Management of Disorders of the Rotator Cuff: Proceedings of the ISAKOS Upper Extremity Committee Consensus Meeting

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Abstract: The goal of this article is to consolidate the International Society of Arthroscopy, Knee Surgery & Orthopaedic Sports Medicine (ISAKOS) Upper Extremity Committee's (UEC's) current knowledge on rotator cuff disease and management, as well as highlight key unresolved issues. The rotator cuff is an anatomically complex structure important for providing glenohumeral function and stability as part of a closed chain system. Current consensus suggests rotator cuff injuries are most accurately diagnosed, at levels similar to diagnosis by magnetic resonance imaging, with a combination of cuff- and impingement-specific clinical tests. Updates in the understanding of acromion morphology, the insertional anatomy of the rotator cuff, and the role of suprascapular nerve release may require changes to current classification systems and surgical strategies. Although initial management focuses on nonoperative protocols, discussion continues on whether surgery for isolated impingement is clinically more beneficial than rehabilitation. However, clear indications have yet to be established for the use of single- versus double-row repair because evidence confirms neither is clinically efficacious than the other. Biceps tenodesis, however, in non-isolated cuff tears has proven more successful in addressing the etiology of shoulder pain and yields improved outcomes over tenotomy. Data reviewing the benefits of tendon transfers, shoulder prostheses, and mechanical scaffolds, as well as new research on the potential benefit of platelet-rich plasma, pluripotential stem cells, and gene therapies, will also be presented.

Introduction

In the city of Buenos Aires, from April 16 to April 19, 2012, 20 members of the International Society of Arthroscopy, Knee Surgery & Orthopaedic Sports Medicine (ISAKOS) Upper Extremity Committee (UEC) met for the Biannual UEC Closed Consensus Meeting. This report, "Management of disorders of the rotator cuff: Proceedings of the ISAKOS Upper Extremity Committee consensus meeting," constitutes an integral part of the agreement encountered during the aforementioned meeting and is intended to describe the current knowledge available about this topic as well as its controversial areas. Given the lack of high levels of evidence to define some of the discussed issues, the best quality of knowledge was taken into account. The ISAKOS UEC members hope the readers find this compendium regarding the status update of rotator cuff disease useful for daily practice.

From the Closed Consensus Meeting of the International Society of Knee Surgery and Orthopaedic Sports Medicine Upper Extremity Committee, Buenos Aires, Argentina, April 2012.

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Section A: Bone, Tendon, Bursa, and Neurovascular Anatomy *by Felix Savoie III, Eiji Itoi, and Guillermo Arce*

Known Facts

1. Acromion Shape and the Risk of Rotator Cuff Injury

Three types of acromion shape assessed on the scapular Y-view have been reported: type 1, flat; type 2, curved; and type 3, hooked.[1] The hooked type of acromion is present in around 26% of the general population[1] as well as the majority of patients with rotator cuff tears.[2] However, it is not easy to assess the 3-dimensional shape of the acromion by use of a single plain radiograph. Later, anatomic studies showed that type 2 was the most common type, with type 3 being found at a rate of less than 10% in the general population. In addition, the contact between the cuff tendon and the undersurface of the acromion showed that shoulders with rotator cuff tears had a wider contact area, which indicated that the acromion shape was more the type 2 shape in cuff tear shoulders.[3] Clinically, Gill et al.[4] reported there was no association between acromial morphology and rotator cuff pathology. Recently, a lateral projection of the acromion measured on an anteroposterior radiograph was reported to be related to the rotator cuff tendon rupture: the cuff tear shoulders showed more laterally projected acromions. Although the routine use of adjunctive acromioplasty during arthroscopic rotator cuff repair is currently a matter of debate, it appears beneficial in patients with an osteophyte located at the anterior rim of the acromion, in which tendon release from extrinsic impingement is warranted. The lateral acromial edge may also be an important factor in the production of symptoms and should be considered when one is evaluating the acromion.

In cases of massive irreparable or partially repairable cuff tears, the coracoacromial arc should be preserved even in the presence of a hooked acromion. An acromioplasty in the previously mentioned scenario could transform a functional cuff tear into a nonfunctional tear because of anterior-superior humeral head instability and escape.

2. Tendon Insertion

Accurate identification of the rotator cuff tear site remains critical for optimal surgical repair. The insertional anatomy of the rotator cuff differs from how it is commonly represented. Several previous anatomic studies have concluded the insertions of the supraspinatus tendon (SSP) and infraspinatus tendon (ISP) are located at the highest impression of the greater tuberosity, known as the superior facet and middle facet, respectively. Nonetheless, recent seminal work by Mochizuki et al.,[5] who performed a revision in 103 human cadaveric shoulders, indicates different. In most cases the ISP footprint was found to cover a large portion of the greater tuberosity whereas the SSP was attached to only a discrete anterior portion of the greater tuberosity. Thus the SSP footprint appeared much smaller whereas the ISP footprint was much wider than previously reported. Of note, in 21% of cadavers, some fibers of the SSP were inserted in the lesser tuberosity. Recent findings also suggest that the SSP inserts more anteriorly and that its insertional fibers may blend with the transverse humeral ligament. Furthermore, the ISP inserts as 2 separate tendons, transverse and oblique. The transverse tendon, being more superior, blends with the SSP and inserts as a confluence of both on the upper facet of the greater tuberosity. The oblique tendon inserts lower and, in many cases, wraps around the lateral aspect of the greater tuberosity. Although these tendons are only 2 components of the rotator cuff, these accepted anatomic modifications in tendon footprint anatomy may, subsequently, require changes not only in rotator cuff tear classification (i.e., from "U" to "L" or "reverse L") but also in surgical strategy (i.e., closed with posterior to anterior oblique with sutures).

3. Relation Between Vasculature and Rotator Cuff Disease

The anterior and posterior humeral circumflex arteries (and their respective branches) perfuse the rotator cuff with additional support from the suprascapular, thoracoacromial, suprahumeral, and subscapular arteries.[6] Although several studies have shown the presence of diminished blood flow at the level of the distal insertion of the SSP, its sole presence does not justify the development of rotator cuff tears.[7,8] Moreover, Doppler flow studies (power Doppler, laser Doppler flowmetry, and contrast-enhanced ultrasonography) have reported diminished blood flow in elderly patients with rotator cuff injury and in cases with impingement[9]; however, increased flow was found during arm exercise. For decades and as supported by cadaveric studies, the mechanism of rotator cuff tears has been considered to be related to inadequate blood supply, especially at the insertion of the SSP. Both the impact of ischemia in the attritional degeneration of the aging tendon and the whole concept of the "critical portion" have been recently challenged by Doppler studies showing that the actual area of tendon impingement could be hypervascularized.

4. The Role of the Subacromial-Subdeltoid Bursa in Rotator Cuff Disease

The medial aspect of the bursa provides blood supply to the rotator cuff tendon that may accelerate tendon healing, and therefore preservation of this bursa remains essential. Its positive effect, along with the presence of anchor holes and bone marrow–derived stem cells, enhances the healing scenario for cuff repair.[10] The lateral bursa is often pathologic and a pain generator, which may dictate surgical excision. In addition, the suture configuration should not jeopardize the tendon blood supply.[11]

5. Bone Quality and Rotator Cuff Repair

The bone of the greater tuberosity atrophies with age and injury and thus complicates rotator cuff repair surgery and postoperative recovery.[12] Surgeons should therefore aim to use bone on the medial aspect of the insertional footprint, near the articular cartilage, for anchor placement. Furthermore, screw fixation can be strengthened by preserving the cortical bone in the area of the anchor. Lastly, decortication, microfracture, and deeper puncture into the marrow should be considered to improve the access of regenerative elements to the repaired tendon.

6. Suprascapular Nerve and Rotator Cuff Disease

Suprascapular nerve preservation is essential to achieving a successful rotator cuff repair.[13] In some cases the nerve can be compressed anteriorly at the suprascapular notch, in the supraspinatus fossa by cysts, or near the spinoglenoid notch.[14] Compression is indicated by rapid atrophy, a positive Lafosse test, imaging showing perineural edema and adhesions, an abnormal electromyography/nerve conduction study, and symptomatic relief after selected, guided injection. With such manifestations, steps must be taken to decompress the nerve and ensure its viability through transverse or spinoglenoid ligament release and cyst decompression before SLAP rotator cuff repair.

The compressed suprascapular nerve can be arthroscopically visualized and released both anteriorly and posteriorly using techniques that provide acceptable, safe, and reproducible results.[15] A key aspect of nerve decompression involves addressing an anatomically inconsistent spinoglenoid ligament and other nearby structures.

Table 1. Section A: Bone, Tendon, Bursa, and Neurovascular Anatomy Summary

- The insertional anatomy of the SSP and ISP deviates from the common representation. Noticeable differences in footprint anatomy may require subsequent changes in rotator cuff tear classification and surgical strategy.
- The development of rotator cuff tears cannot be fully justified by the decreased vascularity of the SSP.
- The medial subacromial-subdeltoid bursa provides blood supply to the rotator cuff tendon and thus may play a role in healing after rotator cuff repair surgery. The lateral bursa is considered pathologic and the cause of pain.
- Patient age and bone density at the greater tuberosity are inversely proportional.
- Surgeons must follow a specific surgical strategy to ensure adequate screw fixation in rotator cuff repair and improve healing potential.
- The suprascapular nerve is prone to anterior compression at the scapular notch by a thickened transverse ligament or by the sling effect of a retracted cuff tear. A paralabral cyst could compress the nerve at the spinoglenoid fossa. Nerve release with rotator cuff repair may be inevitable depending on findings from the Lafosse test, electromyography/nerve conduction study, imaging studies, and relief of symptoms after guided injection.
- The direction of future research should focus on the role the acromion morphology plays in variations in the type of impingement and refining the role of suprascapular nerve release in rotator cuff repair surgery.

Unresolved Issues and Future Directions

1. Further studies are needed to define whether rotator cuff impingement varies according to acromion type (shapes).
2. The mechanical or biological role of the subacromial decompression needs to be determined with better-quality prospective studies. A hooked acromion may not necessarily be the cause of the impingement and rotator cuff tears. The anterior-superior instability related to cuff pathology could lead to functional impingement.
3. The potential for reversal of muscle atrophy requires additional research.
4. The medial bursa provides blood supply to the tendon; however, it is currently unclear whether the bursa has to be excised or preserved. Thus future investigations regarding the appropriate timing for medial bursa reformation after surgical excision, as well as the actual role of the bursa with regard to vascular supply to the healing rotator cuff, are needed.
5. The committee agrees the chronically inflamed bursa has no role other than creating pain. Further research in vivo is needed to confirm that the bursa reforms after surgical resection and that it has the same positive role as the healthy bursa.
6. The role of suprascapular nerve release in patients undergoing rotator cuff repair requires further refinement regarding indications and expected results.

Table 1 summarizes the data from section A.

Section B: Biomechanics *by W. Ben Kibler and Giovanni di Giacomo*

Known Facts

The shoulder is a prime example of a closed chain system anatomically organized to provide stability (ball-and-socket kinematics) and allow for maximal multiplanar function (mobility).[16,17] Biomechanically, it works as a funnel to regulate and transfer forces from the trunk and core to the hand. Specifically, the humeral head is positioned for function by a closed chain formed by the thorax (kinetic chain), scapula, and clavicle. The rotator cuff musculature supports this function by providing the largest proportion of glenohumeral stability.[18,19] Thus it is evident that changes in an element of this system will influence the kinematic and dynamic behavior of the other elements within the system. Any rotator cuff abnormality requires a response (stabilization, change, or any compensatory mechanism) with the system and may affect rotator cuff activation, compression, tension, or motion.[20,21] Kinetic chain activity affects the capability of the rotator cuff to develop strength and act as a compressor to produce effective force couples and be active throughout the full range of motion.[22,23]

The scapula plays a critical role in glenohumeral function by offering a stable base for muscle activation and load transfer within the closed kinetic chain.[16,21] Abnormalities in normal scapular position or kinematics can affect rotator cuff function and thus are an impetus for compression and tensile strain on the cuff, biceps, and superior labrum.[24] Such abnormalities in scapular motion and position are frequent in patients with impingement and rotator cuff injury and often manifest as diminished upward and external rotation, as well as increased anterior tilt. In addition, the upper trapezius compensates for these changes with increased activation in an effort to elevate the shoulder, thereby allowing arm motion and force generation (shoulder strength).[25] In sum, functional scores in patients with rotator cuff tears are strongly dependent on scapular function, and maximal demonstrated rotator cuff strength capability is related to a stabilized scapular position.[26-28]

Internal impingement, partial undersurface rotator cuff tears, superior labral tears, glenohumeral internal rotation deficit, and total range-of-motion deficit are all frequently inter-related in etiology and clinical presentation.[24] In overhead-demand patients, SLAP tears, glenohumeral internal rotation deficit, total range-of-motion deficit, and anterior laxity appear to be associated with partial-thickness rotator cuff tears.[29,30]

Unresolved Issues and Future Directions

Our understanding of shoulder biomechanics has considerably reinforced our surgical strategies; however, several unresolved issues remain and highlight a need for continued research and education. These issues and potential directions for future investigations and education are highlighted as follows:

1. Uncertainty remains regarding how the altered proximal motions and force development relate to rotator cuff injury causation, cuff tear progression, and subsequent decisions for treatment.
2. It is unclear whether altered proximal activations and motions are always associated with rotator cuff injury. If they are always associated, the cause-and-effect relation between the 2 is not well established.
3. The most effective methods for clinically evaluating the altered kinetic chain and scapular factors are not fully elucidated.
4. The exact role of internal impingement in partial rotator cuff injuries needs to be established.

Table 2. Section B: Biomechanics Summary

- The shoulder is a closed chain system that provides maximal functionality and stability, which is highly dependent on muscle contribution. Furthermore, it regulates and transfers energy from the trunk and core to the hand.
- The rotator cuff musculature provides a significant proportion of the glenohumeral stability.
- The scapula provides a stable base for muscle activity and load transfer; thus it plays a significant role in glenohumeral function. Any abnormality in scapular motion and position will affect the functionality and stability of the rotator cuff, biceps, and superior labrum.
- Internal impingement, superior labral tears, rotator cuff tears, and range-of-motion deficits are often related in etiology and clinical presentation.
- Researchers and clinicians have expressed uncertainty as to whether abnormalities in proximal motion and position cause injury or, rather, are due to associated injuries. Thus future research and clinical evaluation and education should focus more closely on the kinetic chain and the role of scapular instability in shoulder dysfunction.

5. The effect of using kinetic chain conditioning methods in the prevention of rotator cuff injuries in susceptible populations needs to be determined.
6. Clinical methods for evaluating and classifying the kinetic chain and scapula and its effect on the shoulder are needed.
7. A more effective rehabilitation program using the entire kinetic chain to improve functional results from rotator cuff repair should be designed.

Table 2 summarizes the data from section B.

Section C: Tendinosis, Impingement, and Ruptures *by Klaus Bak, Eiji Itoi, Tom Ludvigsen, and Augustus Mazzocca*

Known Facts

1. Diagnosis of a Symptomatic Rotator Cuff Tear

Determining the mechanism of injury, degree and type of pain, clinical dysfunction, and patient demands during the initial patient encounter/examination contributes to accurately diagnosing a rotator cuff tear and can guide future treatment.[31] The clinical examination is equally as accurate as, if not more accurate than, any current technology; however, no single test alone is highly accurate. For example, the presentation of impingement signs and/or the presentation of scapular dyskinesis—a commonly encountered sign in patients with symptomatic rotator cuff tears—are very sensitive indicators in patients with an acute rotator cuff tear; however, they are not specific.[31] Conversely, cuff-specific tests, such as the drop-arm test, external rotational lag sign, Whipple test (for a complete supraspinatus tear), and internal rotational lag sign (for the subscapularis), are quite specific but not sensitive. Surgeons can use a subacromial injection of lidocaine to assess passive range of motion and cuff strength, which increases the sensitivity of impingement signs and specificity of cuff-specific tests (>90%) but subsequently also reduces their respective specificity and sensitivity.[31] In sum, single tests as part of the clinical examination are not diagnostically reliable.

A meta-analysis of various cohort studies found the overall sensitivity and specificity of a clinical examination to rule out a full-thickness rotator cuff tear to be 90%.[32] Thus the combination of 2 to 4 examination tests improves diagnostic accuracy reaching the magnetic resonance imaging (MRI) levels.[33] Nevertheless, further confirmation of a diagnosed rotator cuff tear must still be made with noninvasive imaging (i.e., radiography followed by ultrasonography or MRI/magnetic resonance arthrogram).

2. Acromioplasty in 2012: Is There an Indication?

Nonoperative management of impingement is effective in the vast majority of cases; however, acromioplasty is indicated if a patient complains of lateral pain aggravated by night pain, has a positive impingement sign, and has a painful arc with no improvement on the scapular assistance test and scapular retraction test. This procedure is best indicated in patients who do not benefit from a 3-month rehabilitation program. Nevertheless, overall surgical indications for isolated acromioplasty have steadily decreased because of the implementation of a refined clinical examination and the use of reliable noninvasive imaging studies. Data show that no statistical difference exists in rotator cuff repair healing rates with and without acromioplasty.[34,35] Interestingly enough, however, recent evidence suggests a reduction in the long-term retear rate when acromioplasty is performed at the index repair.

3. Coracoid Impingement

Primary coracoid impingement occurs from spurs, subscapularis tendon calcification, and a decrease in the coracoid index (coracoid-humeral distance). The most reliable clinical test is the modified Hawkins-Kennedy impingement sign, in which the arm is positioned in abduction of 45° to 60°, forward flexion, and internal rotation with a slight anterior subluxation force. The occurrence of symptoms, crepitus (grinding), and pain are indicative of coracoid impingement. In addition, pain at the coracoid tip constitutes a common finding. Diagnostic imaging constitutes part of the patient workup, as does measuring the coracoid index, although its role is not well defined.

Nonsurgical management for suspected coracoid impingement is currently recommended for the first 3 to 6 months, during which rehabilitation exercises focus on improvement in posture and scapular retraction to open the subcoracoid interval. Coracoid decompression should be pursued if the patient presents with a positive injection sign and previous conservative measures have failed. The surgery is performed arthroscopically with the removal of the posterior part of the tip of the coracoid projecting beyond the origin of the conjoined tendon.

4. Asymptomatic Tears

Size and location are the most important factors when considering management of asymptomatic rotator cuff tears and may predict symptomatic progression. Most asymptomatic tears responded to nonoperative protocols and remained asymptomatic at 2 years.

5. How and Why the Tendon Fails

The rotator cuff structure is highly dependent on histologic processes, which help explain how and why the rotator cuff tendon fails.[36] More specifically, biopsy specimens of retrieved tendon from rotator cuff tears have shown disorganized collagen, scar tissue, and minimal attempts at a healing process. Furthermore, according to Tuoheti et al.,[37] the confluence of age-related tendinosis and apoptosis leads to tendon failure. Apoptosis is an organized form of cell death in which a programmed sequence of events leads to the cellular elimination. It plays a crucial role in developing and maintaining the health of the body by eliminating old, unnecessary, and unhealthy cells.

6. Tear Retraction Patterns

The rotator cuff tendon degenerates and weakens with age and shows a specific area of high stress concentration at the articular side of the supraspinatus,

Table 3. Section C: Tendinosis, Impingement, and Ruptures Summary

- Clinical examination of suspected rotator cuff tears is considered as accurate as, if not more accurate than, any technology; however, no single test is highly accurate—the tests are highly sensitive with low specificity or vice versa. Combined tests improve diagnostic accuracy to the equivalent of MRI/magnetic resonance arthrogram. Confirmation of the clinical diagnosis is made with radiography and ultrasonography or MRI/magnetic resonance arthrogram.
- Indications for acromioplasty include lateral shoulder pain exacerbated by night pain, as well as a painful arc with no improvement on the scapular assistance test and scapular retraction test.
- Typically, shoulder impingement can be managed nonoperatively because no statistical difference exists between rotator cuff healing rates with and without acromioplasty; however, the retear rate is decreased when the surgery is performed at the index repair.
- Signs and symptoms of coracoid impingement include crepitus and pain on examination. It should be nonsurgically managed for the first 3 to 6 months. Coracoid decompression should only be completed after failure of conservative measures in addition to a positive injection sign.
- Size and location are the most important factors when determining asymptomatic tear management.
- Histologic changes and alterations in apoptotic processes play a role in tendon failure.

close to its most anterior attachment site at or near the biceps tendon. Several factors, such as tendinosis, heel-type acromion, and coracoacromial ligament hardening, have been associated with tear development. Both tendinosis and friction may, in concert, cause a tendon tear. The presence of a more anterolateral acromion overhang leads to an increase SSP workload and friction with the acromion, which consequently is what leads to the development of a rotator cuff tendon tear. The occurrence and depth of a bursal-side tear appear to be related to the coracoacromial arch.

In most cases the rotator cuff tendon retracts along the muscle fibers' line of pull. Tear propagation runs anteriorly and posteriorly at a rate of 5 mm/y but can be amplified by smoking and heavy labor.

Unresolved Issues and Future Directions

1. Factors involved in patient symptomatology after rotator cuff tear and whether symptom manifestation is due to anatomic structural changes or shoulder dysfunction need to be examined.
2. The mechanism by which the subacromial decompression works needs to be established.
3. It has never been proven that surgery for isolated impingement is more clinically efficacious than rehabilitative treatment.
4. The normal coracoid anatomic variants are yet to be defined.
5. It is currently unclear how to perform a precise impingement diagnosis.
6. The exact amount of bone removal required during coracoid decompression is still a matter of debate.
7. There is a need to further investigate the correlation between subacromial impingement and tendon failure considering that the apoptotic index has been shown to increase with impingement and rotator cuff tears.
8. A simple and reproducible set of diagnostic tests and questions should be developed to evaluate the patient with rotator cuff symptoms that can be repeated after treatment to evaluate the effectiveness. Such tests would require further validation in different geographic locations.
9. Direct comparison studies of isolated acromioplasty versus current rehabilitation programs for patients with classical impingement syndrome are needed.

Table 3 summarizes the data from section C.

Section D: Arthroscopic Reconstructions—Surgical Management of Rotator Cuff Tears *by Jaap Willems and Dan Guttmann*

Known Facts

1. Partial Rotator Cuff Tears

The weight of evidence supporting a variety of techniques for partial rotator cuff repair is low because the majority of the studies are either observational or limited in size.[38,39]

Partial tears with greater than 50% involvement should undergo repair, whereas smaller tears can be managed conservatively with physical therapy and activity modification. There are several surgical alternatives for repairing partial tears, including transtendon repair, transosseous repair, completion of the tear, and either single- and/or double-row repair. In certain surgical cases, debridement with or without subacromial decompression may suffice, rather than a formal repair. Regardless of the chosen surgical strategy, tear depth should be assessed preoperatively to gain further insight.

Internal derangements of the shoulder involving the labrum and/or the biceps tendon do not occur in isolation and should be addressed during the index surgical procedures. Secondary factors, such as SLAP lesions, posterior capsule tightness, and/or anterior laxity, may play a role in the pathogenesis of partial-thickness rotator cuff tears. Bursal-side partial rotator cuff tears are usually related to acromial spurring and represent a key step in a pathologic cascade that leads to progressive shoulder deterioration.

2. Full-Thickness Tears

2.1. Arthroscopic Versus Open Repairs. In a thorough meta-analysis, arthroscopic rotator cuff repair showed better visualization and allowed for a more complete understanding of the disease and its associated conditions, including biceps and labral pathology and cartilage, capsular, and ligamentous alterations versus open repair.[40] Moreover, conclusions suggest it permits a better identification of arthritis. Thus one could conclude arthroscopic rotator cuff repair appears to be more efficacious than open repair; however, studies assessing both surgical approaches are limited in size and methodology and provide insufficient evidence for determining the best method.[41,42] Furthermore, with time, the results of arthroscopic repair have continued to improve. Nevertheless, outcomes have proven arthroscopic repair for small tears is clinically advantageous considering that it allows the surgeon to visualize the entire joint, including the rotator cuff; decreases loss of motion; preserves the deltoid muscle; lowers infection rates and postoperative pain; expedites physical therapy; and shortens hospital stays.[43] The long-term functional outcome is also superior with arthroscopy for small tears, though at the expense of longer operating times and higher total cost for equipment and consumables, in comparison to open surgery. Not surprisingly, however, the cost is offset by the reduced cost for analgesics and expedited hospital discharge, rehabilitation, and return to work. These observed benefits of arthroscopy versus open surgery are diminished when repairing large cuff tears.

2.2. Single- Versus Double-Row Repairs. Comparative data between single- and double-row repair techniques are confounded by the use of an equivalent number of anchors in both techniques.[44,45] A recently reported systematic review suggested double-row repair offers higher initial fixation strength and greater footprint coverage, improved contact pressure, and decreased gap formation with higher load to failure compared with single-row repair.[41,46] Nonetheless, this observed biomechanical advantage did not manifest as a superior clinical outcome.[47-50] Double-row repair appears to be particularly advantageous for large tears (2.5 to 3.5 cm in size).[41] Recent data suggest that medial recurrent tears can be very difficult to handle, occurring more frequently after the double-row technique.[15,43] Thus surgeons should pay special attention when applying the double-row technique to stiff retracted tendons. Over-reduction and increased tension due to the double-row fixation technique should be avoided. Overall, we recommend its use in carefully selected cases because it increases operative time and cost and constitutes a technical challenge to the operator.

3. The Biceps Tendon in the Setting of Rotator Cuff Disease

The biceps-pulley anatomy plays a major role in biceps stability and may be partly responsible for the development of a painful shoulder. Pulley reconstruction after an isolated tear is not advised because of its intricate nature.[51] Wearing of the long head of the biceps can trigger pain and should be addressed with either tenotomy or tenodesis depending on the patient's demands and cosmesis.[52,53] Biceps tenodesis is cosmetically more appealing and increases elbow flexion and supination strength compared with tenotomy.[53]

Proximal biceps tenodesis has a high incidence of postoperative pain at the groove. Thus it may be beneficial to move distal with the tenodesis to prevent postoperative pain. Preoperative palpation of the biceps groove below the pectoralis major (the Mazzocca sign) may help determine the feasibility and efficacy of subpectoral tenodesis. These provocative maneuvers are especially relevant because noninvasive imaging (MRI) cannot establish the most appropriate location for tenodesis.[54-56]

Arthroscopic visualization of the glenohumeral joint and the long head of the biceps tendon may be insufficient regarding the surgical decision because the biceps tendon may not be fully appreciated. Thus it is also important to search for edema on the MRI study and attempt to reproduce pain using palpation in the biceps tendon on clinical evaluation. Distal biceps tenodesis could be performed arthroscopically above the pectoralis major tendon or open at the subpectoral area.

Table 4. Section D: Arthroscopic Reconstructions—Surgical Management of Rotator Cuff Tears Summary

- The double-row rotator cuff repair technique has not been proven to be clinically/surgically more efficacious than the single-row repair technique in managing full-thickness rotator cuff tears.
- The threshold for surgical repair of partial rotator cuff tears exists at approximately 50% of the rotator cuff footprint.
- Partial rotator cuff tears do not occur in isolation and are related to underlying pathology, such as SLAP lesions, capsule tightness, and acromial spurring.
- Arthroscopic assessment of a rotator cuff tear provides an excellent way to visualize and anatomically reduce the tear.
- The long head of the biceps is a common pain generator. It can be addressed with tenotomy or tenodesis. The use of the Mazzocca test (palpation in the groove below the pectoralis major) is beneficial for identifying the best place to fix the tenodesis.
- Future relevant areas of research should focus on identifying/stratifying guidelines for nonoperative versus operative approaches to rotator cuff repair, investigating the most effective time to use single- versus double-row rotator cuff repair techniques, and identifying the most efficacious time and anatomic location for biceps tenodesis.

Subscapularis tears should always be considered and coracoid impingement excluded when biceps tendon tears, pulley lesions, and/or subluxations occur. Moreover, the presence of coracoid impingement should be excluded; however, if present, it should be corrected with coracoid decompression in addition to the subscapularis repair. Of note, a subscapularis repair uses different postoperative rehabilitation protocols than repairs of supraspinatus and infraspinatus tears.

Unresolved Issues and Future Directions

1. The expected healing rate after rotator cuff repair has yet to be defined.
2. The possibility of predicting tear progression should be investigated, and it should be used as a guide for surgical decision making.
3. Clear indications for single- versus double-row rotator cuff repair need to be established.
4. Whether the number of anchors placed negatively impacts tendon healing at the bone site should be identified.
5. The timing and location of adjunctive biceps tendon tenodesis during rotator cuff repair need to be established.

Table 4 summarizes the data from section D.

Section E: Augments and Prosthesis for Rotator Cuff Disease *by Felix Savoie III, John Uribe, and Emilio Calvo*

Known Facts

The best surgical outcomes are the result of anatomic restoration to normal anatomy. Biological and mechanical enhancement of rotator cuff repair surgery and postoperative healing remains a viable goal of all surgeons, especially with the development of modern techniques using recent laboratory advancements, gene therapy and pharmaceutical intervention, mechanical patches or scaffolds, tendon transfers, and reverse shoulder prostheses.

Recent laboratory advancements have proven successful in promoting tendon healing; however, the potential for use in rotator cuff repair remains under investigation. Nevertheless, researchers have identified the use of plasma-rich platelets and pluripotential biologic (stem) cells as potential strategies to improve healing and mechanical functionality after rotator cuff repair. Current research shows limited success and therefore diminished clinical efficacy because of harvest system heterogeneity in terms of the amount of material delivered to the tendon.[57-59] In addition, the delivery mechanism does not adequately prevent washout of treatment cells at the repair site. Experimental studies have shown that different growth factors are capable of increasing the strength of repairs. Unfortunately, this seems to be accomplished through an increase in scar tissue production instead of by forming a physiological tendon-to-bone insertion.[57,59] The optimal timing, concentration, and combination of the different growth factors remain unclear, and as in transduced and modified stem cell applications, the optimal dosage and vehicle for delivery have remained elusive. Another promising approach to the biologic augmentation of rotator cuff repair involves modifying postoperative/postinjury catabolic processes through gene and pharmaceutical therapies targeting matrix metalloproteinase 3—an enzyme responsible for degrading extracellular matrix. Postoperative/postinjury catabolism is a normal physiological process, which plays a role in tendon tissue remodeling and degeneration. However, this process may also limit anatomic restoration to normal anatomy and thus limit tendon functionality. The use of gene therapy to target matrix metalloproteinase 3 and enhance tendon healing is a tantalizing area of current and future research. Despite promising findings, randomized comparative clinical studies have failed to show any beneficial effect of these biologic therapeutic interventions. Further research is required to define the correct dosage, quantification, and timing, as well as to fully understand the synergism between modified stem cells and different growth factors.[58,60,61] Thus some clinicians rely more so on mechanical patches and scaffolds to augment surgical repair and healing.

To promote tendon healing, some investigators have used mechanical patches or scaffolds with varying results.[60,61] The rationale for using these devices may include mechanical augmentation or biologically enhancing tendon healing. The ideal scaffold material would serve as an inductive template, with optimal mechanical properties to prevent or limit tendon retear during the process of degradation, engraftment, and remodeling, resulting in an integration and reconstruction of the tissue. Unfortunately, the devices currently available may not provide all of these capabilities. The use of non−cross-linked autograft tissue seems to provide the best solution. The clinical use of any scaffold for bridging or interposition is still a matter of debate. Because most rotator cuff tears can be repaired with proper surgical technique, the use of these devices is usually recommended for massive retracted irreparable tears that cannot be reconstructed with low tension, but they could also be used as augmentation devices in smaller tears with poor tissue quality. Although synthetic patches hold promise, few clinical data exist to show the appropriate indications, efficacy, and adverse effects of scaffolds for rotator cuff repairs. Combination strategies, such as tissue-engineered constructs that mate scaffolds with growth factors or pluripotential biologic cells, may meet the goals of these therapies. Tendon transfers and shoulder prostheses are more established methods of augmentation; however, their use is limited to specific surgical cases.

The use of tendon transfer in massive tears with concomitant atrophy seems a reasonable strategy for supplementation but should be limited to selected cases. Tendon transfers are mainly indicated in relatively young patients with irreparable rotator cuff tears in whom reverse prosthesis is contraindicated. Latissimus dorsi transfer could represent a feasible strategy in a patient with an intact subscapularis, acceptable passive flexion, and a large posterior superior tear and severe atrophy.[62] Moreover, partial or complete subcoracoid pectoralis major transfer may be an attractive solution in a patient with an intact infraspinatus and a severely torn, atrophic, and non-reparable subscapularis.[63] Adherence to the postoperative rehabilitation protocol remains crucial to the success of these procedures, as well as to deltoid integrity and tendon quality. The management of combined anterior and posterosuperior defects continues to be a difficult problem. Although some reports have suggested the benefits of combined pectoralis and latissimus dorsi tendon transfer, data are very scant.

The main indication for reverse shoulder arthroplasty in patients with rotator cuff tears is the presence of rotator cuff tear arthropathy. Reverse shoulder arthroplasty has proven to be very successful in patients with this condition, with substantial improvements in pain and active elevation.[64] Recently, the indications for reverse shoulder arthroplasty have been expanded to include selected massive cuff tears with pseudoparalysis but no arthritis, with good results.[65] In this situation, the use of a reverse shoulder prosthesis during rotator cuff repair should be limited to elderly patients with painful

Table 5. Section E: Augments and Prosthesis for Rotator Cuff Disease Summary

- Technologies currently being investigated for their potential to enhance healing after rotator cuff injury and surgical repair include platelet-rich plasma, pluripotential biologic cells, and mechanical patches, as well as limiting catabolic processes through gene therapy and pharmaceutical intervention.
- Other more established methods include the use of tendon transfers and reverse shoulder prosthesis, both of which have been shown to be most efficacious within specific populations.
- Future investigations should focus on refining current approaches to enhancing postoperative tendon healing.

shoulders, a truly irreparable tear (Goutallier stage 4), severe muscular atrophy, pseudoparalysis, and anterior-superior escape with a positive lag sign. To restore external rotation in individuals with a positive lag sign, adjunctive latissimus dorsi with or without teres major transfer is probably advisable.[66] When one is using the Gerber technique, transferring the latissimus dorsi to the greater tuberosity in reverse shoulder arthroplasty, only the latissimus dorsi is commonly used. When performing the Episcopo technique—redirecting the tendon around the humerus—it is technically difficult to use only the latissimus dorsi; therefore both the teres major and latissimus dorsi are used.

Unresolved Issues and Future Directions

The biological and mechanical enhancement of rotator cuff surgical repair and postoperative healing has increasingly become a viable goal for surgeons, with the introduction of current advancements. Current and future investigations should focus on refining current concepts:

1. The most optimal method for acquiring, processing, delivering, and maintaining autologous pluripotential cells within the healing zone of the rotator cuff to enhance healing should be determined.
2. The most optimal method to inhibit tendon tissue degradation should be determined.
3. In vitro and animal studies are warranted to determine the proper role of augmentation devices during rotator cuff surgery.

Table 5 summarizes the data from section E.

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