CURRENT CONCEPTS

Management of Rotator Cuff Tears

Christopher C. Schmidt, MD, Claudius D. Jarrett, MD, Brandon T. Brown, MME

Every year approximately 18 million Americans report shoulder pain, a large percentage of which are a result of rotator cuff disease. Rotator cuff tear progression can be difficult to predict. Factors associated with tear enlargement include increasing symptoms, advanced age, involvement of 2 or more tendons, and rotator cable lesion. Nonsurgical treatment can be effective for patients with full-thickness tears. When conservative treatment fails, surgical repair provides a reliable treatment alternative. Recurrent tears after surgery can compromise outcomes, particularly for younger patients with physically demanding occupations. Revision surgery provides satisfactory results for those with symptomatic re-tears. If the tear is deemed irreparable, addressing concomitant biceps pathology or performing partial repairs can reliably improve pain and potentially reverse pseudoparalysis. The reverse shoulder arthroplasty has limited indications in the setting of rotator cuff tears and should be reserved for patients with painful pseudoparalysis and associated arthropathy. *(J Hand Surg Am. 2014;■(■):■−■. Copyright © 2014 by the American Society for Surgery of the Hand. All rights reserved.)*

Key words Appropriate Use Criteria (AUC), irreparable tears, natural history, recurrent tears, rotator cuff tears.

Rotator cuff pathology places a growing burden on our aging society.[1] It remains one of the most frequently encountered and surgically addressed diseases treated by the upper extremity surgeon.[2] Since the last update 3 years ago, a plethora of new literature has been published on rotator cuff disease and this article will highlight key findings and advancements.[2]

ANATOMY

The rotator cable, initially described in the early 1990s,[3] has received renewed attention secondary to its important mechanical function.[4,5] The cable can be visualized as a semilunar arch within the rotator cuff.[3] It is a 1-cm thickening within the supraspinatus and infraspinatus tendons that originates anteriorly near the rotator/biceps tendon interval and terminates between the infraspinatus and teres minor insertions[6] (Fig. 1). The cable's collagen fibers run perpendicular to the long axis of both the supraspinatus and infraspinatus tendons, in the sagittal plane.[6] Anatomical studies have demonstrated that it is a continuation of the coracohumeral ligament.[6] The cable forms an arching semicircular cord around the adjacent lateral cuff, named the rotator crescent.[3] The rotator crescent is typically 2 to 3 times thinner than the cable and attenuates with age.[3] The majority of rotator cuff tears seem to originate within the crescent tissue.[2]

The rotator cable appears to stress shield the crescent during loading. The cable's ability to transfer load may explain why the rotator cuff continues to function despite a tear. As long as the cable remains attached, the humeral head can maintain its center of rotation even in the presence of a large to massive tear.[3,7,8] A recent study has shown that a tear in the anterior cable, as opposed to a crescent, creates a larger gap, increases cuff strain, and loses its stress shielding capabilities.[4]

From the Department of Orthopaedic Surgery, University of Pittsburgh Medical School, Pittsburgh, PA; the Department of Orthopaedic Surgery, Emory Orthopaedic Center, Emory University of Hospitals, Atlanta, GA; and the Department of Mechanical Engineering and Materials Science, Swanson School of Engineering, University of Pittsburgh, Pittsburgh, PA.

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Corresponding author: Christopher C. Schmidt, MD, Department of Orthopaedic Surgery, University of Pittsburgh Medical School, 9104 Babcock Blvd, Suite 5113, Pittsburgh, PA 15237; e-mail: schmidtc@upmc.edu.

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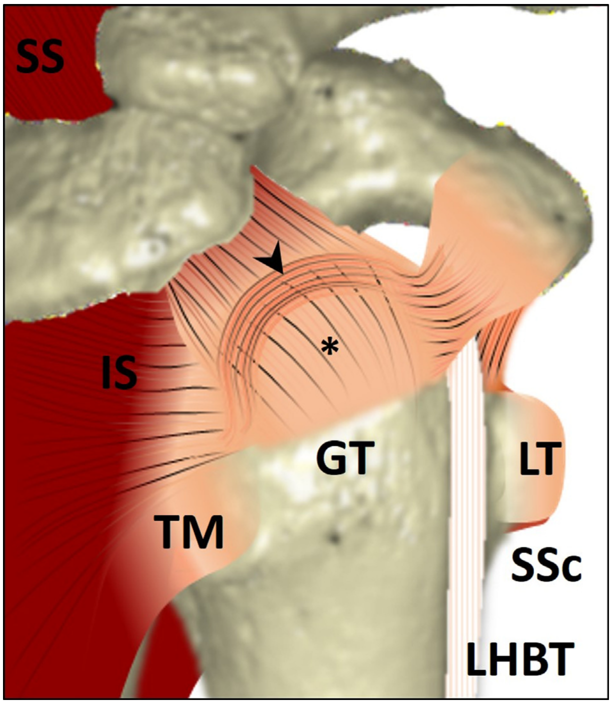

FIGURE 1: The schematic depicts the rotator cable (arrowhead) and crescent (asterisk). The cable is a semilunar arch that originates near the rotator interval/biceps tendon and terminates between the infraspinatus and teres minor. The cable forms an arching semicircular cord around the thinner lateral cuff called the rotator crescent. SS, supraspinatus; SSc, subscapularis; IS, infraspinatus; TM, teres minor; LT, lesser tuberosity; GT, greater tuberosity; LHBT, long head biceps tendon.

NATURAL HISTORY

Rotator cuff disease develops in the supraspinatus tendon mostly as a result of an intrinsic attritional process that leads to partial and then eventually full-thickness tearing.[2] Once developed, the fate of a tear remains difficult to predict.[2,9–11] Some tears continue to increase in size, whereas many others remain dormant and do not show signs of propagation. Those that do increase in size typically do so gradually, with only a minority (18% to 49%) enlarging > 5 mm in 3 years of surveillance.[9–12]

A concern for the patient and surgeon is a lesion that rapidly progresses in size without symptoms (Fig. 2). Fortunately, these progressive types of tears are uncommon. In 1 study they represent 13% of tears that increased more than 10 mm.[9] Although this type of progression is uncommon, continued vigilance remains warranted during nonsurgical management. Shoulder ultrasound seems to be a cost-effective way to monitor propagation that upper extremity surgeons can use with similar predictive values as experienced radiologists.[13]

RISK FACTORS FOR PROGRESSION

Several factors predict the risk for symptoms and/or tear expansion.

Tear size: Small 1-tendon tears may remain dormant, while larger 2-tendon lesions are more likely to undergo structural deterioration.[10,14] Zingg et al reported that approximately 50% of their patients with initially repairable massive rotator cuff tears progressed dramatically, becoming irreparable within 4 years.[14] The critical size for tipping a tear toward rapid decline has yet to be defined. Biomechanically, enlargement of a supraspinatus tear to involve the infraspinatus tendon appears to be the critical change for substantially altering humeral head kinematics.[8]

Symptoms: A strong correlation exists between tear propagation and the development of symptoms. Patients with enlarging rotator cuff tears are 5 times more likely to develop symptoms than those with tears that remain the same.[11]

Location: The location of a tear within the cuff also may impact the risk of progression. Anterior tears are more likely to involve the rotator cable and become associated with advanced cuff degeneration.[15] A recent biomechanical study has shown that anterior rotator cuff cable tears had significantly greater tear migration, decreased tendon stiffness, and increased regional tendon strain in comparison to an equally sized crescent tear posterior to the cable.[4]

Age: Full-thickness tears in younger patients appear to be more capable of withstanding the stress and tear propagation better than those in older patients.[10] Maman and colleagues reported that 17% of their younger patients (< 60 years) developed a measurable increase in the size of their symptomatic cuff tear in comparison to 54% of their older patients (> 60 years).[10]

TREATMENT

The recently published American Academy of Orthopedic Surgeons Rotator Cuff Guidelines, which preferentially weights higher-level evidence, determined that the strength of recommendation for repair of a full-thickness rotator cuff tear was "weak."[16] This finding created concern within the orthopedic community because rotator cuff repair has historically been an extremely successful procedure that decreases pain and improves function.[17] To address this concern, the American Academy of Orthopedic Surgeons developed the Appropriate Use Criteria (AUC) for treatment of full-thickness rotator cuff tears.[18] Partial-thickness cuff

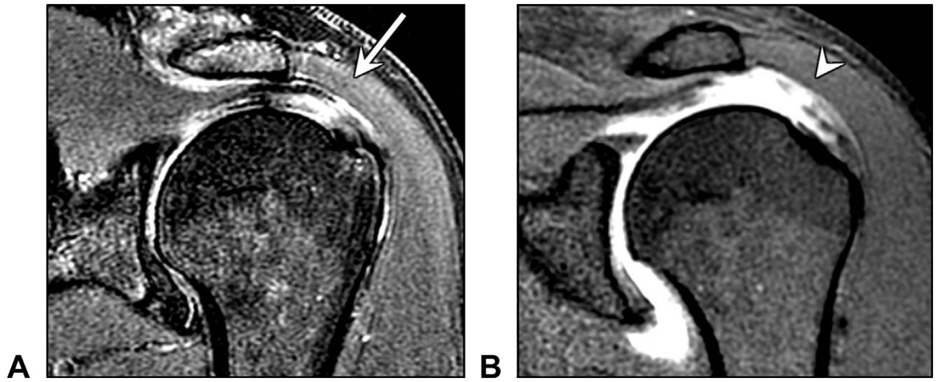

FIGURE 2: MRI of a 45-year-old man with a small tear that progressed without symptoms over the course of 1 year. **A** An asymptomatic small tear (arrow). **B** Depiction of tear enlargement with time (arrowhead).

tears were not studied by the AUC. The AUC takes into account the best available literature, expert opinion, and patient and disease factors in ranking levels of appropriateness, where *appropriate* means benefit greater than risk, *maybe appropriate* denotes benefit equals risk, and *rarely appropriate* equals benefit less than risk for each given clinical scenario.[1,18] The AUC for full-thickness rotator cuff tears developed 432 unique interactive clinical scenarios that can be referenced by the web-based mobile application (www.aaos.org/aucapp).[1,18]

The AUC for all classes of full-thickness rotator cuff tears can be summarized as follows: (1) Nonsurgical management is always *appropriate*, if patients have a positive response to conservative care; (2) repair *maybe appropriate* for a reparable tear even if patients respond to nonsurgical treatment; (3) repair is the *appropriate* treatment in healthy symptomatic patients who failed conservative management; (4) debridement/partial repair and/or reconstructions *may be appropriate* in chronic massive tears; and (5) arthroplasty is a *maybe appropriate* option for healthy patients with painful pseudoparalysis and an irreparable tear (CC Schmidt, BF Morrey, J Murray, JO Sanders, personal communication, December 2013).

The classification of partial-thickness tears into low and high grade, full-thickness tears into small, medium, large, and massive, and subscapularis tears has been previously published by the *Journal* in the earlier 2011 Current Concepts update titled, "Arthroscopic Treatment of Rotator Cuff Diseases."[2] In the past 3 years, the literature has added no significant advancements other than what has been stated in that article. Please reference that article for further discussion on specific classification types and recommended treatments.[2]

NONSURGICAL MANAGEMENT

Nonsurgical treatment has been shown to be effective treatment for full- thickness rotator cuff tears.[14,19] In a prospective cohort of patients with full-thickness tears, conservative management resulted in sustained symptom improvement in 75% of the patients at 2-year follow-up.[20] Surprisingly, low patient expectations were the strongest predictor of failure, not tear size and/or retraction.[19] Those who respond to nonsurgical management will typically do so within the first 6 to 12 weeks.[20]

SURGICAL MANAGEMENT

There has been a national shift from majority open to all-arthroscopic rotator cuff repairs directly paralleling technological advancements and changes in resident/surgeon education.[21] Although each technique poses unique potential risks and benefits, all provide equivocal long-term structural and clinical success rates.[22−24] While arthroscopic repairs may shorten the recovery period,[25,26] open repairs have been shown to decrease direct health care costs.[27,28] The remainder of this article will focus on arthroscopic repairs because of its emphasis in the recent literature.

When conservative management fails, arthroscopic rotator cuff repair continues to provide a high success rate of subjective and functional results.[2,17,29] With modern techniques, structural healing of small to large (1−4 cm) tears seems to be improving, with healing rates ranging from 83% to 93%.[17,30] Despite surgical advances, successfully repairing massive (> 4-cm) tears remains a challenge, with reported failure rates from 21% to 91%.[31,32] While pain relief, clinical improvement, and function can be achieved irrespective of the final state of the repaired tendon,

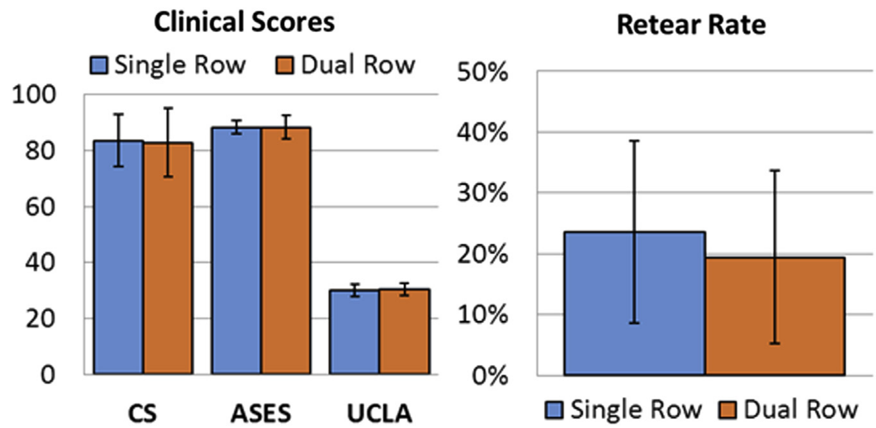

FIGURE 3: Comparison of the single-row and double-row techniques in clinical outcomes and re-tear rates. The table averages the results from 12 articles published in the literature over the past 5 years[2,34,36−39] (SR in blue, DR in orange).

better outcomes and increased shoulder abduction strength are obtained after a healed repair.[17,30,33]

Primary repair

Current research continues to explore avenues to improve both the mechanical strength and biologic milieu of the surgically repaired tendon. Surgical techniques continue to improve time-0 fixation strength. Debate continues over the exact role of the double-row repair (DR), especially when the added cost, time, and unique complications are taken into consideration.[2] The DR technique has been shown to provide a stronger repair, more closely replicating the native footprint than does the classic single-row suture anchor repair.[2,34,35] Although this approach would be expected to decrease the re-tear rate, short to mid term clinical results do not achieve a consistently clear clinical benefit over single-row (SR) repairs (Fig. 3).[2,34,36−40] Lapner and colleagues published a randomized trial comparing clinical and structural outcomes for DR versus SR repairs. Two years after surgery, the authors were unable to identify a difference in clinical results between the 2 groups (Fig. 3).[40] A meta-analysis consisting of 9 Level I and II studies found no difference between both in Constant score, UCLA score, strength, external rotation, or forward elevation. They did, however, find a statistically significant benefit for DR repairs in re-tear rates, ASES score, and internal rotation, in larger tears (> 30 mm in the anteroposterior dimension).[34]

Two of the main concerns with the DR repair are the added cost and location of the re-tear. The general application of this technique may not be economically justified because rotator cuff repair by either a DR or SR has a low rate of revisions. Cost analysis data have shown that a considerable decrease in revision surgery by the DR would be required to justify the increase in healthcare dollars.[41] Bisson et al estimated that to obtain cost neutrality, DR repairs would have to result in 1 fewer revision surgery in every 17 small repairs (1 cm) and in every 4 primary massive repairs (> 5 cm).[41] Further, other investigators have shown that a DR repair is not cost effective for any tear size.[42] In contrast to an SR, a DR repair fails at the muscle-tendon junction instead of at the repair site.[2,37] This type of catastrophic failure requires repair of the muscle-tendon junction, which is achievable but challenging.[37]

Modern, sophisticated single-row repairs (ie, modified Mason-Allen and massive cuff stitch) may be able to match the mechanical strength of double-row repairs (Fig. 4).[43,44] Increasing the number of sutures limbs in an SR to that of a DR can neutralize the biomechanical superiority of the DR.[45]

The treating surgeon should be comfortable with several repair techniques, because the technique applied should be based on the tear pattern and tissue quality. A tension-free suture line should take precedence over coverage of the entire footprint.[3] As the diseased cuff deteriorates, not only does the muscle retract and stiffen, but also the tendon contracts.[46] When this occurs, attempting to reduce the torn tendon edge to the footprint may result in a nonanatomic "lateralized" repair. When the remaining rotator cuff tendon length is < 1 cm, the DR repair is at risk for overreducing the tendon and placing excessive stress at the musculotendinous junction.[36] In such a case, the SR repair may reduce the undesirable tension.

The torn supraspinatus and infraspinatus tendons are typically pulled posteriorly by their respective muscles,

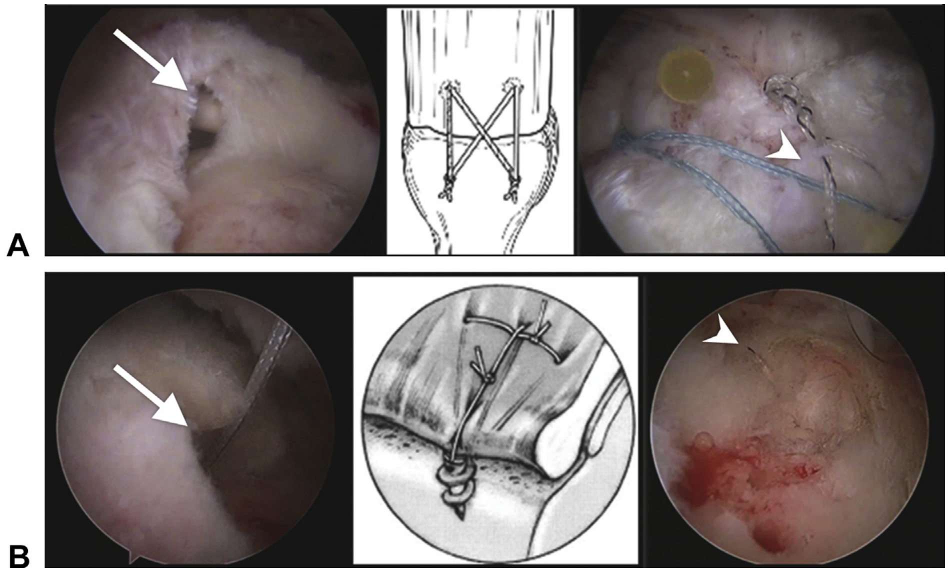

FIGURE 4: A A medium-size tear (arrow), followed by a schematic of a suture-bridge repair next to an arthroscopic view of a completed suture-bridge repair (arrowhead). (Permission from Trappey GJ, Gartsman GM. A systematic review of the clinical outcomes of single row versus double row rotator cuff repairs. *J Shoulder Elbow Surg*. 2011;20(2):S14−S19.[44]) **B** An example of a medium-size tear (arrow), followed by a schematic of an arthroscopic Mason-Allen repair next to an arthroscopic view of the repair (arrowhead). (Permission from Scheibel MT, Habermeyer P. A modified Mason-Allen technique for rotator cuff repair using suture anchors. *Arthroscopy*. 2003;19(3):330−333.[43])

so the tear needs to be repaired by bringing and securing these tendons anteriorly onto their native insertion sites. If possible, the sutures should be placed in or proximal to the rotator cable to decrease suture pullout (Fig. 1).[5] Additionally, achieving adequate fixation near the attachment points of the rotator cuff cable should be top priority.[4,7,15]

Patients with massive rotator cuff tears and pseudoparalysis (inability to forward elevate the arm > 90°) may still be candidates for arthroscopic repair. Two recent studies have shown that modern arthroscopic mobilization and repair techniques can reverse the pseudoparalysis between 75% and 97% in primary repairs.[47,48]

Acromioplasty

The need for concomittent acromioplasty during rotator cuff repair continues to come into question.[49,50] Several studies have shown equivalent results with and without a subacromial decompression during arthroscopic rotator cuff repair for small to massive tears even with acromial anatomic types II and III.[49,50] For instance, MacDonald et al performed a prospective controlled trial enrolling 86 patients with tears ≤ 4 cm and all acromial types; patients were randomized to either arthroscopic rotator cuff repair with or without an acromioplasty.[49] At 24 months after surgery, there were no significant clinical differences between the 2 cohorts in the Western Ontario Rotator Cuff Index or ASES scores.[49] However, they did find a higher reoperation rate, 4 of 41 (10%) versus 0 of 45 (0%), in the group without acromioplasty. The 4 reoperations occurred in 1 type II and 3 type III acromions.[49] A recent Level I meta-analysis found no differences in patient-derived outcomes, but the repeat surgeries in type III acromions with no acromioplasty were concerning.[50] The studies suggest that acromioplasty is not necessary for acromial types I and II but may be beneficial for Type III.

Biological augmentation

Success rates of surgically repaired tears have improved, but the resultant tendon-bone interface does not replicate the native tissue. Several recent studies have attempted to improve the biologic milieu at the repair site through platelet-rich plasma (PRP), individual growth factors, stem cells, and/ or biologic scaffolds.[2,51,52]

PRP and platelet-rich fibrin garners considerable interest by delivering a constellation of autologous growth factors and cytokines at the repair site. An *in vitro* model reported improved collagen formation and repair strength with application of PRP at the tendon-bone interface.[53] However, the majority of

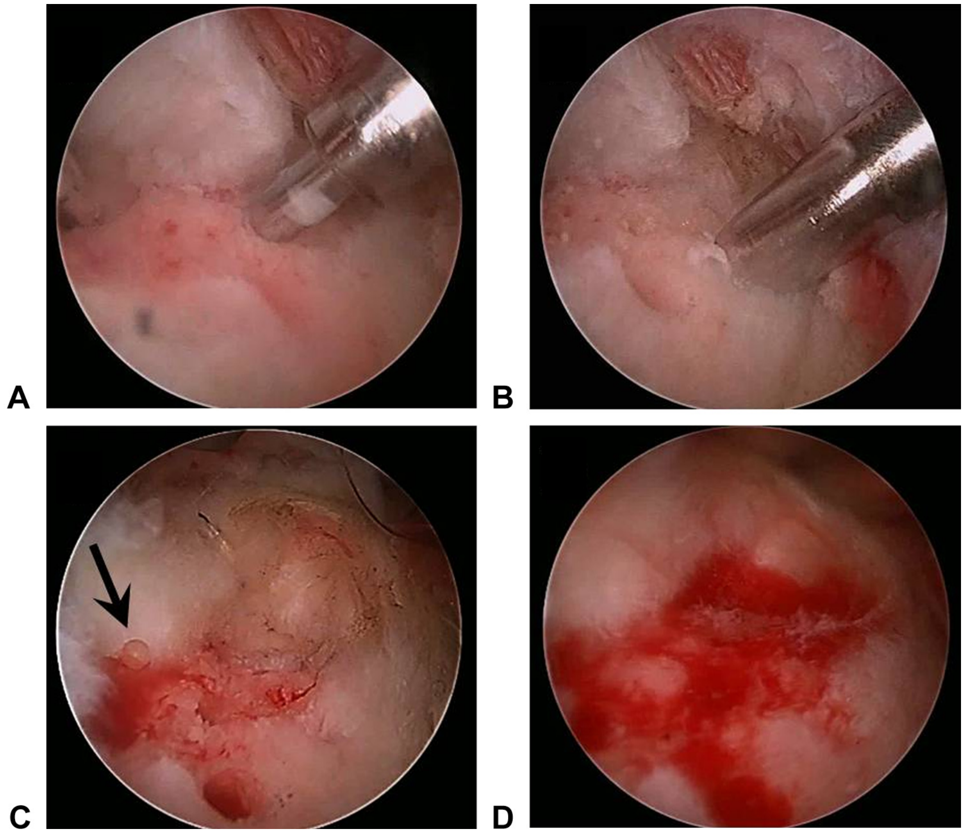

FIGURE 5: Illustrations of repair site humeral venting—"crimson duvet"—technique that is designed to increase growth factors and stem cells. **A**, **B** The photographs show drilling vents through cortical bone. **C** Holes are drilled next to repair site. Notice the bone marrow and blood escaping through the holes (arrow). **D** The pump pressure is decreased and a blood clot forms near the repair site.

clinical studies have been unable to identify a consistent clinical benefit in favor of the application of PRP during rotator cuff repairs.[2,51,52] Some authors have reported an improved healing rate in a subset of tears. Zumstein and colleagues found that when applied to large to massive tears, the PRP-treated group had a lower re-tear rate (20%) in comparison to their control (55%).[51] In comparison, a systematic review by Chahal et al identified a lower re-tear rate with the use of PRP when they only assessed small to medium-sized tears.[52] When larger tears were included, no difference was found.[52] This discrepancy may stem from the variations in the percentages of platelets and white blood cells, dosage, activation, and delivery medium used in many of these investigations.[2,51,52,54] These variations in preparations raise concerns about generalizing their efficacy.

Marrow-stimulating techniques, coined "crimson-duvet," continue to gain popularity.[55–57] Marrow venting as opposed to mere decortication of the greater tuberosity has been shown to encourage an inflow of stem cells, growth factors, and cytokines to the repair site (Fig. 5).[57] The lack of added cost and ease of application of this technique makes it attractive. Two clinical investigations reported improvement in the structural integrity of larger tears with application of this technique.[55,56] Milano and colleagues conducted a blinded, prospective randomized trial comparing clinical and structural outcomes following arthroscopic single-row cuff repairs with and without venting of the greater tuberosity. At 1 year postoperatively, the massive tears that underwent venting were statistically ($P < .04$) more likely to maintain the continuity of their repair, 60% with venting compared to 12% without venting.[56]

RECURRENT TEARS

Recent studies have shown that the majority of recurrent tears occur within the first 6 months following repair.[17,58] Although some patients may achieve successful clinical results despite the presence of a re-tear,[59] many will report inferior results if tendon continuity is lost.[17,30,33] A multicenter study reported a significant ($P < .02$) decrease in abduction strength compared to the uninjured side in the re-tear group when compared with intact patients.[17] Patients with physically demanding occupations are more likely to be affected, as isometric testing has shown a 45% loss of shoulder strength in patients with failed repairs.[30,33,60]

Several studies have reported that revision rotator cuff repair can lead to a statistical ($P < .05$) reduction in pain and increase in the Simple Shoulder Test, American Shoulder and Elbow Surgeons (ASES) scores, UCLA scores, and active forward elevation.[61–63] Intact repairs at 1-year follow up were observed in 70% of single-tendon tears (10 of 21) and 27% of 2-tendon tears (4 of 11).[63] Successful repairs had significantly ($P < .05$) better Constant scores and scapular elevation strength measurements.[63] Preoperative forward elevation < 90°, pain score > 5, and female sex were predictors of poor outcome.[61,62] Surprisingly, the size of the tear was not a negative predictor, and patients with a recurrent massive tear still can have an acceptable result with revision surgery.[61,62] However, reversal of pseudoparalysis with advanced arthroscopic techniques was found in only 43% (6 of 14).[48]

THE IRREPARABLE TEAR

The nonreparable tear remains a difficult problem to address. Prior to the development of arthritis, several reconstructive and salvage soft tissue procedures can be considered if conservative management fails. The patient's presenting symptoms, age, risk factors, and functional demands should dictate which option to recommend.[1,18] Although preoperative imaging can provide some insight into the reparability of a tear, intraoperative assessment should provide the final verdict on reparability and not an acromiohumeral interval < 7 mm and stage III fatty infiltration.[2,47,48]

Partial repair and/or debridement and reconstruction can be acceptable alternatives when repair is not possible. These procedures have merit in the literature for irreparable tears.[2,32,64–71] A recent study reported that an arthroscopic partial repair significantly improved the Simple Shoulder Test, ASES score, and the UCLA score.[72] The goal of the partial repair is to restore the transverse force couple by repairing the rotator cable in an attempt to stabilize the humeral head on the glenoid. The percentage of patients that had reversal of pseudoparalysis with a primary partial repair was 63%, and with revision partial repair, 30%.[48,64] In elderly patients with a minimum of 90° of preoperative forward elevation, arthroscopic debridement without an acromioplasty with a biceps tenotomy has been shown to significantly increase ASES scores and decrease pain.[73]

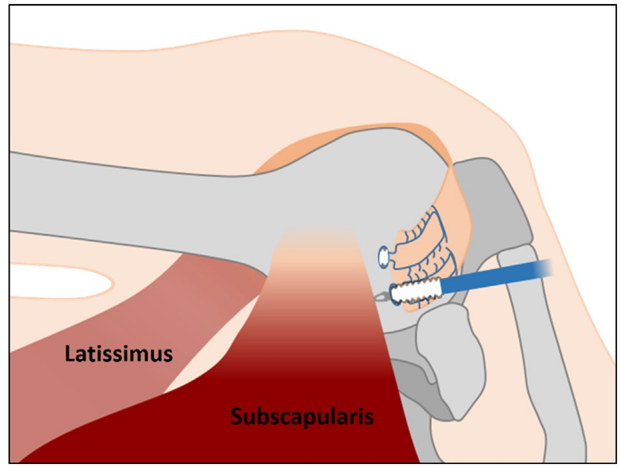

FIGURE 6: The schematic shows the latissimus dorsi tendon being transferred to the greater tuberosity and repaired with 2 knotless anchors. This transfer is ideal in a patient with > 90° of forward elevation, but who lacks strong external rotation. We have found that repairing the latissimus into the greater tuberosity with knotless anchors instead of the traditionally described technique of suturing it to the subscapularis tendon simplifies the operation without compromising function.

Reconstruction, including both muscle transfers and patch-augmented repairs, has been used successfully in salvage procedures. An ideal candidate for latissimus dorsi tendon transfer would be a patient with an irreparable tear and intact subscapularis muscle, teres minor stage 2 (may have considerable amount of fat, but still more muscle than fat present on an imaging study) or lower fatty atrophy, and forward elevation of at least 90° (Fig. 6).[67,70,71] This option should be thought of as a transfer to restore shoulder external rotation and not forward elevation.

Extracellular matrix scaffolds have produced mixed results in limited number of clinical studies.[2,68,69] Investigators have reported a high rate of postoperative inflammatory reaction in the non–cross-linked porcine scaffold and have discouraged its use in humans.[68] Several authors have documented success using non-cross-linked human dermis scaffolds as onlay or inlay grafts in case series without control groups.[69] The Food and Drug Administration has not approved any of the current matrix grafts for spanning of defects > 1 cm.[69]

The reverse shoulder arthroplasty has gathered much enthusiasm over the past decade.[74] The best indications for this implant are patients with rotator cuff arthropathy with painful pseudoparalysis; they can reliably experience substantial improvement in pain and forward elevation.[74–76] Although some authors report promising results in patients with irreparable cuff tears without arthritis, such expanded application should be approached with caution because of the high complication rates and potential loss of preoperative forward elevation.[77,78]

POSTOPERATIVE REHABILITATION

Traditionally, postoperative adhesive capsulitis has been a concern with open cuff repairs, and this led to the recommendation of early aggressive therapy focused on regaining preoperative motion.[79] Mini-open and all-arthroscopic repairs appear to minimize that risk of stiffness, allowing more time to protect the integrity of the repair.[22–24,80] Particularly, arthroscopic rotator cuff repairs can be immobilized for 6 weeks without a significant fear of loss of motion.[81,82] In a prospective randomized clinical trial, Kim and colleagues found no clinical differences or re-tear rates between early passive range of motion and complete immobilization following repair of small to medium-sized tears.[82] Keener et al performed a similar prospective randomized trial comparing a therapist direct passive range of motion program or complete shoulder immobilization for the first 6 weeks following repair of full-thickness tears measuring < 30 mm in width.[81] The researchers reported an equally successful healing rate between the 2 groups (90% early motion vs 90% immobilization group [$P > .05$]).[81]

In conclusion, rotator cuff disease and management will continue to demand our attention. Because of the unpredictable natural history of the torn rotator cuff, close follow-up is warranted when nonsurgical management is chosen. An intact rotator cable may allow patients to preserve function despite the presence of a tear. Surgical repair continues to provide a high success rate for patients who have failed conservative management. Advances in surgical technique have improved our ability to provide rigid repair fixation. Biological modalities aimed at enhancing repair quality show promise but their efficacy is still unclear. Those with physically demanding occupations should be counseled appropriately about the risk for compromised outcomes if a re-tear occurs. Both the clinician and patient should remain optimistic when a recurrent or an irreparable tear is encountered because available salvage procedures can offer decreased pain and improved function.

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