios to test whether lower hemoglobin status, assessed using the HemoCue B-Hemoglobin System, was associated with an increased relative risk of morbidity symptoms compared to non-anemic status, controlling for infant age, sex, weight-for-height z-score, maternal education, and repeated measures in 515 infants aged 6–12 months. Infants with fewer current respiratory and diarrheal morbidity symptoms had a lower risk of low hemoglobin compared to participants who were not anemic (p-value < 0.10). Infants with fewer current respiratory infection symptoms had a statistically significant (p-value < 0.05) reduction in risk of moderate anemia compared to infants who were not anemic. In this study, morbidity status was not predictive of hemoglobin status over a six-month interval period, but anemia status was shown to be associated with current morbidity symptoms.

20.9 Dual Burden of Malnutrition

Exposure to infectious disease is not the only cause of immune activation due to inflammation. Research suggests that both chronic pathogen exposure and high levels of adiposity activate pro-inflammatory pathways (McDade et al., 2008a; Thompson et al., 2015; Vahdat et al., 2012), thus overweight and obesity may also influence the efficacy of iron supplementation programs. In countries undergoing rapid dietary and lifestyle changes, obesity exists alongside illnesses associated with undernutrition, a phenomenon known as the 'dual burden of malnutrition' (Popkin et al., 2012). A common manifestation of the dual burden in individuals is the co-occurrence of overweight and anemia. The co-existence between the two is attributed to increased iron requirements among overweight individuals (Yanoff et al., 2007) or physiological changes associated with overweight that influence iron absorption and utilization, such an increase of inflammatory acute-phase proteins, like CRP (Cheng et al., 2012). High levels of these proteins cause inflammation, triggering an innate immune response and increases one's risk for anemia due to iron sequestration and reduced iron absorption.

While the inverse correlation between adiposity and iron-level was established in the early 1960s (Seltzer & Mayer, 1963; Wenzel et al., 1962), more recent evidence of the association between overweight and anemia has been mixed. Some studies report that higher BMI results in increased risk for iron deficiency and anemia among children and adolescents in both high income and transitioning settings (Aeberli et al., 2009; Eftekhari et al., 2009; Nead et al., 2004; Zimmermann et al., 2008). Other studies observed lower rates of anemia in women and children experiencing overnutrition (Eckhardt et al., 2008; Kroker-Lobos et al., 2014). In a study examining the efficacy of iron supplementation, Baumgartner et al. (2013) reported that South African children with high BMI-for-age z-scores have a greater risk for remaining iron-deficient after iron supplementation for 8.5 months when compared to children with low BMI-for-age z-scores. These seemingly contradictory findings may be due to a complex set of environmental and individual variables that include differences in disease exposure and immune activation caused by specific economic and cultural contexts. Additionally, while BMI has traditionally been used as a proxy for body fat (Albrecht et al., 2015), visceral adiposity or waist circumference may provide greater insight into the relationship between adiposity and anemia due to differences in the production of inflammatory cytokines by fat tissue.

Investigating iron supplementation in children from an evolutionary medicine perspective within a dual burden context is important because of their high exposure to pathogens and energetic demands for growth and immune function. Life history theory offers a framework for investigating the benefits and risks of anemia, as energy devoted to immune defense can't be allocated to growth and development (Charnov, 1993; Stearns, 1992). The trade-off between allocating limited resources to immune defense or growth differs for those living in energy-rich environments versus those living in energy-poor contexts. Children with reliable access to nutrients can replenish the costs of immune activation while children experiencing undernutrition have more limited energy to devote to growth and consequently exhibit impaired immunity (McDade et al., 2008b). The simple comparison between energy-rich and energy-poor environments is challenged by a global rise in overnutrition and urbanization, resulting in the dual burden of disease. While fat represents stored energy that is utilized for metabolic processes associated with growth and immune function (Kuzawa, 1998), higher body weight and BMI have been associated with chronic inflammation in adults and children (Choi et al., 2013; Cook et al., 2000; Dowd et al., 2010; Thompson et al., 2014). Additional studies report that the association between central adiposity and pro-inflammatory markers may be particularly strong in younger populations (Fransson et al., 2010; Nguyen et al., 2009), suggesting that high energy stores (in the form of visceral body fat) may not always be beneficial.

20.10 Statistical Methods to Test Adiposity as a Moderator

My previous analysis demonstrated a relationship between higher CRP and a lack of response to treatment. To expand this finding and investigate whether body fat moderates the impact of immune activation on response to iron supplementation, I included several body fat variables in the multivariate logistic models developed in testing our previous prediction. Moderation was tested by including interaction terms between immune activation and body fat measures (high waist-to-height ratio [WHtR] and high BMI z-score) at the final interview. Children with greater than 0.5 WHtR and/or greater 1.0 WAZ were classified as "high." Statistical analyses were conducted with STATA 13. In all logistic regression models, I included age, sex, and season as covariates and used robust standard errors accounting for clustering by maternal identification to account for siblings. This process adjusts for siblings included in the sample and provides a more conservative estimate of variance within the models. For brevity, only some of my findings are presented here, additional information is not shown (Dorsey et al., 2021).

20.11 Adiposity as a Moderator for Response to Iron Supplementation

High WHtR was common in the sample, but a high BMI z-score was not - with only 28% of children having a BMI z-score > 1.0. As dichotomous variables, WHtR (OR:32.54, CI: 2.67–396.08, p-value<0.05) and BMI z-score (OR:3.76, CI:0.96–14.79, p-value<0.10) were associated with response to supplementation in logistic regression models. I hypothesized that variation in body fat stores would moderate the association between immune function and response to treatment.

This study provides evidence that WHtR moderates the relationship between final CRP and response to supplementation (p-value<0.10) (Table 20.3). Anemic children with low CRP at the end of treatment and high WHtR have the highest predicted probability of responding to supplementation (71%) (Fig. 20.1). Children with low WHtR have a significantly lower chance of responding to iron supplementation than children with high WHtR, whether they are categorized as having low or high CRP values.

In this sample, BMI-for-age z-score moderates the relationship between immune activation and response to treatment (p-value <0.05) (Table 20.3). Children with high CRP and low BMI z-scores have the lowest predicted probability of recovering from anemia (15%) while participants categorized as having high BMI z-scores with both high and low CRP after 1-month of treatment have a greater probability of responding to iron supplementation (Fig. 20.2). It is interesting to note that children categorized with both low BMI z-score and low CRP values have a significantly higher chance of responding to treatment (55%) than children with low BMI z-score but an elevated level of CRP (15%).

Table 20.3 Multivariate logistic regression and regression models predicting response to iron supplementation[a] by categorical adiposity measures

	WHtR[b]		BMI Z-Score[c]	
Variable	OR	CI	OR	CI
Age (years)	2.23*	0.89–5.63	1.28	0.68–2.40
Sex	3.19	0.65–15.52	0.78	0.17–3.50
Season[d]	0.03**	0.00–0.18	0.04**	0.01–0.38
Elevated CRP (final)[e]	1.21	0.09–16.05	0.05**	0.01–0.50
Adiposity Measure[f]	149.42	8.30–2690.00	1.80	0.35–9.29
Adiposity Measure X CRP[g]	0.05*	0.00–1.68	34.75**	1.08–1120.51
Constant	0.02*	0.00–1.41	7.39	0.73–74.94

OR Odds Ratios, *CI* Confidence Interval, Constant = Model Intercept

*p-value <0.10, **p-value <0.05

[a]Response to iron supplementation (categorical) = >11.0g/dL at final interview

[b]Waist-to-height Ratio (WHtR): participant's waist circumference in cm divided by height in cm and dichotomized (>0.5 = High)

[c]Body Mass Index (BMI)-for-age z-score: Z-scores were calculated using WHO growth standards (de Onis et al., 2006) and dichotomized (>1.0 = High)

[d]Dichotomous variable based on the month in which the initial interview took place, summer (December–April) and winter (May–November)

[e]C-reactive protein levels were dichotomized (>2.2 mg/dL = Elevated)

[f]Either WHtR or BMI-for-age Z-score

[g]Adiposity measure X CRP represents the interaction term to test for moderation in the two models

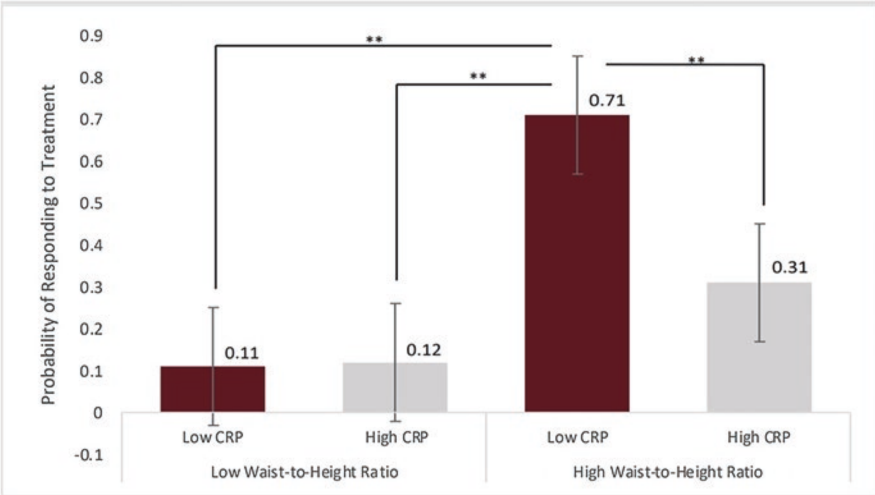

Fig. 20.1 Probability of responding to treatment by dichotomized waist-to-height ratio and dichotomized C-reactive protein (CRP)
Waist-to-height ratio was calculated by dividing participant's waist circumference in cm by height in cm and dichotomized with high waist-to-height ratio: >0.5
Low CRP <2.2 mg/L, High CRP >2.2 mg/L
**p-value <0.05

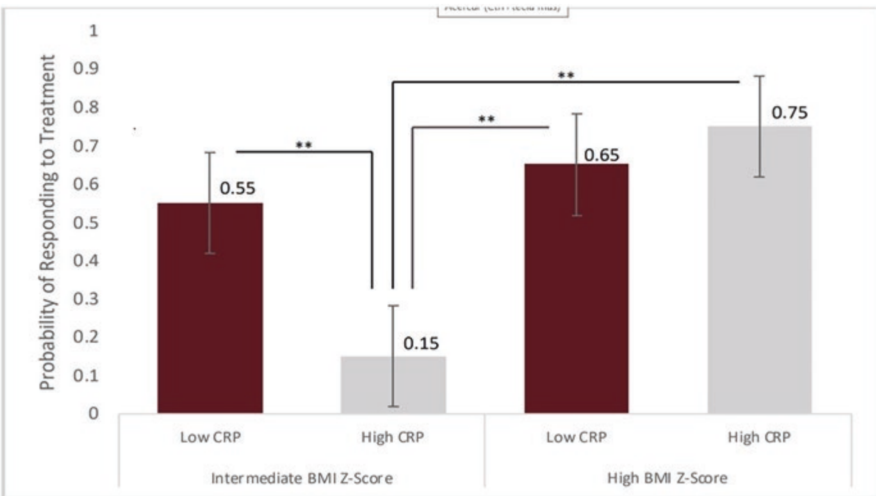

Fig. 20.2 Probability of responding to treatment by dichotomized body mass index (BMI) Z-score and dichotomized C-reactive protein (CRP)
BMI-for-age z-scores were calculated using WHO growth standards (de Onis et al., 2006) and dichotomized, high BMI-for-age z-score > 1.0
Low CRP ≤2.2 mg/L, High CRP >2.2 mg/L
**p-value <0.05

20.12 Reflections on Adiposity and Efficacy of Treatment

This study uses an evolutionary medicine perspective to assess response to iron supplementation, rather than the likelihood of anemia, and to assess the relationships between immune activation, anemia, and adiposity in a dual burden context. These findings suggest that examining both immune activation and adiposity is important in understanding the effectiveness of iron supplementation programs in such settings.

Rates of overweight in the sample varied depending on the adiposity measure examined, with the highest rates of overweight seen in WHtR and the lowest rates of overweight with BMI-for-age z-score. Higher WHtR and BMI-for-age z-scores, measures of central adiposity and overall weight for height, respectively, were associated with increased odds of responding to treatment. These results suggest that type (visceral or subcutaneous) and/or distribution of body fat may be important when investigating the relationship between adiposity, immune activation, and nutritional status.

This study also found that both BMI-for-age z-score and WHtR moderate the interaction between CRP and response to iron supplementation, but that these two adiposity measures were associated with different likelihood of response. Children with a high BMI-for-age z-score (in both high and low CRP groups) and those with low BMI-for-age z-score and low CRP all had greater than a 50% probability of responding to iron supplementation. Participants with low BMI-for-age z-score and high CRP were the least likely to respond to treatment. While a high probability of responding to treatment was expected from children with low CRP and low BMI-for-age z-score when compared to children with high CRP and low BMI-for-age z-score, the higher probability of responding to treatment among children with high BMI z-scores with either high or low CRP was not. This pattern may be due to the protective effects of high energy stores (in the form of body fat) in children. McDade et al. (2008b) report that Tsimane' children (aged 2–10 years) with low body fat and elevated CRP experienced smaller gains in height over 3 months, providing evidence for a trade-off between investment in immune function and growth. My results suggest that higher levels of adiposity may protect against competing demands for energy stores.

Generally, higher BMI-for-age z-score was associated with a greater likelihood of responding to iron supplementation, whether the child had elevated CRP. These results supplement the ambiguous findings in the literature on the relationship between anemia status and BMI (Aeberli et al., 2009; Eckhardt et al., 2008; Eftekhari et al., 2009; Kroker-Lobos et al., 2014; Nead et al., 2004; Zimmermann et al., 2008). The results reported here support findings from a previous study investigating anemia in a presentative sample of children (aged 10–15 years) from a rural community outside of Lima that reports older children and those with a greater BMI were less likely to present with anemia (Rodríguez-Zúñiga, 2015). My findings are counter to previous research on iron supplementation that reported South African children aged 6–11 years with higher BMI-for-age z-score were more likely to remain anemic despite receiving treatment than their low BMI-for-age z-score counterparts (Baumgartner et al., 2013). The dissimilarity between these findings and the aforementioned study may be due to differences in the participants' age, study design, diet, and baseline disease ecology. In Peru, where diet quality is likely to be poor (Creed-Kanashiro et al., 2003), the overweight children in this sample may have accrued enough iron or other minerals related to iron absorption (e.g. vitamin A and zinc) to lower their risk of anemia compared to non-overweight participants (Eckhardt et al., 2008).

While previous studies exploring the relationship between weight and anemia status used BMI to represent adiposity, we expanded our investigation to include an additional measure of central obesity, WHtR. This variable was investigated due to the disproportionate increase in waist circumference relative to overall body mass in in Mexico and China, two middle-income countries undergoing rapid economic and urbanization transitions like the shifts observed in Peru (Albrecht et al., 2015). We found that higher WHtR was associated with a greater probability of responding to treatment, but the likelihood of responding to treatment in the WHtR categories differed from the corresponding BMI z-score categories. Children with high WHtR and low CRP had the greatest probability of responding to treatment compared to children with high WHtR and high CRP and children with low WHtR. Participants with low WHtR are the least likely to respond to treatment, despite having high or low CRP.

The variation in patterns observed between the two adiposity measures may be due to differences in what the body fat variables were measuring. In this sample, BMI-for-age z-score was associated with triceps skin fold (TSF) z-score, WHtR was not. This suggests that BMI is a better measure of peripheral body fat while WHtR may better reflect an accumulation of visceral adipose tissue. Visceral adipose tissue produces a variety of pro-inflammatory cytokines that stimulate CRP production, such as IL-6 and TNF-α (Thompson et al., 2015). Elevated pro-inflammatory cytokines in children with greater central body fat may explain the lower probability of responding to treatment in children with high WHtR and CRP when compared to children with high BMI-for-age z-score and CRP.

The cumulative effect of high CRP and other pro-inflammatory cytokines may also explain the variation in probability of responding to treatment between children with high and low CRP among participants with high WHtR. Having high CRP along with high levels of other pro-inflammatory markers may work together to reduce a child's probability of responding to treatment due to a stronger innate immune response (resulting in iron sequestration and/or lack of iron absorption), while having low CRP doesn't create a larger cumulative effect. Research investigating the environmental and behavioral risk factors associated with central obesity and inflammation among Chinese adults report evidence for this potential association. Thompson et al. (2015) found that men and women with high WHtR and inflammation were more likely to have infectious disease symptoms than those with high WHtR and no inflammation. More work is needed to understand the range of variation in inflammatory processes associated with central and peripheral adiposity.

20.13 Conclusion

This study investigates a large range of factors that allow for an in-depth investigation of predictors for response to iron supplementation and test more directly the association between children's biology and socio-ecological context. However, the results are limited by several important factors and should be considered preliminary. This study did not use a random sampling strategy to identify potential participants due to barriers preventing the identification and random selection of pre-school aged children in this specific context, therefore these results may be subject to sampling bias and should be considered exploratory. Nevertheless, most children in the area visited the clinic and the author and Ms. Barbagelatta followed up with every household that could be identified as having children between the ages of 2 and 5 years. While the total sample size is relatively large (n = 102), the subsample of children who received iron supplementation is considerably smaller (n = 50). This small sample size may have limited power to find statistically significant differences between response and non-response.

Additionally, I used Hb as our measure of iron deficiency. While Hb concentration is the most common hematological assessment method used to measure anemia (Chaparro & Suchdev, 2019), it lacks specificity for establishing nutritional anemias, such as iron status. Nevertheless, in Peru, recent initiatives by the Ministry of Health use Hb to assess anemia status in national-level programs at health centers and in schools, incorporating methods used by these initiatives allows for comparison between reported prevalence and rates of anemia in this sample. Moreover, measuring Hb is inexpensive and easy to measure with field-friendly testing. Thus, despite the lack of specificity for establishing nutritional anemias, such as iron status (Balarajan et al., 2011), Hb was used as an objective measure of anemia in this study. Additionally, while some studies suggest that Hb may not be affected by iron supplementation and recommend including measures of iron status (Stolzfus et al., 2004), others report increases in Hb but not in markers of iron status (serum ferritin and free erythrocyte protoporphyrin) in participants receiving daily iron supplementation (Zavaleta et al., 2000). Due to the conflicting reports on iron supplementation's impact on Hb status, future research should explore the effects of iron supplementation on additional biomarkers associated with anemia and iron level. Another limitation of our study is the use of a single inflammation measure, CRP. To further explore the association between adiposity, immune activation, and response to iron supplementation a variety of pro-inflammatory cytokine biomarkers should be used in future research.

Despite these limitations, these findings highlight the importance of incorporating a developmental microniche perspective and methodology in research investigating child response to iron supplementation. Factors that affect the prevalence and distribution of anemia in a population involve the complex interplay of political, ecological, social, and biological factors. Given the persistent nature of childhood anemia in Peru and the failure of interventions focusing on the iron supplementation and fortification strategies, understanding the roles of the developmental microniche and factors that can be modified to improve nutritional status and disease exposure is a critical step in reducing childhood anemia prevalence.

Furthermore, these results advance our understanding of the relationship between immune activation and anemia status within a dual burden context. This study demonstrates evolutionary medicine's potential to provide insight into patterns of disease and highlights the need for further investigation of child inflammatory profiles within a dual burden context. The human immune system is characterized by substantial developmental plasticity. Longitudinal research on immune function demonstrates nutritional and microbial exposures in early childhood are important determinants of inflammation in adulthood (McDade, 2012). The inclusion of central and peripheral adiposity measures in this study expands our knowledge on the influence of visceral adipose tissue on the relationship between immune function and anemia in children. Further research on the variation of inflammatory processes associated with visceral adiposity in childhood is needed to investigate pathways to health and disease later in life.

This research has important public health implications. While the probability of anemia and overweight co-occurring may be low, both conditions are caused by malnutrition and have links to chronic disease and negative developmental effects (Popkin et al., 2006; Stoltzfus et al., 2004). The high prevalence of anemia and the rising rates of overweight and obesity in Peru warrant prevention and education efforts as well as further investigation into the dual burden of malnutrition.

Acknowledgements The author would like to thank the study participants and their parents, Dr. Mary Penny (Director of the *Instituto de Investigación Nutricional*), Gisella Barbagelatta (field coordinator), Dr. Teobaldo Herrera Acuña (health center pediatrician), and Dr. Amanda Thompson (dissertation advisor). This research received support from the National Science Foundation (BCS-1731120), Fulbright Program, Frank Porter Graham Institute, Sigma Xi, American Philosophical Society, University of North Carolina, International Chapter of P.E.O. Sisterhood, and the Population Research Infrastructure Program awarded to the Carolina Population Center (P2C HD050924) at the University of North Carolina at Chapel Hill by the Eunice Kennedy Shriver National Institute of Child Health and Human Development.

References

Aeberli, I., Hurrell, R. F., & Zimmermann, M. B. (2009). Overweight children have higher circulating hepcidin concentrations and lower iron status but have dietary iron intakes and bioavailability comparable with normal weight children. *International Journal of Obesity (London), 33*, 1111–1117. https://doi.org/10.1038/ijo.2009.146

Albrecht, S. S., Gordon-Larsen, P., Stern, D., & Popkin, B. M. (2015). Is waist circumference per body mass index rising differentially across the United States, England, China and Mexico? *European Journal of Clinical Nutrition, 69*, 1306–1312. https://doi.org/10.1038/ejcn.2015.71

Alcazar, L. (2013). *The economic impact of anemia on Peru*. GRADE; Action Against Hunger.

Balarajan, Y., Ramakrishnan, U., Özaltin, E., Shankar, A. H., & Subramanian, S. V. (2011). Anaemia in low-income and middle-income countries. *Lancet, 378*, 2123–2135. https://doi.org/10.1016/S0140-6736(10)62304-5

Baltussen, R., Knai, C., & Sharan, M. (2004). Iron fortification and iron supplementation are cost-effective interventions to reduce iron deficiency in four sub-regions of the world. *Journal of Nutrition, 134*, 2678–2684. https://doi.org/10.1093/jn/134.10.2678

Baumgartner, J., Smuts, C. M., Aeberli, I., Malan, L., Tjalsma, H., & Zimmermann, M. B. (2013). Overweight impairs efficacy of iron supplementation in iron-deficient South African children: A randomized controlled intervention. *International Journal of Obesity, 37*, 24–30. https://doi.org/10.1038/ijo.2012.145

Beard, J. L. (2001). Iron biology in immune function, muscle metabolism, and neuronal functioning. *Journal of Nutrition Supplement, 131*, 568S–580S. https://doi.org/10.1093/jn/131.2.568S

Bothwell, T., & Charlton, R. (Eds.). (1981). *Iron deficiency in women*. Nutrition Foundation.

Brewis, A. (2003). Biocultural aspects of obesity in young Mexican schoolchildren. *American Journal of Human Biology, 15*, 446–460. https://doi.org/10.1002/ajhb.10161

Chang, S., El Arifeen, S., Bari, S., et al. (2010). Supplementing iron and zinc: Double blind, randomized evaluation of separate or combined delivery. *European Journal of Clinical Nutrition, 64*, 153–160. https://doi.org/10.1038/ejcn.2009.127

Chang, M. R., Velapatino, G., Campos, M., Chea-Woo, E., Baiocchi, N., Cleary, T. G., & Ochoa, T. J. (2015). Rotavirus seasonal distribution and prevalence before and after the introduction of rotavirus vaccine in a Peri-Urban Community of Lima, Peru. *American Journal of Tropical Medicine and Hygiene, 92*(5), 986–988. https://doi.org/10.4269/ajtmh.14-0431

Chaparro, C. M., & Suchdev, P. S. (2019). Anemia epidemiology, pathophysiology, and etiology in low- and middle-income countries. *Annals of New York Academy of Science, 1450*, 15–13. https://doi.org/10.1111/nyas.14092

Charnov, E. L. (1993). *Life history invariants*. Oxford University Press.

Cheng, H. L., Bryant, C., Cook, R., O'Connor, H., Rooney, K., & Steinbeck, K. (2012). The relationship between obesity and hypoferraemia in adults: A systematic review. *Obesity Reviews, 13*(2), 150–161. https://doi.org/10.1111/j.1467-789X.2011.00938.x

Choi, J., Joseph, L., & Pilote, L. (2013). Obesity and C-reactive protein in various populations: A systematic review and meta-analysis. *Obesity Reviews, 14*, 232–244. https://doi.org/10.1111/obr.12003

Cook, D. G., Mendall, M. A., Whincup, P. H., Carey, I. M., Ballam, L., Morris, J. E., Miller, G. J., & Strachan, D. P. (2000). C-reactive protein concentration in children: Relationship to adiposity and other cardiovascular risk factors. *Atherosclerosis, 149*, 139–150. https://doi.org/10.1016/s0021-9150(99)00312-3

Creed-Kanashiro, H. M., Bartolini, R. M., Fukumoto, M. N., Uribe, T. G., Roberty, R. C., & Bentley, M. E. (2003). Formative research to develop a nutrition education intervention to improve dietary iron intake among women and adolescent girls through community kitchens in Lima, Peru. *American Society for Nutritional Sciences, 0022-3166*(03), 3987S–3991S. https://doi.org/10.1093/jn/133.11.3987S

de Onis, M., Garza, C., Onyango, A. W., et al. (Eds.). (2006). *WHO child growth standards* (Vol. 450, pp. 1–101). World Health Organization.

Dorsey, A. F., & Thompson, A. L. (2020). Child, caretaker, and community: Testing predictors of anemia and response to iron supplementation in Peruvian pre-school-aged children. *American Journal of Human Biology, 33*(6), e23538. https://doi.org/10.1002/ajhb.23538

Dorsey, A., Thompson, A. L., Kleinman, R. E., Duggan, C. P., & Penny, M. E. (2018). Iron and infection: An investigation of the optimal iron hypothesis in Lima, Peru. *American Journal of Human Biology, 2018*, e23114. https://doi.org/10.1002/ajhb.23114

Dorsey, A. F., Penny, M. E., & Thompson, A. L. (2021). Adiposity and pathogen exposure: An investigation of response to iron supplementation and hypothesized predictors in anemic pre-school-aged children living in a dual burden environment. *American Journal of Physical Anthropology, 176*(1), 54–65. https://doi.org/10.1002/ajpa.24287

Dowd, J. B., Zajacova, A., & Aiello, A. E. (2010). Predictors of inflammation in U.S. children aged 3–16 years. *American Journal of Preventive Medecine, 39*, 314–320. https://doi.org/10.1016/j.amepre.2010.05.014

Eckhardt, C. L., Torheim, L. E., Monterrubio, E., Barquera, S., & Ruel, M. T. (2008). The overlap of overweight and anaemia among women in three countries undergoing the nutrition transition. *European Journal of Clinical Nutrition, 62*, 238–246. https://doi.org/10.1038/sj.ejcn.1602727

Eftekhari, M., Mozaffari-Khosravi, H., & Shidfar, F. (2009). The relationship between BMI and iron status in iron-deficient adolescent Iranian girls. *Public Health Nutrition, 12*, 2377–2381. https://doi.org/10.1017/S1368980009005187

Ewald, P. W. (1994). *Evolution of infectious disease*. Oxford University Press.

Farley, P., & Foland, J. (1990). Iron deficiency anemia: How to diagnose and correct. *Postgraduate Medicine, 87*(2), 89–101. https://doi.org/10.1080/00325481.1990.11704556

Fransson, E. I., Batty, G. D., Tabak, A. G., Brunner, E. J., Kumari, M., Shipley, M. J., et al. (2010). Association between change in body composition and change in inflammatory markers: An 11-year follow-up in the Whitehall II study. *Journal of Clinical Endocrinology & Metabolism, 95*, 5370–5374. https://doi.org/10.1210/jc.2010-0730

Galloway, R., & McGuire, J. (1994). Determinants of compliance with iron supplementation: Supplies, side effects, or psychology? *Social Science & Medicine, 39*(3), 381–390. https://doi.org/10.1016/0277-9536(94)90135-x

Gera, T., & Sachdev, H. P. (2002). Effect of iron supplementation on incidence of infectious illness in children: Systematic review. *British Medical Journal, 325*, 1142. https://doi.org/10.1136/bmj.325.7373.1142

Hadley, C., & Decaro, J. A. (2015). Brief communication: Does moderate iron deficiency protect against childhood illness? A test of the optimal iron hypothesis in Tanzania. *American Journal of Physical Anthropology, 157*, 675–679. https://doi.org/10.1002/ajpa.22756

Harkness, S., & Super, C. M. (1994). The developmental niche: A theoretical framework for analyzing the household production of health. *Social Science and Medicine, 38*, 218–226. https://doi.org/10.1016/0277-9536(94)90391-3

Iannotti, L. L., Tielsch, J. M., Black, M. M., & Black, R. E. (2006). Iron supplementation in early. childhood: health benefits and risks. *American Journal of Clinical Nutrition, 84*, 1261–1276. https://doi.org/10.1093/ajcn/84.6.1261

Instituto Nacional de Estadística e Informática [INEI]. (2014). *Una mirada a Lima Metropolitana [A look at Metropolitan Lima]*. Lima PERÚ.

Kroker-Lobos, M. F., Pedroza-Tobias, A., Pedraza, L. S., & Rivera, J. (2014). The double burden of undernutrition and excess body weight in Mexico. *American Journal of Clinical Nutrition, 100*(suppl), 1652S–1658S. https://doi.org/10.3945/ajcn.114.083832

Kuzawa, C. L. (1998). Adipose tissue in human infancy and childhood: An evolutionary perspective. *Yearbook of Physical Anthropology, 41*, 177–210. https://doi.org/10.1002/(sici)1096-8644(1998)107:27+<177::aid-ajpa7>3.0.co;2-b

Leonard, W. R., & Thomas, B. R. (1989). Biosocial responses to seasonal food stress in Highland Peru. *Human Biology, 61*(1), 65–85.

Lopez, A., Cacoub, P., Macdougall, I. C., & Peyrin-Biroulet, L. (2016). Iron deficiency anaemia. *Lancet, 387*, 907–916. https://doi.org/10.1016/S0140-6736(15)60865-0

Macgregor, M. (1963). Maternal anaemia as a factor in prematurity and perinatal mortality. *Scottish Medical Journal, 8*, 134–140. https://doi.org/10.1097/AOG.0000000000003557

Marin, C. A., Segura, J. L., Bern, C., Freedman, D. S., Lescanol, A. G., Benavente, L. E., Cordero, L. G., Clavijo, L., & Gilman, J. B. (1996). Seasonal change in nutritional status among young children in an urban shanty town in Peru. *Transactions of the Royal Society of Tropical Medicine and Hygiene, 90*, 442–444. https://doi.org/10.1016/s0035-9203(96)90541-6

Marini, A., Rokx, C., & Gallagher, P. (2017). *Standing tall: Peru's success in overcoming its stunting crisis*. International Bank for Reconstruction and Development/The World Bank.

McDade, T. W. (2012). Early environments and the ecology of inflammation. *Proceedings of the National Academy of Sciences, 109*(Suppl 2), 17281–17288. https://doi.org/10.1073/pnas.1202244109

McDade, T. W., Rutherford, J. N., Adair, L., & Kuzawa, C. (2008a). Adiposity and pathogen exposure predict C-reactive protein in Filipino women. *The Journal of Nutrition, 138*, 2442–2447. https://doi.org/10.3945/jn.108.092700

McDade, T. W., Reyes-Garcia, V., Tanner, S., Huanca, T., & Leonard, W. R. (2008b). Maintenance versus growth: Investigating the costs of immune activation among children in Lowland Bolivia. *American Journal of Physical Anthropology, 136*, 478–484. https://doi.org/10.1002/ajpa.20831

Ministerio de Salud. (2015). *Análisis de Situación de Salud DISA IV LE 2015*. Ministerio de Salud.

Navarrete Mejía, P. J., Velasco Guerrero, J. C., Loayza Alarico, M. J., & Huatuco Collantes, Z. A. (2016). Situación nutricional de niños de tres a cinco años de edad en tres distritos de Lima Metropolitana. *Horizonte Médico, 16*(4), 55–59.

Nazmi, A., Diez-Roux, A., Jenny, N., Tsai, M., Szklo, M., & Aiello, A. (2010). The influence of persistent pathogens on circulating levels of inflammatory markers: A cross-sectional analysis from the multi-ethnic study of atherosclerosis. *BMC Public Health, 10*, 706. https://doi.org/10.1186/1471-2458-10-706

Nead, K. G., Halterman, J. S., Kaczorowski, J. M., Auinger, P., & Weitzman, M. (2004). Overweight children and adolescents: A risk group for iron deficiency. *Pediatrics, 114*, 104–108. https://doi.org/10.1542/peds.114.1.104

Nemeth, E., & Ganz, T. (2006). Regulation of iron metabolism by hepcidin. *Annual Review of Nutrition, 26*, 323–342. https://doi.org/10.1146/annurev.nutr.26.061505.111303

Nguyen, X. M., Lane, J., Smith, B. R., & Nguyen, N. T. (2009). Changes in inflammatory biomarkers across weight classes in a representative US population: A link between obesity and inflammation. *Journal of Gastrointestinal Surgery, 13*, 1205–1212. https://doi.org/10.1007/s11605-009-0904-9

Nyakeriga, A. M., Troye-Blomberg, M., Dorfman, J. R., Alexander, N. D., Bäck, R., Kortok, M., Chemtai, A. K., Marsh, K., & Williams, T. N. (2004). Iron deficiency and malaria among children living on the coast of Kenya. *Journal of Infectious Diseases, 190*, 439–447. https://doi.org/10.1086/422331

Oppenheimer, S. J. (2001). Iron and its relation to immunity and infectious disease. *Journal of Nutrition, 131*, 616s–635s. https://doi.org/10.1093/jn/131.2.616S

Popkin, B. M., Kim, S., Rusev, E., Du, S., & Zizza, C. (2006). Measuring the full economic costs of diet, physical activity and obesity related chronic diseases. *Obesity Reviews, 7*, 271–293. https://doi.org/10.1111/j.1467-789X.2006.00230.x

Popkin, B. M., Adair, L. S., & Ng, S. W. (2012). Global nutrition transition and the pandemic of obesity in developing countries. *Nutrition Reviews, 70*(1), 3–21. https://doi.org/10.1111/j.1753-4887.2011.00456.x

Ramakrishnan, U., Aburto, N., McCabe, G., & Martorell, R. (2004). Multimicronutrient interventions but not vitamin A or iron interventions alone improve child growth: Results of 3 meta-analyses. *Journal of Nutrition, 134*, 2592–2602. https://doi.org/10.1093/jn/134.10.2592

Richard, S. A., Zavaleta, N., Caulfield, L. E., et al. (2006). Zinc and iron supplementation and malaria, diarrhea, and respiratory infections in children in the Peruvian Amazon. *American Journal of Tropical Medicine and Hygiene, 75*, 126–132. https://doi.org/10.4269/ajtmh.2006.75.1.0750126

Rodríguez-Zúñiga, M. (2015). Obesidad, sobrepeso y anemia en niños de una zona rural de Lima, Perú. *Medicina (Buenos Aires), 75*, 379–383.

Rogerson, S. J., Van Den Broek, N. R., Chaluluka, E., Qongwane, C., Mhango, C. G., & Molyneux, M. E. (2000). Malaria and anemia in antenatal women in Blantyre, Malawi: A twelve-month survey. *American Journal of Tropical Medicine and Hygiene, 62*(3), 335–340. https://doi.org/10.4269/ajtmh.2000.62.335

Sazawal, S., Black, R. E., Ramsan, M., et al. (2006). Effects of routine prophylactic supplementation with iron and folic acid on admission to hospital and mortality in preschool children in a high malaria transmission setting: Community-based, randomised, placebo-controlled trial. *Lancet, 367*, 133–143. https://doi.org/10.1016/S0140-6736(06)67962-2

Scholl TO, & Hediger, M. (1994). Anemia and iron-deficiency anemia: Compilation of data on pregnancy outcome. *American Journal of Clinical Nutrition, 59*, 492S–500S. https://doi.org/10.1093/ajcn/59.2.492S

Seltzer, C. C., & Mayer, J. (1963). Serum iron and iron-binding capacity in adolescents. II. Comparison of obese and non-obese subjects. *American Journal of Clinical Nutrition, 13*, 354–361. https://doi.org/10.1093/ajcn/13.6.354

Senn, N., Maraga, S., Sie, A., Rogerson, S. J., Reeder, J. C., et al. (2010). Population hemoglobin mean and anemia prevalence in Papua New Guinea: New metrics for defining malaria endemicity? *PLoS One, 5*(2), e9375. https://doi.org/10.1371/journal.pone.0009375

Soofi, S., Cousens, S., Iqbal, S. P., et al. (2013). Effect of provision of daily zinc and iron with several micronutrients on growth and morbidity among young children in Pakistan: A cluster-randomised trial. *Lancet, 382*, 29–40. https://doi.org/10.1016/S0140-6736(13)60437-7

Stearns, S. C. (1992). *The evolution of life histories*. Oxford University Press.

Stoltzfus, R. J., & Dreyfuss, M. L. (1998). *Guidelines for the use of iron supplements to prevent and treat iron deficiency anemia*. ILSI Press.

Stoltzfus, R., et al. (2004). Low dose daily iron supplementation improves iron status and appetite but not anemia, whereas quarterly anthelminthic treatment improves growth, appetite and anemia in Zanzibari preschool children. *The Journal of Nutrition, 134*, 348–356. https://doi.org/10.1093/jn/134.2.348

Super, C. M., & Harkness, S. (2002). Culture structures the environment for development. *Human Development, 45*, 270–274. https://doi.org/10.1159/000064988

Thompson, J., Biggs, B. A., & Pasricha, S. R. (2013). Effects of daily iron supplementation in 2- to 5- year-old children: Systematic review and meta-analysis. *Pediatrics, 131*(4), 739–753. https://doi.org/10.1542/peds.2012-2256

Thompson, A. L., Houck, K. M., Adair, L. S., Gordon-Larsen, P., Du, S., Zhang, B., & Popkin, B. M. (2014). Associations between pathogenic and obesogenic factors and inflammation in Chinese children, adolescents, and adults. *American Journal of Human Biology, 26*, 18–28.

Thompson, A. L., Adair, L., Gordon-Larsen, P., Zhang, B., & Popkin, B. (2015). Environmental, dietary, and behavioral factors distinguish Chinese adults with high waist-to- height ratio with and without inflammation. *Journal of Nutrition, 145*, 1335–1344. https://doi.org/10.3945/jn.114.206102

Vahdat, K., Azizi, F., Zandi, K., Assadi, M., & Nabipour, I. (2012). Chronic inflammation is correlated with percentage of body fat independent of the burden of infection. *Inflammation, 35*, 1322–1329. https://doi.org/10.1007/s10753-012-9445-6

Wander, K., Shell Duncan, B., & McDade, T. (2009). Evaluation of iron deficiency as a nutritional adaptation to infectious disease: An evolutionary medicine perspective. *American Journal of Human Biology, 21*, 172–179. https://doi.org/10.1002/ajhb.20839

Weinberg, E. D. (1992). Iron withholding in prevention of disease. In P. Stuart-Macadam & S. Kent (Eds.), *Diet, demography, and disease: Changing perspectives on anemia* (pp. 105–150). New York Aldine Gruyter, Inc.

Wenzel, B. J., Stults, H. B., & Mayer, J. (1962). Hypoferraemia in obese adolescents. *Lancet, 2*, 327–328. https://doi.org/10.1016/s0140-6736(62)90110-1

Williams, G. C., & Nesse, R. M. (1991). The dawn of Darwinian medicine. *Quarterly Review Biology, 66*, 1–22. https://doi.org/10.1086/417048

World Health Organization. (2002). *Reducing risks, promoting healthy life. The world health report 2002*. World Health Organization.

World Health Organization. (2009). *Global health risks: Mortality and burden of disease attributable to selected major risks*. World health Organization.

Worthman, C. (1994). Developmental microniche: A concept for modeling relationships of biology, behavior, and culture in development. *American Journal of Physical Anthropology Supplement., 18*, 210–562. https://doi.org/10.1177/0022022110362627

Worthman, C. (2010). The ecology of human development: Evolving models for cultural psychology. *Journal of Cross-Cultural Psychology, 41*(4), 546–562. https://doi.org/10.1177/0022022110362627

Yanoff, L. B., Menzie, C. M., Denkinger, B., Sebring, N. G., McHugh, T., Remaley, A. T., & Yanovski, J. A. (2007). Inflammation and iron deficiency in the hypoferremia of obesity. *International Journal of Obesity (London), 31*, 1412–1419. https://doi.org/10.1038/sj.ijo.0803625

Zavaleta, N., Respicio, G., & Garcia, T. (2000). Efficacy and acceptability of two iron supplementation schedules in adolescent school girls in Lima, Peru. *Journal of Nutrition, 130*, 462S–464S. https://doi.org/10.1093/jn/130.2.462S

Zhu, J., Quyyumi, A. A., Norman, J. E., Csako, G., Waclawiw, M. A., Shearer, G. M., & Epstein, S. E. (2000). Effects of total pathogen burden on coronary artery disease risk and C-reactive protein levels. *American Journal of Cardiology, 85*, 140–146. https://doi.org/10.1016/s0002-9149(99)00653-0

Zimmermann, M. B., & Hurrell, R. F. (2007). Nutritional iron deficiency. *Lancet, 11*, 511–520. https://doi.org/10.1016/S0140-6736(07)61235-5

Zimmermann, M. B., Zeder, C., Muthayya, S., Winichagoon, P., Chaouki, N., Aeberli, I., & Hurrell, R. F. (2008). Adiposity in women and children from transition countries predicts decreased iron absorption, iron deficiency and a reduced response to iron fortification. *International Journal of Obesity, 32*(7), 1098–1104. https://doi.org/10.1038/ijo.2008.43

Zlotkin, S., Newton, S., Aimone, A. M., et al. (2013). Effect of iron fortification on malaria incidence in infants and young children in Ghana: A randomized trial. *Journal of American Medical Association, 310*, 938–947. https://doi.org/10.1001/jama.2013.277129

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