Review Article

Posterosuperior Rotator Cuff Tears: Classification, Pattern Recognition, and Treatment

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Abstract

The posterosuperior rotator cuff, composed of the supraspinatus and infraspinatus tendons, is the most common site for full-thickness rotator cuff tears and represents a significant source of shoulder disability worldwide. Recognition of and classification of full-thickness tear patterns are essential in order to optimize surgical treatment and to improve prognosis. Until recently, tear patterns have been described using one- or two-dimensional classification systems. Three-dimensional pattern recognition is critical to achieving the most successful outcome possible. For more complex patterns, a combination of side-to-side stitching, margin convergence, and interval slide techniques may be needed to achieve a tension-free tendon-bone repair. Biomechanical and anatomic evidence supports the use of linked double-row repairs for most full-thickness tears. Although double-row repairs seem to result in improved structural outcomes, clinical evidence has not shown differences in outcomes scores between single-row and double-row repairs. Single-row repair may be performed in partial-thickness, small full-thickness, or very massive, immobile tears, whereas double-row repair may be performed in most other cases.

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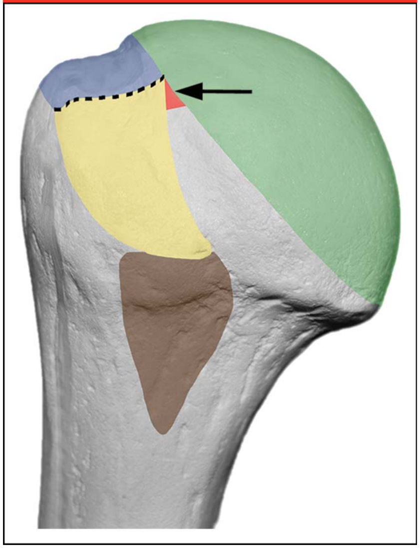
J Am Acad Orthop Surg 2014;22: 521-534

http://dx.doi.org/10.5435/JAAOS-22-08-521

The ideal management strategy for rotator cuff tears has been debated by orthopaedic surgeons for several generations. In 1933, Codman was the first to note that rotator cuff tears occur in predictable patterns that, once recognized, could be used to optimize management.[1] Little progress was made until 1984, however, when DeOrio and Cofield[2] devised a classification scheme for rotator cuff tears. In their study, tears were divided into broad categories based on the "length of the greatest diameter of the tear"—whether small, medium, large, or massive. Whereas this system still has some utility, no studies have shown its ability to predict prognosis with respect to specific repair techniques.

The recent advancement of arthroscopy has allowed for improved identification, visualization, and classification of rotator cuff tears. Furthermore, most rotator cuff tears can now be repaired using all-arthroscopic techniques. Therefore, it is critical to distinguish between the most common tear patterns in order to plan and achieve the most accurate, functional, and stable anatomic reduction possible. Davidson et al[3] found that high-quality MRI could be used to predict specific tear patterns encountered at diagnostic arthroscopy. In 2010, Davidson and Burkhart[4] geometrically classified tear patterns with respect to prognosis. As a result of these studies, a surgeon can now detect three-dimensional tear

Figure 1



Model of the proximal humerus highlighting the insertion sites of the posterosuperior cuff relative to the humeral head articular cartilage. The bare area represents the triangular region (red) between the articular cartilage (green) and the insertion sites of the posterior cuff (yellow = infraspinatus; brown = teres minor). The dashed line represents the interval between the supraspinatus (blue) and infraspinatus tendon insertions.

patterns using high-resolution MRI, select an appropriate repair method, and estimate the prognosis at the initial consultation, all before entering the surgical suite.

Three-dimensional tear pattern recognition has now become a standard method of evaluation in patients with posterosuperior rotator cuff tears because specific patterns are associated with favorable prognoses and outcomes when the correct repair technique is chosen. As a modification of work done by Ellman,[5,6] the four most common patterns were described by Davidson and Burkhart[4] as crescent; U-shaped; L-shaped; and massive, contracted, immobile tears. Each pattern has a recommended treatment method based on biomechanical and functional considerations.

Anatomic Considerations

The influence of exact anatomic footprint restoration on shoulder kinematics and function is currently unknown. However, it is thought that reestablishment of normal anatomy both enhances tendon-footprint healing and restores normal rotator cuff force couples. To accurately repair the footprint, a working knowledge of insertional anatomy is helpful and may increase the likelihood of a successful outcome.

The greater tuberosity is composed of three insertional facets to which the muscles of the posterosuperior cuff attach—superior, middle, and inferior. From anterior to posterior, the supraspinatus spans an area that includes the most anterior aspect of the superior facet, eventually blending with the fibers of the infraspinatus at the superior aspect of the middle facet. Continuing posteriorly, the intermingling of fibers diminishes such that the inferior facet contains only the infraspinatus.[7,8] Because of this fiber overlap, identification of the interval between the supraspinatus and the infraspinatus is often difficult.[8] The "bare area" is a triangular region between the humeral head articular cartilage and the medial margin of the posterior cuff insertion (Figure 1). The region just lateral to the superior confluence of the bare area may be a useful landmark to delineate the approximate location of the supraspinatus-infraspinatus interval where some fibers of the infraspinatus turn anteriorly and laterally while the remaining fibers fan out inferiorly.[9] Volk and Vangsness[10] and Dugas et al[11] attempted to describe interval landmarks; however, these landmarks are likely to be inconsistent because of the variability in reported insertional dimensions.

For the past two decades, several investigators attempted to report the precise dimensions of the rotator cuff insertion, producing significantly varied results[7-13] (Table 1). Tendon overlap and intermingling of fibers makes it difficult to identify the exact intermuscular intervals, thereby hindering the reproducibility of any given AP footprint measurement.[7,8,13] In addition to reported differences in AP dimensions, the extent of lateral excursion of each tendon footprint is also debated, leading to reported differences in medial-lateral dimensions.

The primary aim of both Dugas et al[11] and Curtis et al[8] was to precisely define the medial-lateral and AP dimensions of each rotator cuff tendon footprint. Both groups mapped the individual footprint sites using similar procedures; they found similar mean AP dimensions of both the supraspinatus and infraspinatus tendon insertion sites where small variability likely existed because of intermingling of fibers, tendon crossover, and differences in interpretation. These findings showed improved inter-study agreement between the anatomic footprint dimensions of each tendon in the AP direction compared with other studies. However, significant differences were seen when the medial-lateral dimensions of each insertion site between these two studies were compared, even though both groups found that the supraspinatus and infraspinatus footprints began nearly immediately adjacent to the lateral margin of the articular cartilage. Because the articular margin is an easily defined area, it appears that differences in the medial-lateral length therefore must be attributed to differences in reporting the most lateral point of each tendinous footprint. Further studies using similar dissection techniques should be conducted such that meaningful comparisons can be made between studies and reproducible results can be obtained.

Evolution of Rotator Cuff Tear Classification Systems

Neer[14] stratified rotator cuff disease into various stages corresponding to

Table 1

Reported Dimensions of the Posterosuperior Cuff Insertion

	Supraspinatus		Infraspinatus		
Study	**Medial-lateral Length (mm)**	**AP Length (mm)**	**Medial-lateral Length (mm)**	**AP Length (mm)**	**Measurement Techniques**
Minagawa et al[7]	NR	22.5	NR	14.1	Layered dissection performed
Curtis et al[8]	23	16	29	19	Separated individual myotendinous units
Roh et al[9]	NR	21.2	NR	NR	No direct insertion measurements
Volk and Vangsness[10]	27.9	NR	NR	NR	Measured only coronal and sagittal sections
Dugas et al[11]	12.7	16.3	13.4	16.4	Separated myotendinous units, mapped insertion with 3-space digitizer
Ruotolo et al[12]	NR	25	NR	NR	AP length measured with caliper
Mochizuki et al[13]	6.9	12.6	10.2	32.7	Used bilateral shoulders, separated myotendinous units

AP = anterior-posterior, NR = not reported

the histopathologic findings. However, this classification system could not be used to guide treatment decisions or to estimate a prognosis, thus significantly limiting its applicability in clinical practice. Later, DeOrio and Cofield[2] described full-thickness tears as being small, medium, large, or massive. In 1990, Patte[15] indicated that the classification of rotator cuff tears should not only address the extent of the tear, but also the coronal and sagittal topography. In addition, tendon quality, involving factors such as the degree of fatty infiltration, as described by Goutallier et al,[16] and the status of the long head of the biceps tendon should be ascertained such that successful repair can be achieved. Table 2 summarizes the important rotator cuff classification systems.

Tear Extension

Patte[15] developed a comprehensive classification scheme in which full-thickness tears were divided into four groups, depending on the degree of tear extension and the presence or absence of glenohumeral arthrosis. Gschwend et al[17] used this system to describe full-thickness rotator cuff tears and their correlation with clinical findings. In their study of 256 patients with rotator cuff tears, all patients with partial-thickness or full-thickness tears <1 cm in AP length (ie, group I) had pain without functional limitation (see Table 2). This finding supports the biomechanical "suspension bridge" principle, described by Burkhart[18] in 1990, in which the intact tendon fibers of a small- to medium-sized full-thickness tear are able to transmit similar force vectors to that of the intact cuff, thereby resulting in minimal functional losses for the patient. In contrast, pain alone was present in only 51%, 48%, and none of the patients in groups II, III, and IV, respectively. The authors reported that although pain relief after surgical repair was most often achieved, improvement in range of motion was less predictable and likely related to the initial severity of the tear.

Sagittal Topography

Patte[15] also developed a six-segment classification system relating to sagittal topography. Similarly, Habermeyer et al[19] classified sagittal topography as being composed of three distinct zones, generally reflecting the number of tendons involved in the tear. Sethi et al[20] reported a 17% re-tear rate a minimum of 1 year after arthroscopic repair of two-tendon rotator cuff tears using a linked double-row construct. The authors implied that their rate of re-tears after arthroscopic double-row repair of two-tendon tears was similar to reported re-tear rates after arthroscopic repair of single-tendon tears. However, it must be noted that anatomic studies have yet to determine the exact intermuscular interval between the supraspinatus and infraspinatus tendons, thus making it impossible to determine which borderline tears are, in fact, "two-tendon" posterosuperior tears.

Coronal Topography

Classification of coronal topography, also described by Patte,[15] takes into account the degree of tendon retraction, which also has significant technical implications regarding the chosen repair method. In

Table 2

Summary of Rotator Cuff Tear Classification Systems

Study	Variable	Group/Stage/Grade	Classification
Patte[15]	Tear extent	Group I	Partial- or full-thickness tears <1 cm in sagittal diameter
		Group II	Full-thickness tears of entire supraspinatus tendon
		Group III	Full-thickness tears involving more than one tendon
		Group IV	Massive tears with secondary osteoarthritis
Patte[15]	Sagittal tear topography	Segment 1	Subscapularis tear
		Segment 2	Coracohumeral ligament tear
		Segment 3	Isolated supraspinatus tear
		Segment 4	Entire supraspinatus tear including half of the infraspinatus
		Segment 5	Supraspinatus and infraspinatus tear
		Segment 6	Subscapularis, supraspinatus, and infraspinatus tears
Habermeyeret al[19]	Sagittal tear topography	Zone A - Anterior	Rotator interval, LHB, and subscapularis tendon
		Zone B - Central	Entire supraspinatus tendon
		Zone C - Posterior	Infraspinatus and teres minor tendons
Patte[15]	Coronal tear topography	Stage 1	Degree of tendon retraction: Lateral margin close to footprint area
		Stage 2	Degree of tendon retraction: Lateral margin at level of humeral head
		Stage 3	Degree of tendon retraction: Lateral margin at level of glenoid
Thomazeau et al[23]	Muscle atrophy	Stage 1	Normal or slight atrophy[a]
		Stage 2	Moderate atrophy[b]
		Stage 3	Severe atrophy[c]
Goutallier et al[16]	Fatty infiltration	Stage 0	Normal muscle without fatty streaks
		Stage 1	Some fatty streaks
		Stage 2	More muscle than fat
		Stage 3	Equal amounts of fat and muscle
		Stage 4	More fat than muscle

(*continued*)

[a]Occupation ratio: 1.00 – 0.60
[b]Occupation ratio: 0.60 – 0.40
[c]Occupation ratio: <0.40
LHB = long head of the biceps

a series of 51 patients who underwent arthroscopic single-row repair, Tashjian et al[21] found that postoperative re-tears were more common in patients who had greater tendon retraction. In a multicenter, prospective analysis of re-tears in 145 patients older than 70 years who underwent single-row or double-row repair, Flurin et al[22] found no correlation of clinical outcomes or re-tear rates with regard to preoperative tear retraction. However, this study included only patients with tear retraction that corresponded to stages 1 or 2 using Patte's classification of coronal topography (see Table 2).

Tendon Quality

Regardless of the repair technique, repair integrity relies heavily on adequate tendon quality. In this

Table 2 (*continued*)

Study	Variable	Group/Stage/Grade	Classification
Ellman[5]	Depth of partial-thickness tears	Grade 1	Tear <3 mm in depth
		Grade 2	Tear 3 to 6 mm in depth (does not exceed one half of tendon thickness)
		Grade 3	Tear >6 mm in depth (involves more than one half of tendon thickness)
Snyder et al[24]	Partial- and full-thickness tears	Type A	Articular-sided partial tear
		Type B	Bursal-sided partial tear
		Type C	Complete tear
		Grade 0	Partial tears (A and B): Normal cuff surface
		Grade I	Partial tears (A and B): Minimal synovial/bursal irritation in small area
		Grade II	Partial tears (A and B): Synovial/bursal irritation with fraying of some cuff fibers
		Grade III	Partial tears (A and B): Fraying and fragmentation of cuff fibers involving entire surface of cuff tendon
		Grade IV	Partial tears (A and B): Fraying and fragmentation in addition to the presence of a flap tear involving more than one tendon
		Grade I	Complete tears (C): Small, complete tear
		Grade II	Complete tears (C): Moderate tear (<2 cm) involving only one rotator cuff tendon
		Grade III	Complete tears (C): Larger tear (>2 cm) with some tendon retraction
		Grade IV	Complete tears (C): Massive tear involving more than one tendon with significant retraction

[a] Occupation ratio: 1.00 – 0.60
[b] Occupation ratio: 0.60 – 0.40
[c] Occupation ratio: <0.40
LHB = long head of the biceps

context, tendon quality refers to suture-holding capability, as determined by tissue quality at the time of surgery, along with the degree of muscle atrophy and fatty degeneration which are best determined based on preoperative imaging studies. Several studies have attempted to quantify supraspinatus atrophy through advanced imaging modalities (see Table 2). Thomazeau et al[23] used MRI to calculate the occupation ratio of the supraspinatus muscle belly (ie, ratio of supraspinatus fossa volume to muscle belly volume). In their study, patients with repairable rotator cuff tears had significantly decreased occupation ratios. Using these data, a classification scheme was developed to describe supraspinatus atrophy.

Goutallier et al[16] classified the degree of fatty infiltration, which is also a key indicator of tendon quality. In their study, 63 patients with rotator cuff tears underwent CT both preoperatively and postoperatively to evaluate for fatty infiltration. In patients with supraspinatus tears, fatty infiltration of the infraspinatus and subscapularis muscles occurred even when these tendons were not torn. Whereas supraspinatus fatty degeneration was found to regress after repair, this did not predictably occur in the infraspinatus muscle, leading to the speculation that incomplete suprascapular nerve injury distal to the suprascapular notch may be present in some of these patients. Patients with both supraspinatus and infraspinatus tears had worse outcomes than did patients with isolated supraspinatus tears. Using their results, a five-stage classification system was developed to describe the degree of fatty infiltration of rotator cuff muscles using high-quality CT.

Arthroscopic Classification

Arthroscopic classification systems have also been developed to help describe tear morphology in patients with rotator cuff tears (see Table 2). In 1990, Ellman[5] was the first to arthroscopically classify partial-thickness rotator cuff lesions based on the depth of the tear. Snyder et al[24] then developed a more comprehensive system describing both partial-thickness and full-thickness tears; this system has been used extensively in the literature. In a study by Kuhn et al,[25] 12 orthopaedic surgeons reviewed arthroscopic videos from 30 shoulders with various rotator cuff tear morphologies and classified them according to six widely used classification systems. Using the system developed by Snyder et al,[24] most reviewers agreed when considering whether the partial-thickness tear was articular-sided or bursal-sided (kappa = 0.85); however, when using the classification of tear depth system developed by Ellman et al,[6] results were widely variable (kappa = 0.19). A study by Spencer et al[26] resulted in similar conclusions when classifying rotator cuff tears using MRI. However, surgeons have continued to use somewhat arbitrary designations of tear depth to guide clinical and surgical decision-making because of their ease of use and applicability despite the lack of published biomechanical or clinical evidence advocating their use, such as the "50% rule" that has been widely referenced in the orthopaedic literature.[27]

Three-dimensional Tear Patterns

Rotator cuff lesions have historically been classified using one- and two-dimensional parameters that have proven to be insufficient when planning complex surgical interventions and predicting outcomes. Due to this lack of information, it has been impossible to match tear types with treatment options and prognosis before surgery. Thus, many surgical decisions were made only after diagnostic arthroscopy had taken place. In 1993, Ellman[6] described a series of common three-dimensional tear patterns that were encountered during diagnostic arthroscopy: L-shaped, reverse L-shaped, triangular, trapezoidal, and massive retracted tears. Later, a study by Davidson et al[3] of 55 patients with full-thickness posterosuperior rotator cuff tears showed that they were able to accurately and reliably predict these tear patterns based on standardized preoperative, high-quality, T2-weighted MRI. The MRI predictions were significantly correlated with arthroscopic findings ($P < 0.001$). Several years later, Davidson and Burkhart[4] devised a geometric, three-dimensional cuff tear classification system that accounted for the inherent mobility of the tear margins, thus aiding in treatment decisions and the estimation of prognosis and outcomes (Table 3). Therefore, a surgeon is now able to accurately and reliably predict tear patterns, treatment options, and prognosis using MRI alone before diagnostic arthroscopy. However, widespread proficiency in the use of MRI to predict tear patterns will require time, experience, and validation. Until then, diagnostic arthroscopy will remain the benchmark for three-dimensional pattern recognition.

Arthroscopic Tear Pattern Recognition and Repair Techniques

The classification scheme developed by Davidson et al,[3] along with recommended treatment and prognosis,[4] is still applicable when arthroscopically evaluating tear patterns. It is important to recognize tear patterns in order to achieve an anatomic low-tension repair with the avoidance of "dog ears," leading to subsequent bursal irritation, while also preventing improper force transmission.[28] In general, tear patterns are best visualized through the lateral portal (ie, bird's-eye view or 50-yard-line view). After the creation of a working anterosuperior portal and after gentle débridement, medial-lateral and AP mobility must be assessed to determine the tear pattern, which most often dictates the appropriate repair technique. After pattern recognition, temporary reduction of the tear is performed using a grasper, with or without a reduction stitch, followed by anatomic repair using the chosen technique. This method allows for a thorough evaluation of tissue quality, suture-holding properties, and tendon mobility before choosing an appropriate repair technique.

Crescent-shaped Tears

The crescent-shaped tear is the most common individual tear pattern and accounts for approximately 40% of full-thickness posterosuperior cuff tears. Crescent-shaped tears are characterized by direct avulsion from the greater tuberosity without extension into the rotator interval.[28] Regardless of its AP length, this pattern provides excellent medial to lateral mobility of the tear margins, thus allowing for a tension-free repair directly back to the greater tuberosity[4,28] (Figure 2). Good to excellent outcomes have been achieved using this method of repair.[4]

V-shaped and U-shaped Tears

V-shaped and U-shaped tears together account for approximately 15% of all full-thickness posterosuperior rotator cuff tears.[28] The apex of V-shaped and U-shaped tears extends much farther medially toward the glenoid than does that of the crescent-shaped tear. Because of this medial extension,

Table 3

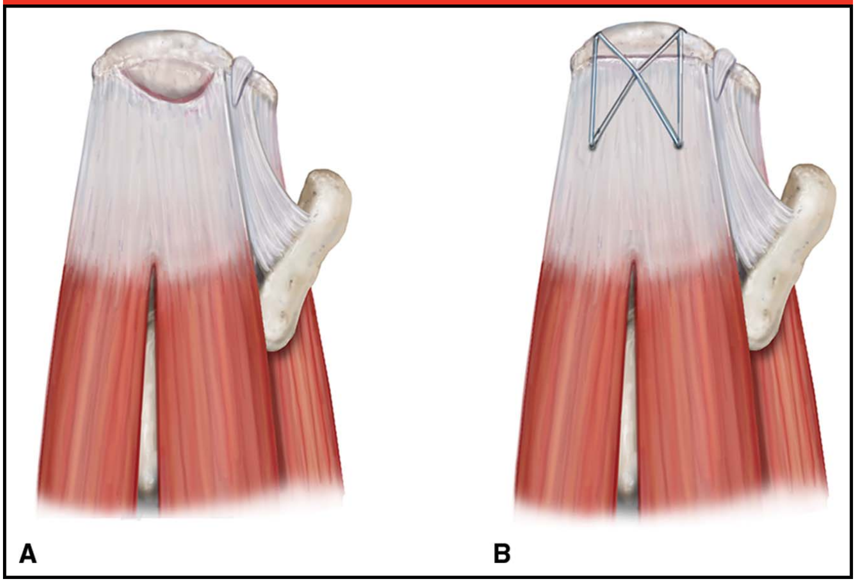
Classification of Posterosuperior Cuff Tear Patterns[3,4]

Tear Pattern	AP Length (cm)	Medial-lateral Length (cm)	Inherent Mobility	Repair Technique	Prognosis
Crescent	<2	<2	Excellent (medial-lateral)	Repair directly to bone	Good to excellent
U- or L-shaped	<2	>2	Excellent (AP)	Margin convergence	Good to excellent
Massive, contracted, immobile	>2	>2	Minimal	Interval slide/partial repair	Fair to good
Cuff arthropathy	NA	NA	NA	Reverse arthroplasty	Fair to good

AP = anterior-posterior, NA = not available

medial to lateral mobility is extremely limited; attempting to repair the apex to the lateral bone bed will result in certain failure because of the tensile overload in the mid-portion of the tendon.[28] To reduce repair tension, a single anchor can be placed at the anterolateral corner of the infraspinatus to achieve initial reduction of the supraspinatus. Adequate AP mobility allows the tear margins to be approximated with side-to-side stitches, beginning with a lateral "keystone suture" and working medially.[28] After the free margins have been stitched together, the apex of the tear "converges" on the greater tuberosity, creating a smaller crescent-shaped tear that can then be reattached to the tendon footprint in a tension-free manner[28,29] (Figure 3). This technique, also known as margin convergence, has been biomechanically proven to reduce repair tension and to provide good to excellent clinical outcomes.[30,31]

Figure 2



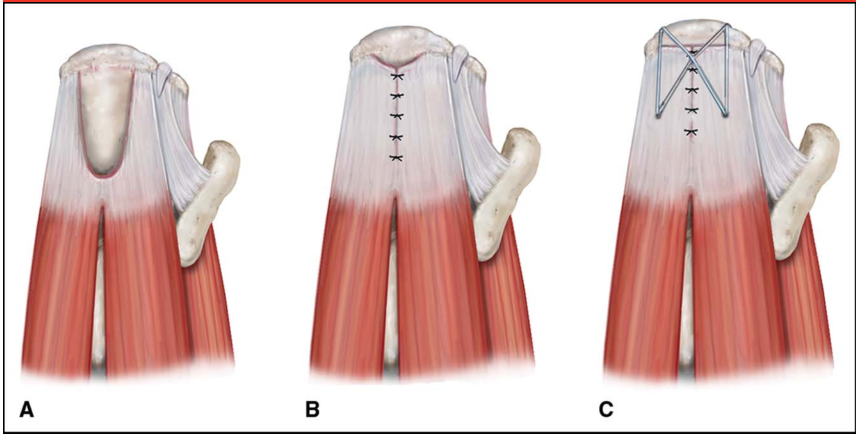
Recommended sequence of repair for crescent-shaped rotator cuff tears.

L-shaped and Reverse L-shaped Tears

L-shaped and reverse L-shaped tears account for approximately 30% of all full-thickness posterosuperior tears and are described as having both transverse and longitudinal components.[28] These tears are similar to V-shaped or U-shaped tears in configuration but differ in mobility. The free margin is either taut or lax, leaving one edge more mobile than the other. Whereas L-shaped tears tend to propagate along the interval between the supraspinatus and the infraspinatus, reverse L-shaped tears tend to propagate through the rotator interval. After identification of the tear apex, it is often useful to place a temporary reduction stitch or a single suture anchor at the posterolateral corner (L-shaped tear) or anterolateral corner (reverse L-shaped tear) to facilitate anatomic repair. The longitudinal split is then sutured in a side-to-side manner to allow for a tension-free repair of the loose margin back to its bone bed, similar to the margin convergence technique[29] (Figure 4). Surgeon discretion should be used regarding the number of side-to-side stitches placed in the rotator interval because more stitches may increase the risk for postoperative stiffness.

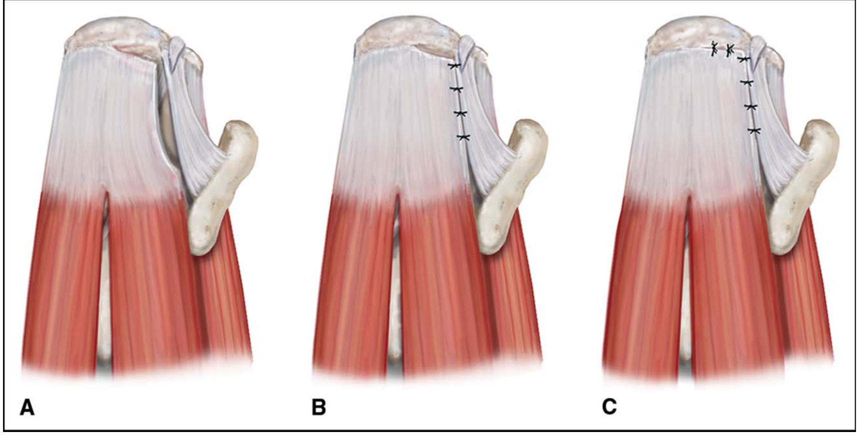
Chronic L-shaped tears are more challenging because they tend to evolve into U-shaped patterns over time; therefore, it is critical to determine the relative mobility of each free margin and to find where the "corner" of the tear should be reapproximated. Placing a traction suture at the "corner" is helpful for

Figure 3



Recommended sequence of repair for U- or V- shaped rotator cuff tears.

Figure 4



Recommended sequence of repair for L- and reverse L-shaped rotator cuff tears.

visualization. Similar to the more acute L-shaped tear, margin convergence is performed followed by direct repair of the remaining free margin to the greater tuberosity (Figure 5).

Massive, Contracted, Immobile Tears

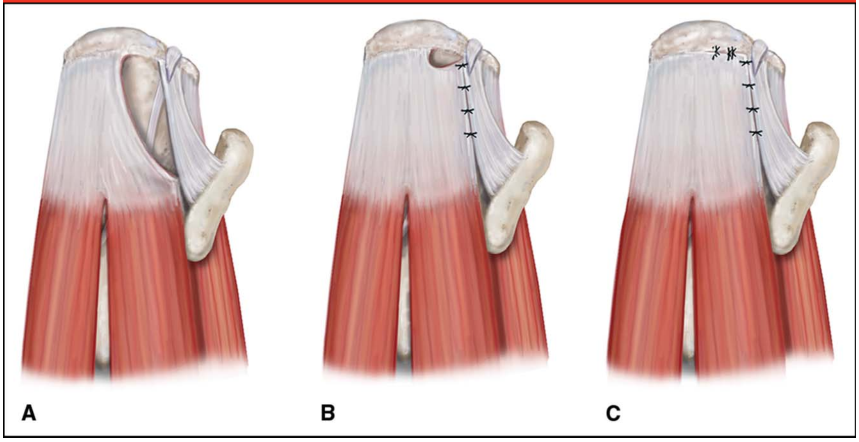
These tear patterns, which have historically been referred to as "irreparable," are less common and are very immobile in both the anterior-posterior and medial-lateral directions. These tears exist in either longitudinal or crescent forms and, because of their immobility, require more advanced arthroscopic skill to achieve the most optimal outcome. Most of the methods used for the repair of massive tears involve various interval slide techniques, highlighting the importance of supraspinatus tendon mobility when repairing the tendon to its lateral bone bed. In most cases, mobility of the supraspinatus tendon is improved by incising the coracohumeral ligament near the base of the coracoid at the inferior margin of the supraspinatus tendon and the superior margin of the rotator interval (ie, anterior interval slide technique).[32,33] This technique improves medial-lateral mobility without creating excessive tension in the midportion of the tendon during lateral excursion, especially in the repair of massive longitudinal tears. Tendon-to-bone repair is then undertaken, followed by side-to-side stitching of the remaining free margins (Figure 6).

In massive, contracted, immobile crescent tears, performing an anterior interval slide may not provide sufficient medial-lateral mobility to allow for adequate reduction. Therefore, in addition to performing an anterior interval slide maneuver, a posterior interval slide can also be performed (ie, double interval slide), which may significantly improve medial-lateral mobility while also allowing for reduction of both the supraspinatus and infraspinatus back to the greater tuberosity.[32] The posterior interval slide is performed by incising the interval between the supraspinatus and infraspinatus tendons, thus allowing increased mobility of both tendons. Visualization of the scapular spine is important during this procedure for both orientation and the avoidance of injury to the suprascapular nerve which travels in close apposition to the base of the scapular spine at the junction of the glenoid neck. After incising the supraspinatus-infraspinatus interval, side-to-side stitching of the remaining free tear margins is performed to complete the repair. We typically do not use this posterior interval slide technique because we prefer not to disrupt intact tendons. In our experience, such releases are less likely to heal and may result in unsatisfactory long-term outcomes.

Using a double interval slide technique, Lo and Burkhart[32] demonstrated good to excellent results with a high rate of patient satisfaction after repair of massive, immobile, longitudinal and crescent-shaped tears after a minimum 10-month follow-up period. Kim et al[30] followed 41 patients with massive, retracted rotator cuff tears for a minimum of 2 years after arthroscopic partial repair or the use of anterior or posterior interval slide techniques to improve tendon mobility. The authors found no differences in clinical outcomes or structural integrity after a minimum 2-year follow-up period. Unfortunately, long-term data are currently lacking regarding the outcomes after repairs with these types of extensive releases.

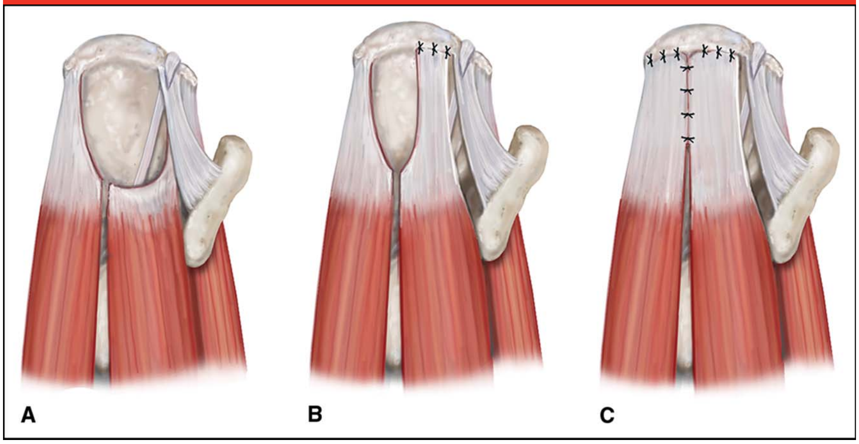
In massive tears, partial repair may be indicated, especially in patients with decreased functional demands. If a partial repair is contemplated, it is essential, at a minimum, to repair the inferior portion of the infraspinatus muscle in order to maintain proper glenohumeral kinematics and balanced axial-plane force couples.[34] Other repair options, such as graft augmentation or muscle transfer procedures, should also be considered before performing a partial cuff repair.

Figure 5



Recommended sequence of repair for chronic L-shaped rotator cuff tears.

Figure 6



Recommended sequence of repair for massive, contracted, immobile rotator cuff tears.

Tendon-bone Repair Techniques

Numerous procedures have been developed and are available for the repair of rotator cuff tears at the tendon-bone interface. Single-row repair, a technique in which one to three anchors are placed laterally on the greater tuberosity (ie, a single, lateral row of anchors), has been a mainstay of cuff repair for many years (Figure 7). In 2003, double-row repair, a technique in which an additional medial row of anchors is placed just lateral to the articular margin (typically two to six anchors), was introduced in an attempt to improve healing rates and functional outcomes by way of optimizing the insertional anatomy of the repaired footprint[35] (Figure 8).

Many biomechanical studies have shown a superiority of the double-row technique, citing increased cyclic mechanical strength, along with improved anatomy, tendon-to-bone contact, footprint compression, and gap formation compared with single-row methods.[36-38] This configuration has significant theoretic advantages over the single-row construct because improved compression and strength at the tendon-footprint interface is thought to enhance tendon healing, while also allowing for earlier and more aggressive rehabilitation.

Therefore, in response to this evidence, several level I studies have been conducted that compare the clinical and structural outcomes following either single-row or double-row repair.[38-45] Only a few of these studies found clinical or structural differences between single-row and double-row repairs. As a result, other investigators have questioned the cost efficiency of double-row repairs due to the lack of documented clinical improvement and increased operating costs (eg, increased surgical time and use of more suture anchors).[46] However, although a meta-analysis of level I studies conducted at this institution found undetectable differences in clinical outcomes scores (ie, American Shoulder and Elbow Surgeons [ASES], University of

Figure 7

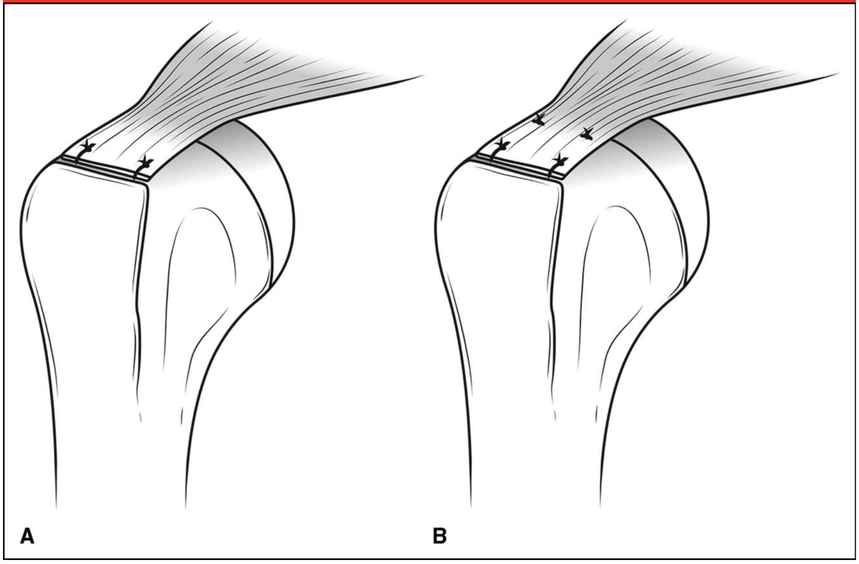


Illustration depicting (**A**) standard single-row and (**B**) standard double-row rotator cuff repairs. Simple sutures are used for single-row repairs and the lateral row of double-row repairs. The medial row of anchors in double-row repairs utilizes horizontal mattress sutures.

Figure 8

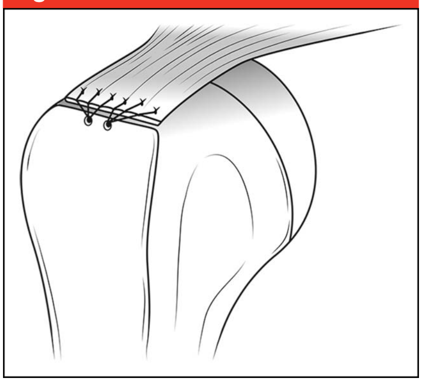


Illustration depicting a single-row repair with two triple-loaded suture anchors.

California, Los Angeles [UCLA], and Constant scores) between the single-row and double-row groups, a statistically significant increase in imaging-diagnosed re-tears was found in the single-row group; the majority of this difference was attributed to the high rate of partial-thickness re-tears.[47] Specifically, single-row repairs resulted in a 76% increased risk of sustaining an imaging-diagnosed re-tear. The high rate of re-tears did not correlate with a decline in clinical outcomes scores after a mean 23.2-month follow-up; however, other authors have shown that the gradual progression of partial-thickness tears to full-thickness tears in some patients, along with their associated symptomatology, may require more than 2 years to develop.[48,49]

In a large series of 195 patients with asymptomatic cuff tears, Mall et al[48] found that only 44 of 195 tears (23%) had become symptomatic 2 years after study enrollment. Yamaguchi et al[49] reported on 45 patients with asymptomatic rotator cuff tears diagnosed by ultrasonography; they found that 23 of 45 patients (51%) eventually became symptomatic after a mean of 2.8 years, with a corresponding decline in clinical outcomes scores. Because most studies report clinical outcomes after a minimum of 2 years postoperatively, these results suggest that differences in clinical outcomes between single-row and double-row techniques may not be detected in the 2-year postoperative period because the clinical symptomatology resulting from the gradual progression from asymptomatic to symptomatic re-tears may require more than 2 years to become clinically apparent. Thus, longer-term prospective studies need to be conducted to help define the long-term effects of asymptomatic re-tears on clinical outcomes scores.[50]

Whereas structural outcomes after double-row repair may prove to be clinically relevant with time, the initial tear size may also be an important factor related to clinical outcomes. Park et al[51] documented the effects of initial tear size on clinical outcomes in a level II trial of 78 consecutive patients with full-thickness rotator cuff tears. In that study, there were no differences in clinical outcomes scores between the single-row or double-row groups when tears of all sizes were considered. However, stratification of their results by initial tear sizes revealed significant improvements in ASES and Constant scores in double-row repairs when compared with single-row repairs. In addition, improved shoulder strength was demonstrated when double-row repair was performed for tears measuring >3 cm in sagittal length. Similarly, a level II randomized clinical trial conducted by Ma et al[52] evaluated 53 patients who received either single-row or double-row repairs for full-thickness rotator cuff tears. In that study, significant improvements in abduction and external rotation strength were observed in patients who had initial tears of >3 cm in AP length and who underwent double-row repair. In a level I randomized trial, Lapner et al[41] concluded that healing rates were improved in patients with smaller initial tear sizes treated with the double-row method. When compared with single-row repairs, the

Figure 9

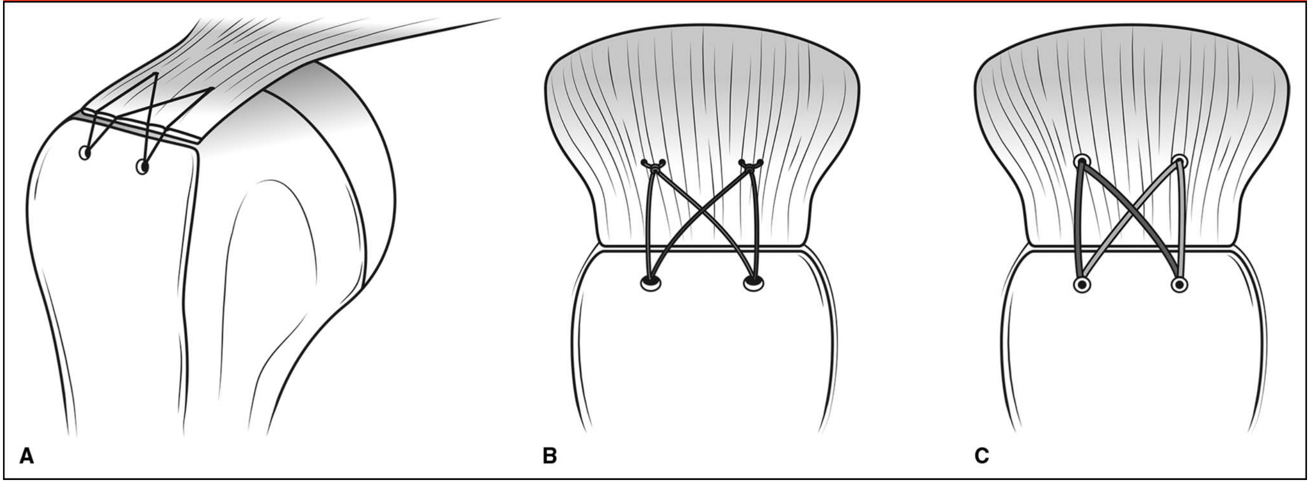


Illustration depicting (**A**) transosseous equivalent (TOE), (**B**) knotted TOE, and (**C**) knotless TOE rotator cuff repairs.

randomized trial performed by Carbonel et al[40] also demonstrated significant improvements in ASES and UCLA scores when double-row repair was performed for tears measuring 3 to 5 cm. These studies suggest that the stratification of outcomes by initial tear sizes may help to quantify the possible clinical differences between single-row and double-row rotator cuff repair.

Currently, subjective, objective, and structural outcomes favor double-row repair in most cases, potentially justifying the increased surgical cost of double-row repair. However, both single-row and double-row repair techniques have evolved extensively over the past decade. For example, single-row repairs using double-loaded or triple-loaded suture anchors have been developed to increase the number of suture passes through the tendon; this has been shown to improve biomechanical properties compared with standard single-row repair constructs[53] (see Figure 8). Linked double-row constructs have also shown improved biomechanical properties when compared with standard double-row repairs.[54-56] Most of these more recently described double-row constructs rely on suture bridging techniques in which a distal-lateral row of anchors are "linked," or connected to, the medial row anchors with sutures (Figure 9, A). This type of repair was first described by Millett et al[57] and then modified by Park and colleagues[54,55,58] into a transosseous equivalent (TOE) technique. These constructs preserve the suture limbs of the medial row and "bridges" them over the footprint insertion to a distal-lateral row of suture anchors. Thus, medial and lateral suture anchors are "linked" where the interconnecting suture compresses the tendon over its footprint. This configuration takes advantage of the bone quality of the proximal humerus, avoids sutures at the tendon-bone interface where healing occurs, and allows the lateral anchors to be placed away from the tendon-bone interface. These factors theoretically enhance the healing process and improve tendon-footprint compression when compared with standard double-row repairs.[54-56] A study by Burkhart et al[56] also found these linked repairs to increase the grasping strength as the mechanical load is increased, described by the authors as a "Chinese Finger Trap" model.

Knotless TOE constructs in which only the lateral row of anchors is tied have also been developed due to concerns regarding tendon strangulation, increased surgical time, and the increased cost associated with TOE repairs in which medial knots are tied arthroscopically. In addition, knotless TOE repairs typically use a wider suture material (ie, "suture tape") that is thought to dissipate the force applied by the suture material over a larger tendon surface area and to provide increased ultimate load-to-failure[59,60] (Figure 9, B and C). However, biomechanical and clinical results have been variable to this point. A systematic review by Mall et al[61] concluded that knotless TOE constructs were biomechanically inferior to repairs in which the medial knots were tied, especially with regard to ultimate load-to-failure and gap formation. Failure of knotless TOE repairs has been attributed to suture slippage and loosening.[62] On the other hand, Boyer et al[63] and Rhee et al[64] found higher MRI-diagnosed re-tear rates in their knotted TOE groups when compared with their knotless TOE groups, without a difference in clinical outcomes. Many of the re-tears following knotted TOE repairs in both of these studies occurred medially near the musculotendinous junction, possibly suggesting that tendon strangulation may be an important factor in the development of re-tears when this technique is used. Although biomechanical data favor the presence of medial row knots, this has yet to result in improved clinical outcomes when compared with knotless TOE techniques. Therefore, currently, knotted or knotless TOE repairs are the preferred methods of repair for most full-thickness posterosuperior rotator cuff tears. Exceptions include partial-thickness, very small full-thickness, or very large, immobile tears in which double-row repair may not be possible or necessary. In these cases, single-row repair can be performed.

Summary

Three-dimensional tear pattern recognition has become the standard in rotator cuff classification and treatment. Although clinical data are limited, using side-to-side stitching, margin convergence, and interval slide techniques are helpful in managing both simple and complex tear patterns. After reapproximation of the torn cuff, tendon-bone repair can be performed using a variety of methods; however, preliminary biomechanical, clinical, and structural data suggest that double-row suture bridging repair constructs are most likely to provide satisfactory results. In partial-thickness, smaller full-thickness, or very massive tears, single-row repair may be performed.

References

Evidence-based Medicine: Levels of evidence are described in the table of contents. In this article, references 39-44, and 46 are level I studies. References 25, 49, 50, and 63 are level II studies. References 3-5, 15, 23, 26, 28, 29, 60, and 61 are level III studies. References 2, 20-22, 24, 27, and 51 are level IV studies.

References printed in **bold type** are those published within the past 5 years.

1. Codman EA, DePalma AF: Operative treatment of shoulder lesions, in *The Shoulder: Rupture of the Supraspinatus Tendon and Other Lesions in or About the Subacromial Bursa*. Boston, MA, Krieger Publishing Company, 1984, pp 225-261.
2. DeOrio JK, Cofield RH: Results of a second attempt at surgical repair of a failed initial rotator-cuff repair. *J Bone Joint Surg Am* 1984;66(4):563-567.
3. Davidson JF, Burkhart SS, Richards DP, Campbell SE: Use of preoperative magnetic resonance imaging to predict rotator cuff tear pattern and method of repair. *Arthroscopy* 2005;21(12):1428.
4. **Davidson JF, Burkhart SS: The geometric classification of rotator cuff tears: A system linking tear pattern to treatment and prognosis. *Arthroscopy* 2010;26(3):417-424.**
5. Ellman H: Diagnosis and treatment of incomplete rotator cuff tears. *Clin Orthop Relat Res* 1990;254:64-74.
6. Ellman H: Rotator cuff disorders, in Ellman H, Gartsman GM, eds: *Arthroscopic Shoulder Surgery and Related Disorders*. Philadelphia, PA, Lea & Febiger, 1993, pp 98-119.
7. Minagawa H, Itoi E, Konno N, et al: Humeral attachment of the supraspinatus and infraspinatus tendons: An anatomic study. *Arthroscopy* 1998;14(3):302-306.
8. Curtis AS, Burbank KM, Tierney JJ, Scheller AD, Curran AR: The insertional footprint of the rotator cuff: An anatomic study. *Arthroscopy* 2006;22(6):e1.
9. Roh MS, Wang VM, April EW, Pollock RG, Bigliani LU, Flatow EL: Anterior and posterior musculotendinous anatomy of the supraspinatus. *J Shoulder Elbow Surg* 2000;9(5):436-440.
10. Volk AG, Vangsness CT Jr: An anatomic study of the supraspinatus muscle and tendon. *Clin Orthop Relat Res* 2001;384:280-285.
11. Dugas JR, Campbell DA, Warren RF, Robie BH, Millett PJ: Anatomy and dimensions of rotator cuff insertions. *J Shoulder Elbow Surg* 2002;11(5):498-503.
12. Ruotolo C, Fow JE, Nottage WM: The supraspinatus footprint: An anatomic study of the supraspinatus insertion. *Arthroscopy* 2004;20(3):246-249.
13. **Mochizuki T, Sugaya H, Uomizu M, et al: Humeral insertion of the supraspinatus and infraspinatus: New anatomical findings regarding the footprint of the rotator cuff. Surgical technique. *J Bone Joint Surg Am* 2009;91(suppl 2 pt 1):1-7.**
14. Neer CS II: Impingement lesions. *Clin Orthop Relat Res* 1983;173:70-77.
15. Patte D: Classification of rotator cuff lesions. *Clin Orthop Relat Res* 1990;254:81-86.
16. Goutallier D, Postel JM, Bernageau J, Lavau L, Voisin MC: Fatty muscle degeneration in cuff ruptures: Pre- and postoperative evaluation by CT scan. *Clin Orthop Relat Res* 1994;304:78-83.
17. Gschwend N, Ivosević-Radovanović D, Patte D: Rotator cuff tear: Relationship between clinical and anatomopathological findings. *Arch Orthop Trauma Surg* 1988;107(1):7-15.
18. Burkhart SS: Fluoroscopic comparison of kinematic patterns in massive rotator cuff tears: A suspension bridge model. *Clin Orthop Relat Res* 1992;284:144-152.
19. Habermeyer P, Magosch P, Lichtenberg S: Classifications of rotator cuff, in *Classifications and Scores of the Shoulder*. Berlin, Germany, Springer Publishing, 2006.
20. **Sethi PM, Noonan BC, Cunningham J, Shreck E, Miller S: Repair results of 2-tendon rotator cuff tears utilizing the transosseous equivalent technique. *J Shoulder Elbow Surg* 2010;19(8):1210-1217.**
21. **Tashjian RZ, Hung M, Burks RT, Greis PE: Influence of preoperative musculotendinous junction position on rotator cuff healing using single-row technique. *Arthroscopy* 2013;29(11):1748-1754.**
22. **Flurin PH, Hardy P, Abadie P, et al: Arthroscopic repair of the rotator cuff: Prospective study of tendon healing after 70 years of age in 145 patients. *Orthop Traumatol Surg Res* 2013;99(suppl 8):S379-S384.**
23. Thomazeau H, Rolland Y, Lucas C, Duval JM, Langlais F: Atrophy of the supraspinatus belly: Assessment by MRI in 55 patients with rotator cuff pathology. *Acta Orthop Scand* 1996;67(3):264-268.
24. Snyder SJ, Pachelli AF, Del Pizzo W, Friedman MJ, Ferkel RD, Pattee G: Partial thickness rotator cuff tears: Results of arthroscopic treatment. *Arthroscopy* 1991;7(1):1-7.
25. Kuhn JE, Dunn WR, Ma B, et al: Interobserver agreement in the classification of rotator cuff tears. *Am J Sports Med* 2007;35(3):437-441.
26. Spencer EE Jr, Dunn WR, Wright RW, et al: Interobserver agreement in the classification of rotator cuff tears using magnetic resonance imaging. *Am J Sports Med* 2008;36(1):99-103.
27. **Pedowitz RA, Higashigawa K, Nguyen V: The "50% rule" in arthroscopic and orthopaedic surgery. *Arthroscopy* 2011;27(11):1584-1587.**

28. Sallay PI, Hunker PJ, Lim JK: Frequency of various tear patterns in full-thickness tears of the rotator cuff. *Arthroscopy* 2007;23(10):1052-1059.

29. Burkhart SS, Athanasiou KA, Wirth MA: Margin convergence: A method of reducing strain in massive rotator cuff tears. *Arthroscopy* 1996;12(3):335-338.

30. **Kim SJ, Kim SH, Lee SK, Seo JW, Chun YM: Arthroscopic repair of massive contracted rotator cuff tears: Aggressive release with anterior and posterior interval slides do not improve cuff healing and integrity. *J Bone Joint Surg Am* 2013;95(16):1482-1488.**

31. **Mazzocca AD, Bollier M, Fehsenfeld D, et al: Biomechanical evaluation of margin convergence. *Arthroscopy* 2011;27(3):330-338.**

32. Lo IK, Burkhart SS: The interval slide in continuity: A method of mobilizing the anterosuperior rotator cuff without disrupting the tear margins. *Arthroscopy* 2004;20(4):435-441.

33. Tauro JC: Arthroscopic "interval slide" in the repair of large rotator cuff tears. *Arthroscopy* 1999;15(5):527-530.

34. Mura N, O'Driscoll SW, Zobitz ME, et al: The effect of infraspinatus disruption on glenohumeral torque and superior migration of the humeral head: A biomechanical study. *J Shoulder Elbow Surg* 2003;12(2):179-184.

35. Lo IK, Burkhart SS: Double-row arthroscopic rotator cuff repair: Re-establishing the footprint of the rotator cuff. *Arthroscopy* 2003;19(9):1035-1042.

36. **Baums MH, Spahn G, Buchhorn GH, Schultz W, Hofmann L, Klinger HM: Biomechanical and magnetic resonance imaging evaluation of a single- and double-row rotator cuff repair in an in vivo sheep model. *Arthroscopy* 2012;28(6):769-777.**

37. Mazzocca AD, Millett PJ, Guanche CA, Santangelo SA, Arciero RA: Arthroscopic single-row versus double-row suture anchor rotator cuff repair. *Am J Sports Med* 2005;33(12):1861-1868.

38. Milano G, Grasso A, Zarelli D, Deriu L, Cillo M, Fabbriciani C: Comparison between single-row and double-row rotator cuff repair: A biomechanical study. *Knee Surg Sports Traumatol Arthrosc* 2008;16(1):75-80.

39. **Gartsman GM, Drake G, Edwards TB, Elkousy HA, Hammerman SM, O'Connor DP, Press CM: Ultrasound evaluation of arthroscopic full-thickness supraspinatus rotator cuff repair: Single-row versus double-row suture bridge (transosseous equivalent) fixation. Results of a prospective randomized study. *J Shoulder Elbow Surg* 2013;22(11):1480-1487.**

40. **Carbonel I, Martinez AA, Calvo A, Ripalda J, Herrera A: Single-row versus double-row arthroscopic repair in the treatment of rotator cuff tears: A prospective randomized clinical study. *Int Orthop* 2012;36(9):1877-1883.**

41. **Lapner PL, Sabri E, Rakhra K, et al: A multicenter randomized controlled trial comparing single-row with double-row fixation in arthroscopic rotator cuff repair. *J Bone Joint Surg Am* 2012;94(14):1249-1257.**

42. **Koh KH, Kang KC, Lim TK, Shon MS, Yoo JC: Prospective randomized clinical trial of single- versus double-row suture anchor repair in 2- to 4-cm rotator cuff tears: Clinical and magnetic resonance imaging results. *Arthroscopy* 2011;27(4):453-462.**

43. **Burks RT, Crim J, Brown N, Fink B, Greis PE: A prospective randomized clinical trial comparing arthroscopic single- and double-row rotator cuff repair: Magnetic resonance imaging and early clinical evaluation. *Am J Sports Med* 2009;37(4):674-682.**

44. **Grasso A, Milano G, Salvatore M, Falcone G, Deriu L, Fabbriciani C: Single-row versus double-row arthroscopic rotator cuff repair: A prospective randomized clinical study. *Arthroscopy* 2009;25(1):4-12.**

45. Franceschi F, Ruzzini L, Longo UG, et al: Equivalent clinical results of arthroscopic single-row and double-row suture anchor repair for rotator cuff tears: A randomized controlled trial. *Am J Sports Med* 2007;35(8):1254-1260.

46. **Genuario JW, Donegan RP, Hamman D, et al: The cost-effectiveness of single-row compared with double-row arthroscopic rotator cuff repair. *J Bone Joint Surg Am* 2012;94(15):1369-1377.**

47. **Millett PJ, Warth RJ, Dornan GJ, Lee JT, Spiegl UJ: Clinical and structural outcomes after arthroscopic single-row versus double-row rotator cuff repair: A systematic review and meta-analysis of the Level I randomized clinical trials. *J Shoulder Elbow Surg* 2014;23(4):586-597.**

48. **Mall NA, Kim HM, Keener JD, et al: Symptomatic progression of asymptomatic rotator cuff tears: A prospective study of clinical and sonographic variables. *J Bone Joint Surg Am* 2010;92(16):2623-2633.**

49. Yamaguchi K, Tetro AM, Blam O, Evanoff BA, Teefey SA, Middleton WD: Natural history of asymptomatic rotator cuff tears: A longitudinal analysis of asymptomatic tears detected sonographically. *J Shoulder Elbow Surg* 2001;10(3):199-203.

50. **Denard PJ, Jiwani AZ, Lädermann A, Burkhart SS: Long-term outcome of arthroscopic massive rotator cuff repair: The importance of double-row fixation. *Arthroscopy* 2012;28(7):909-915.**

51. Park JY, Lhee SH, Choi JH, Park HK, Yu JW, Seo JB: Comparison of the clinical outcomes of single- and double-row repairs in rotator cuff tears. *Am J Sports Med* 2008;36(7):1310-1316.

52. **Ma HL, Chiang ER, Wu HT, et al: Clinical outcome and imaging of arthroscopic single-row and double-row rotator cuff repair: A prospective randomized trial. *Arthroscopy* 2012;28(1):16-24.**

53. **Jost PW, Khair MM, Chen DX, Wright TM, Kelly AM, Rodeo SA: Suture number determines strength of rotator cuff repair. *J Bone Joint Surg Am* 2012;94(14):e100.**

54. Park MC, ElAttrache NS, Tibone JE, Ahmad CS, Jun BJ, Lee TQ: Part I: Footprint contact characteristics for a transosseous-equivalent rotator cuff repair technique compared with a double-row repair technique. *J Shoulder Elbow Surg* 2007;16(4):461-468.

55. Park MC, Tibone JE, ElAttrache NS, Ahmad CS, Jun BJ, Lee TQ: Part II: Biomechanical assessment for a footprint-restoring transosseous-equivalent rotator cuff repair technique compared with a double-row repair technique. *J Shoulder Elbow Surg* 2007;16(4):469-476.

56. **Burkhart SS, Adams CR, Burkhart SS, Schoolfield JD: A biomechanical comparison of 2 techniques of footprint reconstruction for rotator cuff repair: The SwiveLock-FiberChain construct versus standard double-row repair. *Arthroscopy* 2009;25(3):274-281.**

57. Millett PJ, Mazzocca A, Guanche CA: Mattress double anchor footprint repair: A novel, arthroscopic rotator cuff repair technique. *Arthroscopy* 2004;20(8):875-879.

58. Park MC, Elattrache NS, Ahmad CS, Tibone JE: "Transosseous-equivalent" rotator cuff repair technique. *Arthroscopy* 2006;22(12):e1-e5.

59. **De Carli A, Lanzetti RM, Monaco E, Labianca L, Mossa L, Ferretti A: The failure mode of two reabsorbable fixation systems: Swivelock with Fibertape versus Bio-Corkscrew with Fiberwire in bovine rotator cuff. *J Orthop Sci* 2012;17(6):789-795.**

60. **Bisson LJ, Manohar LM: A biomechanical comparison of the pullout strength of No. 2 FiberWire suture and 2-mm FiberWire tape in bovine rotator cuff tendons. *Arthroscopy* 2010;26(11):1463-1468.**

61. **Mall NA, Lee AS, Chahal J, et al: Transosseous-equivalent rotator cuff repair: A systematic review on the biomechanical importance of tying the medial row. *Arthroscopy* 2013;29(2):377-386.**

62. Wieser K, Farshad M, Vlachopoulos L, Ruffieux K, Gerber C, Meyer DC: Suture slippage in knotless suture anchors as a potential failure mechanism in rotator cuff repair. *Arthroscopy* 2012;28(11): 1622-1627.

63. Boyer P, Bouthors C, Delcourt T, et al: Arthroscopic double-row cuff repair with suture-bridging: A structural and functional comparison of two techniques. *Knee Surg Sports Traumatol Arthrosc* 2013.

64. Rhee YG, Cho NS, Parke CS: Arthroscopic rotator cuff repair using modified Mason-Allen medial row stitch: Knotless versus knot-tying suture bridge technique. *Am J Sports Med* 2012;40(11): 2440-2447.