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Massive rotator cuff tears: pathomechanics, current treatment options, and clinical outcomes

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Rotator cuff tear size has an important effect on clinical outcomes after repair. Management options for massive rotator cuff tears are numerous, and selection of the most appropriate treatment method for individual patients can be a challenge. An understanding of the pathomechanics, treatment, and clinical outcomes in patients with massive rotator cuff tears can serve as a guide for clinical decision-making. The purpose of this article was to review treatment options and clinical outcomes for the management of massive rotator cuff tears.

Level of evidence: Narrative Review.

Keywords: Rotator cuff; massive rotator cuff tears; repair; clinical outcomes

The treatment of massive rotator cuff tears poses a challenge to orthopedic surgeons. The reported prevalence of massive rotator cuff tears has been as high as 40% of all rotator cuff tears.[5] Studies have indicated a higher rate of recurrent tearing for massive rotator cuff tears after surgery compared with smaller tears.[36] Adding to the complexity of the treatment of massive rotator cuff tears is the fact that structural failure does not always equate to clinical failure.[17,36,42]

Many classification systems have been proposed to help guide the evaluation and treatment of massive rotator cuff tears.[22,25,42,85] DeOrio and Cofield classified massive rotator cuff tears as tears that are >5 cm in size in either the anterior-posterior or medial-lateral dimension, whereas Gerber defined massive tears as those involving complete tears of at least 2 tendons.[25,42] Davidson and Burkhart recently proposed a classification system linking rotator cuff tear patterns to treatment and prognosis.[22] No consensus currently exists as to which classification system is best, and it is important to interpret the tear pattern information in light of the patient's clinical situation.[85]

Numerous surgical management options are available to treat massive rotator cuff tears, including nonoperative management, arthroscopic débridement with a biceps tenotomy or tenodesis, complete repair, partial repair, patch augmentation, superior capsular reconstruction, muscle-tendon transfer, and reverse total shoulder arthroplasty

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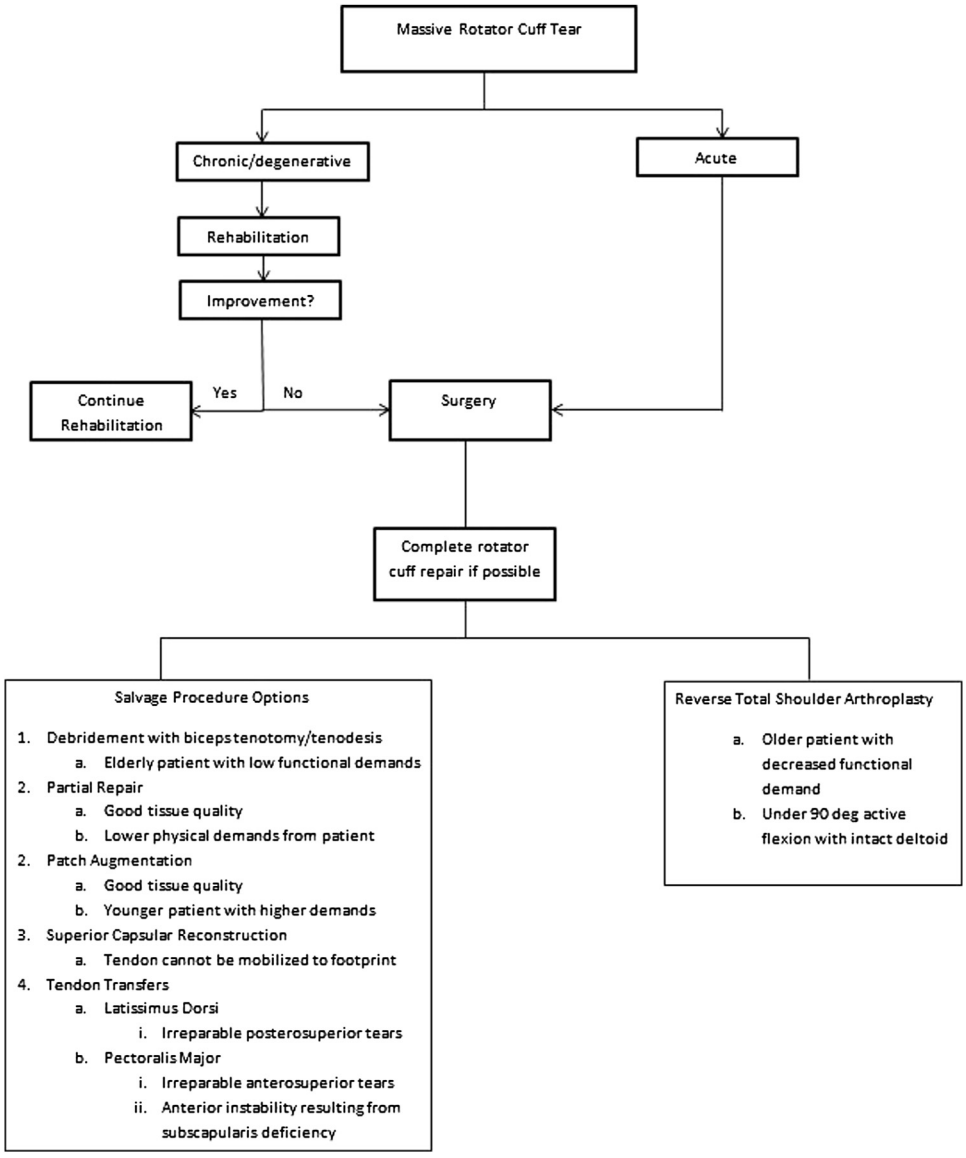

Figure 1 An algorithm that summarizes the approach to treatment of massive rotator cuff tears.

(rTSA).[5,80] Figure 1 provides a summary of surgical treatment options for massive rotator cuff tears. To achieve the best outcomes for a patient, the orthopedic surgeon should have a good understanding of the indications for and clinical outcomes of the various treatment modalities.

Biomechanical consequences of rotator cuff tears

The muscles of the rotator cuff play an important role in normal glenohumeral motion and stability. The supraspinatus acts to initiate abduction, the infraspinatus and teres minor are responsible for external rotation, and the subscapularis is the main internal rotator of the shoulder. As the rotator cuff muscles act as force couples with each other and the deltoid, they work together to contain the inherently unstable glenohumeral joint. The deltoid and supraspinatus muscles act as the coronal force couple, compressing the humeral head to the glenoid in abduction.[101] The subscapularis and infraspinatus muscles represent the axial force couple, providing joint stability by a compressive joint reaction force in the axial plane.[101]

Massive rotator cuff tears adversely affect normal shoulder biomechanics. Shoulders with massive cuff tears demonstrated an increase in maximum internal rotation in posterosuperior tears, maximum external rotation in anterosuperior tears, and total rotation range of motion at all abduction angles in a cadaveric model compared with the intact state for both.[99] Disruption of the muscle-tendon units that contribute to active external rotation (infraspinatus and teres minor) leads to weakness in active external rotation and

an increase in passive internal rotation, whereas massive rotator cuff tears involving the subscapularis lead to weakness in active internal rotation and increased passive external rotation. These cadaveric findings highlight the important dynamic unloaded effects that the rotator cuff tendons have on glenohumeral kinematics.[47]

To restore normal kinematics in patients with massive tears of the posterosuperior rotator cuff tendons, greater forces are required by both the deltoid and the intact muscle-tendon units of the rotator cuff, particularly the subscapularis, to achieve stable abduction.[54] The progression of a rotator cuff tear to disrupt the axial force couple leads to superior subluxation of the humeral head and dysfunction of the shoulder.[101] Forces required to move the arm increase with tear size and can contribute to the anterior or posterior extension of a tear. Torn tendons cannot participate in load sharing, therefore increasing the tensile load on the remaining fibers. This can readily lead to tear propagation, particularly if the remaining tendon is of poor quality.

In addition, pseudoparalysis of the shoulder can occur when the force couples of the glenohumeral joint are disrupted. Pseudoparalysis of the shoulder has been defined as a patient's having $<90^{\circ}$ of active anterior elevation with full passive range of motion and the lack of neurologic impairment.[18] The risk factors for pseudoparalysis are still being investigated; however, a recent study by Collin et al found disruption of the entire subscapularis or of 3 rotator cuff muscles to be risk factors for pseudoparalysis.[18]

Large retracted tears have also been shown to cause traction on the suprascapular nerve and may contribute to the progression of atrophy and fatty infiltration of the supraspinatus and infraspinatus muscles.[21,77,108] Repair of the massive tear with or without associated suprascapular nerve neurolysis may relieve tension on the suprascapular nerve, allowing recovery of the nerve and improvement in function.[21,77]

Medial (longitudinal) extension of supraspinatus tears can also disrupt glenohumeral kinematics. The pathomechanism involved with this tear pattern typically results from proximal humeral head migration. With initiation of abduction, superior migration of the humeral head as a result of muscle weakness or tendon retraction can occur, leading to increased cuff impingement between the greater tuberosity and undersurface of the acromion.[93,113] This can exacerbate tear size, leading to a cycle of upward humeral head migration and tear extension. Usually, a massive rotator cuff tear involving at least 2 torn tendons is needed to provoke superior migration of the humeral head.[42]

Treatment options and clinical outcomes

Nonoperative management

Nonoperative management is typically indicated in patients who have largely intact rotator cuff force couples with symptoms primarily related to function. Management typically involves activity modification, corticosteroid injections, and strengthening of the deltoid and periscapular musculature.[87,117] A randomized clinical trial of 78 patients with rotator cuff tears comparing repeated injections (once a week for 5 weeks) of either dexamethasone or sodium hyaluronate revealed comparable therapeutic efficacies of sodium hyaluronate and dexamethasone.[109] In an elderly patient cohort of 22 patients with a mean age of 78 years and rotator cuff tears, a series of infiltrations with hyaluronic acid (once a week for 3 weeks) followed by rehabilitative treatment yielded significant pain reduction, improvement of range of motion, and autonomy in daily life activities.[19]

Clinical outcomes

A study conducted by Zingg et al evaluated the clinical and structural midterm outcomes in 19 patients with nonoperatively managed massive rotator cuff tears, defined as full-thickness complete tears of at least 2 tendons.[128] After a mean follow-up duration of 48 months, the mean relative Constant score was 83% and the mean subjective shoulder value was 68%. However, as the size of the tendon tear increased, fatty infiltration according to the Goutallier classification system progressed on average by 1 stage in all 3 muscles, the acromiohumeral distance decreased, and glenohumeral osteoarthritis progressed.[128] The authors concluded that in select patients, satisfactory shoulder function can be maintained despite progression of adverse joint changes, but there is a risk of the rotator cuff tears progressing. A study involving 10 elderly patients with massive rotator cuff tears evaluated a physiotherapy regimen focused on anterior deltoid strengthening and functional rehabilitation.[1] After 3 months, scores on the Oxford Shoulder Disability Questionnaire showed a mean improvement of 9, and pain scores on the 36-Item Short Form Health Survey increased on average by 22 points, whereas the perceived health subsection declined by 9 points.

Two additional studies, one with a mean follow-up of 3.5 years[64] and the other with 7.6 years,[10] reported favorable results with nonoperative management of full-thickness rotator cuff tears. The authors did suggest that nonoperative management may not be sustainable in the long term. However, both studies failed to indicate the size of the tears that were included in their analysis, and therefore these conclusions may not be entirely applicable.

Yamaguchi et al followed the natural history of 45 patients with initially asymptomatic rotator cuff tears during a 5-year period. They demonstrated that 51% of these patients became symptomatic after a mean of 2.8 years, with a high risk for tear size progression over time.[127]

Débridement and tenotomy of the biceps tendon

Débridement procedures of the rotator cuff are usually labeled "salvage procedures" or "limited goals surgery."

Débridement and a biceps tenotomy are indicated for elderly patients with irreparable tears who seek pain relief, having failed to respond to nonoperative management,[5,119] and who have limited functional expectations.[5,125] The main goals of surgery are to alleviate pain and to improve range of motion. Shoulder strength is likely to remain unchanged or to decrease after surgery.[38] Ideally, the patient should have a competent deltoid muscle and an intact coracoacromial arch[105,125] and neither pseudoparalysis nor severe cuff tear arthropathy.[7]

Clinical outcomes

Rockwood et al demonstrated an 83% satisfaction rate in a cohort of 50 patients with massive irreparable tears 6.5 years after open débridement and subacromial decompression.[105] Of interest, mean active forward flexion improved from 105° preoperatively to 140° postoperatively in their cohort.[105] These findings were supported by Gartsman, who reported a 79% satisfaction rate in patients with irreparable rotator cuff tears after open débridement and subacromial decompression.[38] Pain significantly decreased, whereas range of motion and the ability to perform activities of daily living significantly increased. However, elevation strength significantly decreased after surgery.[38]

The long head of the biceps tendon is a significant pain generator of the shoulder, and massive rotator cuff tears often go along with biceps lesions. Walch et al reported a satisfaction rate of 87% in a series of 307 patients with massive rotator cuff tears treated by biceps tenotomy only.[120] However, it did not alter the progression of cuff tear arthropathy at a mean follow-up of 4.5 years.[120]

Boileau et al confirmed that both arthroscopic biceps tenotomy and arthroscopic biceps tenodesis effectively reduced pain and dysfunction caused by irreparable rotator cuff tears associated with a biceps lesion. There was no difference in outcomes of patients who received a tenotomy or a tenodesis. Outcomes were inferior in case of teres minor atrophy, true preoperative pseudoparalysis, and severe cuff tear arthropathy.[7]

Of interest, a comparative study between arthroscopic débridement alone and débridement plus tenotomy of the long biceps tendon found significant clinical improvements 2.5 years postoperatively compared with the preoperative baseline, but no significant differences were found between the 2 groups.[72]

Rotator cuff repair

Advancements in surgical skills, techniques, technology, and equipment have facilitated the arthroscopic repair of massive rotator cuff tears. The ideal rotator cuff repair restores biomechanics, decreases pain, improves function, and achieves a strong fixation that allows a more aggressive rehabilitation process and promotes healing.[24,115] Complete anatomic repair, when reasonable, should be performed. However, the outcomes of massive rotator cuff tears after repair are less predictable and associated with a higher retear rate at postoperative follow-up relative to smaller cuff tears. Factors that contribute to the retear rates at follow-up are increased fatty infiltration of tissue, decreased acromiohumeral distance, smoking,[95] size of the rotator cuff tear,[68] and increased tension on the repair.[17] The association between anatomic failure and functional outcomes remains controversial as several studies have indicated functional improvement in patients despite evidence of a retear on postoperative magnetic resonance imaging (MRI).[36,42] However, clinical outcomes tend to be better when the rotator cuff repair has healed and the tendon is intact.[82,114]

Healing rates and biomechanics

Jost et al studied the long-term outcomes of patients who had a structural failure of open rotator cuff repairs. At a mean of 7.6 years postoperatively, 19 of 20 patients continued to be either satisfied or very satisfied with the outcome.[66] The size of retears did not progress between 3.2 years and 7.6 years of follow-up, indicating that retears may not have the same natural history as primary tears, which usually progress in size over time.[66] There were adverse signs of progressed structural deterioration observed in the failed repairs that were not present in the intact repairs, including a decrease in acromiohumeral distance, progression of osteoarthritis, and progressive fatty degeneration of the infraspinatus.

In an effort to identify factors associated with healing, Chung et al investigated 108 patients who underwent arthroscopic repair of massive cuff tears at a minimum of 1 year of follow-up. Anatomic failures occurred in 39.8% of patients.[17] This is a comparable retear rate to that reported by Zumstein et al (57%),[129] Miller et al[83] (41%), Kim et al[69] (42.4%), and Park et al[100] (25%). All patients had significant improvement in pain as measured by several outcomes scores; however, functional outcome was poor in 38 of 108 patients as they had an American Shoulder and Elbow Surgeons (ASES) score less than 80. Fatty infiltration of the infraspinatus was found to be an independent prognostic factor for poor structural healing. Further analysis of failed structural healing revealed that a postoperative acromiohumeral distance of <4.1 mm was associated with poor functional outcomes. Zumstein et al indicated that open repair of massive rotator cuff tears yielded excellent results at a mean follow-up of 9.9 years.[129] A wide lateral extension of the acromion has been identified as a risk factor for retearing.[129] A study conducted by Ames et al found that patients with a larger acromial index were more likely to have an increased number of rotator cuff tendons torn as well as a larger number of anchors used in the repair.[2]

Biomechanical studies have shown superiority of the double-row rotator cuff repair on the basis of increased load

to failure and better restoration of the tendon footprint.[78,84] Denard et al investigated the clinical outcomes of patients with a massive rotator cuff tear who received either single- or double-row repairs.[24] On multivariate analysis, a double-row repair was 4.89 times more likely to result in a good or excellent University of California–Los Angeles score. Millett et al recently conducted a meta-analysis of level I randomized clinical trials comparing arthroscopic single-row vs. double-row rotator cuff repair.[86] Even though they were not able to detect differences in improvement in outcomes scores between single-row and double-row repairs, single-row repairs had significantly higher retear rates compared with double-row repairs, especially with regard to partial-thickness retears.[86]

Although stage 3 and stage 4 fatty degeneration of the rotator cuff muscles according to the Goutallier classification is considered by some to be an indicator of irreparability,[48,49] Burkhart et al found significant functional improvements in 86.4% of arthroscopic cuff repairs that would have been classified as likely to fail.[13] Mean active abduction, forward elevation, and external rotation all improved. The surgical technique used by Burkhart et al[13] is significantly different from the technique used by Goutallier et al[48,49] and may account for the discrepancy of results between the studies.

The optimal postoperative rehabilitation strategy to promote healing has yet to be determined. The ideal protocol protects the repair construct during the healing process while minimizing the risk of postoperative stiffness. A study conducted by Iannotti et al investigated the time to failure after rotator cuff repair of full-thickness tears ranging from 1 to 4 cm.[60] The investigators found that the majority of retears occurred between 6 and 26 weeks postoperatively, suggesting that rehabilitation should focus on protecting the repair for a longer time.

Partial repair

A complete anatomic repair of massive rotator cuff tears is not always surgically possible as a result of poor tissue quality, tendon loss, severe retraction, or increased tension of the repair.[57] In these cases, partial repairs of the tendons have been used successfully. Burkhart introduced the concept of partial repair on the basis of restoring biomechanical force couples and increasing acromio-humeral distances, therefore improving function and pain.[12,14] The outcomes of partial repair have subsequently been studied by many investigators.[6,14,27,58,70,71,90,91,102]

Although the reported clinical outcomes of partial repairs of massive cuff tears have been favorable, a biomechanical study found that partial repair resulted in abnormal shoulder kinematics.[99] In a cadaver model, partial repairs fail to restore maximum internal rotation, maximum external rotation, and total rotational range of motion to the intact state, whereas complete repair successfully did so at all angles of abduction.[99] Partial repair did successfully restore the position of the humeral head apex to the intact condition. The authors concluded that the nonphysiologic biomechanics of the glenohumeral joint after a partial repair may render patients susceptible to subsequent injury and decreased function.

Clinical outcomes

Supplementary Table I summarizes the studies reporting clinical outcomes of patients who underwent partial repair of a rotator cuff tear.[6,14,27,58,70,71,90,91,102] Overall, functional outcomes showed significant improvement over preoperative levels. Several studies have investigated differences in outcomes between complete and partial repair. Moser et al observed improvements in patients who underwent partial repair and complete repair.[91] Active external rotation was significantly better in the complete repair vs. partial repair; however, differences in subjective pain and function were not statistically significant. Iagulli et al found that both partial repair and complete repair groups exhibited significant improvements in the University of California–Los Angeles shoulder score after surgery at a mean follow-up of 24 months; however, there was no significant difference in score between the 2 groups.[58] Kim et al compared clinical outcomes at 2 years between complete arthroscopic repair with aggressive cuff release and partial repair with margin convergence.[70] Again, no statistically significant differences were found with respect to functional outcomes between the 2 groups at the time of follow-up. Statistical power issues may explain the failure to show difference in outcomes between complete and partial repair groups.

Recently, the relationship between clinical and surgical findings and the arthroscopic reparability of rotator cuff tears was analyzed.[57] High subjective disability, limited active external rotation, poor tendon quality, larger tear size, and U-shaped tears could often be repaired only partially. In the cohort, both partial and complete repair groups demonstrated improved function and level of disability.

The successful clinical use of partial rotator cuff repairs represents a good example of translational research. Partial repair of massive rotator cuff tears is an acceptable treatment option for patients in whom a complete repair is not possible. Patients can expect good clinical and functional outcomes after surgery.

Patch augmentation

Active patients with massive rotator cuff tears with minimal glenohumeral arthritis are particularly challenging to treat. The significant rate of failures of rotator cuff repairs led to the investigation of patch augmentation materials to enhance the strength of the repair and theoretically to enhance healing potential, thus serving as an alternative

to tendon transfers in this population of patients. Many varieties of patch augmentation have been developed and used clinically, including nondegradable structures, extracellular matrix–based patches, and degradable synthetic scaffolds.

When a patch augmentation device is used, the rotator cuff is repaired to nearly normal status either arthroscopically or with an open approach. The patch is then either implemented into the repair construct or sutured over the top of the repaired tendon by an arthroscopic, mini-open, or open technique.

A biomechanical cadaveric study investigated whether a patch-reinforced repair decreased gap formation at the tendon-bone repair site relative to a standard rotator cuff repair. Gap formation was reduced by 40% relative to the unreinforced group when it was subjected to cyclic loading. There was also an increased load to failure with the augmented repair.[107] These results are similar to those of McCarron et al, who also found a decrease in gap formation when using an augmentation material.[79] The investigators also noted that all augmented repairs completed the cyclic loading protocol, whereas 3 of 9 (33%) of nonaugmented repairs failed. Because increased gap formation has been implicated as a factor associated with decreased healing,[13] these studies suggest that patch augmentation may facilitate healing of the rotator cuff tendon. Contrary to the results of Shea et al,[107] an investigation of the biomechanics of massive rotator cuff repairs found that an augmented double-row repair did not increase the load to failure relative to nonaugmented double-row repairs, although the rotator cuff tendons were of normal quality in this study.[118] Furthermore, these studies take place at time zero and do not take into account healing effects, and therefore biomechanical in vivo results may differ from the in vitro findings.

Clinical outcomes

Iannotti et al reported no improvement of healing rate or clinical outcomes for augmentation of the surgical repair of large and massive chronic rotator cuff tears with porcine small intestine submucosa in a randomized clinical trial.[59] They concluded that augmentation with this type of patch was not recommendable. However, favorable clinical outcomes have been reported in several studies using different patch materials, with results summarized in Supplementary Table II.[4,11,16,32,46,53,90,103,126] This emphasizes that the type of patch seems to influence the outcome. Mori et al investigated the clinical outcomes of patients who underwent arthroscopic partial repair or a patch graft procedure to repair large or massive rotator cuff tears with low-grade fatty degeneration of the infraspinatus.[90] The group of patients who underwent the patch graft procedure had significantly better mean postoperative Constant scores and ASES scores compared with the partial repair group at a mean follow-up of 35 months. The retear rate of the infraspinatus in the patch graft group was 8.3% whereas the rate was 41.7% in the partial repair group as detected by MRI, suggesting that the patch graft procedure can improve healing and clinical outcomes.

Patch augmentation has shown promising results to improve the treatment of massive rotator cuff tears. Additional studies are needed to better understand the cellular factors associated with the healing of rotator cuff repairs and how to further stimulate these factors with augmentation material. Future studies comparing partial repair and patch augmentation may be of particular interest to determine the appropriate treatment of patients in whom complete repair is not achievable.

Superior capsular reconstruction and bridging reconstructions

The shoulder capsule is an important static stabilizer of the glenohumeral joint.[63] The anterior capsule serves to maintain glenohumeral stability anteriorly, whereas the posterior capsule plays an important role with posterior stability.[63] However, less is known about the function of the superior capsule.

The superior capsule attaches to a significant portion of the greater tuberosity, with an anatomic study indicating a range between 30% and 61% of total surface area.[96] As a result, it is often disrupted when complete tears of the supraspinatus or infraspinatus occur.[80] A recent biomechanical study determined that superior capsular defects led to increased glenohumeral translation in all directions, particularly with superior translation at 5° and 30° of abduction.[63] Biomechanically, reconstruction of the superior capsule with a patch graft restored superior translation to physiologic conditions, with the reconstruction having comparable translation to the normal intact rotator cuff.[81] The graft used to reconstruct the superior capsule was attached medially to the superior glenoid and laterally to the greater tuberosity.

Superior capsular reconstruction is a treatment option for a large to massive irreparable rotator cuff tear, defined as the inability of the torn rotator cuff tendon to reach the original footprint.[80] Mihata et al investigated clinical outcomes of superior capsular reconstructions in 24 shoulders (23 patients) that had irreparable tears.[80] A fascia lata autograft was used as the augmentation material to reconstruct the superior capsule. The lateral side of the fascia lata was attached to the greater tuberosity by a compression double-row technique. Side-to-side sutures were used to attach the graft to the infraspinatus, anterior supraspinatus, or subscapularis. All average clinical outcomes scores significantly improved at a minimum 2-year follow-up period. The ASES scores, a validated measure of rotator cuff function,[73] improved from 23.5 preoperatively to 92.9 postoperatively ($P < .0001$), and shoulder muscle strength significantly improved.[80] Acromiohumeral

distance significantly increased by 4.1 ± 1.7 mm after surgery. MRI findings indicated that 20 of 24 shoulders (83.3%) did not have retears or graft tears at the time of final follow-up, and there was no progression of muscle atrophy.[80] The authors speculated that the superior capsule reconstruction restored anterior and posterior force couples because of its attachment to the subscapularis and infraspinatus, respectively.[80] Furthermore, the authors did not report any surgical complications related to the procedure. These results indicate that superior capsular reconstruction may be a promising new tool to manage massive, irreparable rotator cuff tears.

Gupta et al suggested a bridging interposition reconstruction of irreparable massive rotator cuff tears, sewing a human dermal allograft into the native tendon and anchoring it laterally onto the greater tuberosity. They reported promising results in a prospective observational study of 24 patients with an average 3-year follow-up.[52,53] However, patch augmentation devices are not Food and Drug Administration approved to span a gap in the rotator cuff repair greater than 1 cm.

Tendon transfers

Concerns about the longevity and complications of rTSA procedures render it a less favorable treatment modality in young patients with massive irreparable rotator cuff tears with poor tissue quality. However, it is possible to provide pain relief and to improve function by performing tendon transfers. The primary goal of tendon transfers is to restore the anterior and posterior biomechanical force couples of the glenohumeral joint. Transfers of many different tendons have been used, with the most common being latissimus dorsi with or without the teres major, pectoralis major, and trapezius. Tendon transfer is most suitable for a young, active patient with minimal glenohumeral arthritis and severe functional limitations.[5,94]

Latissimus dorsi transfer

Transfer of the latissimus dorsi with or without the teres major is most commonly used for massive irreparable posterosuperior tears. The latissimus dorsi has a large muscle excursion, making it a good candidate for muscle transfer.[43] A transfer of the teres major individually is challenging, given its small muscle excursion and small tendon. Consequently, if it is transferred, it is usually done in conjunction with the latissimus dorsi. Several surgical techniques have been used for latissimus dorsi transfer, including single-incision, double-incision, and more recently arthroscopically assisted transfer.[88,92]

Normal function of the latissimus dorsi muscle-tendon unit on the humerus includes adduction, internal rotation, and extension. When it is transferred, the muscle no longer serves as an internal rotator but rather is an external rotator and humeral head depressor.[56] There is currently a controversy about whether the transferred latissimus dorsi tendon exerts the clinical effects by a passive tenodesis effect or by active muscle contractions. The most recent study found that the transferred tendon has active synergistic contractile properties during abduction and external rotation.[56] Transferring the muscle-tendon from its insertion on the midbicipital groove anteriorly to the greater tuberosity posterosuperiorly serves to restore the posterior force couple and therefore improves glenohumeral function. The humeral head depression induced by the transferred tendon likely contributes to improving biomechanics of the glenohumeral joint by centering the humeral head on the glenoid, creating a better fulcrum.[56] This can be tailored intraoperatively as more posterior placement results in more external rotation, whereas more superior placement results in more humeral head depression.[121]

Clinical outcomes

Studies regarding the clinical outcomes of latissimus dorsi tendon transfers are summarized in Supplementary Table III.[3,15,20,23,26,29,41,43-45,61,62,75,89,92,98,116,121,122] A systematic review conducted by Namdari et al analyzed 10 studies between 1992 and 2010 to determine the expected outcomes, predictive factors for success, and complications of latissimus dorsi transfers.[94] Frequency-weighted mean follow-up was 45.5 months. The frequency-weighted mean adjusted Constant score improved from 45.9 preoperatively to 73.2 postoperatively. Frequency-weighted mean active forward elevation improved from 101.9° preoperatively to 137.4° postoperatively, and active external rotation improved from a frequency-weighted mean of 16.8° to 26.7°. Active abduction improved from a frequency-weighted mean of 91.4° preoperatively to 130.7° postoperatively. The overall reported complication rate was 9.5%, which included infection, neurapraxia, tears of the transferred tendon, failures of deltoid repair, hematomas, and wound dehiscence. In addition, in more than half of the shoulders, glenohumeral arthritis progressed, and there was superior migration of the humeral head. Further analysis of the data led the authors to conclude that poor functional outcomes are more likely after revision surgery, with advanced teres minor fatty muscle atrophy, and in patients with a deficient subscapularis.

Moursy et al investigated the effect of removing a small piece of bone with the latissimus dorsi when doing the transfer with respect to detachment of the tendon from the greater tuberosity compared with sharp separation of the tendon from the insertion on the humerus.[92] The ASES score, mean Constant score, range of motion, and strength were all significantly better in the group that had the tendon harvested along with a bone chip. In addition, MRI showed detachment of the tendon in 4 of 22 patients (18%) in the sharp separation group and 0 of 20 patients (0%) in the bone chip group.[92] Inclusion of a bone chip when

harvesting can decrease reruptures of the transferred tendon, one of the factors associated with failure.

A recent study examined the short-term results of arthroscopically assisted latissimus dorsi transfer.[15] Results were similar to those of previous studies. Less strength in forward elevation and lower Constant scores were observed for revision surgeries relative to primary surgeries. There was significant improvement in pain and range of motion in external rotation as well. Arthroscopic latissimus dorsi transfer at short-term follow-up has results comparable to those of open procedures and provides an alternative technique to traditional methods.

Latissimus dorsi transfers are a reasonable surgical treatment in young patients with poor tissue quality and massive posterosuperior rotator cuff tears. Improvements in pain and function allow improvements in activities of daily living and a higher quality of life. Proper selection of patients is important for the success of this technique.

Pectoralis major transfer

Irreparable anterosuperior rotator cuff tears can be surgically salvaged with a transfer of the pectoralis major. This technique is particularly useful in treating patients with recurrent anterior instability resulting from subscapularis insufficiency.[37]

The deltopectoral approach is used for surgery, and several surgical techniques have been described; however, the subcoracoid pectoralis major transfer most closely approximates the inferior and posterior force vector originally provided by the subscapularis.[74] Gerber et al described a technique using split pectoralis major transfers to re-establish the posterior and inferior force vectors.[40] This technique reduces the risk of injury to the musculocutaneous nerve by going underneath the conjoined tendon.[40] Reliable improvements in function and pain have been recorded in several studies for patients who underwent a pectoralis major transfer for isolated subscapularis tears and multitendon tears involving the subscapularis.

Clinical outcomes

The results of studies that investigated the outcomes of patients who underwent a pectoralis major transfer for massive rotator cuff tears are summarized in Supplementary Table IV.[31,37,39,40,65,104] Jost et al noted that outcomes were less favorable in patients who had a concomitant irreparable supraspinatus tear.[65] A recent systematic review of 8 studies (195 shoulders) noted an improvement in Constant scores from a mean preoperative value of 37.8 to 61.3 postoperatively.[110] The Constant scores were significantly higher in patients who had a subcoracoid transfer of the pectoralis major tendon as opposed to a supracoracoid transfer, in agreement with the biomechanical observations of Konrad et al.[74] Elhassan et al found that patients with irreparable ruptures of the subscapularis tendon after shoulder replacement had a high risk of failure of the pectoralis major transfer, especially in case of preoperative anterior subluxation of the humeral head.[31] Pectoralis major transfers are a reasonable surgical option for the management of irreparable anterosuperior rotator cuff tears, particularly when the patient is experiencing anterior instability as a result of subscapularis insufficiency. Patients can expect a significant improvement in pain and function, with better outcomes if there is an isolated subscapularis tear.

Trapezius transfer

Trapezius transfers are currently used to improve external rotation in patients with brachial plexopathy.[30] A biomechanical investigation found that a lower trapezius transfer is more effective in restoring external rotation than the latissimus dorsi transfer.[55] Consequently, there is increased interest in using trapezius transfers for treatment of massive irreparable posterosuperior rotator cuff tears. We are not aware of any clinical studies detailing outcomes regarding the use of trapezius transfer for posterosuperior rotator cuff tears. Additional biomechanical and clinical studies will be needed to see if this method has utility in the management of massive rotator cuff tears.

Reverse total shoulder arthroplasty

A major indication for rTSA is cuff tear arthropathy, in which a massive rotator cuff tear goes along with secondary glenohumeral joint damage.[5] rTSAs are also frequently used for pseudoparalysis due to massive irreparable rotator cuff tears even in the absence of osteoarthritic degeneration of the glenohumeral joint.[28] Hemiarthroplasty has been considered the treatment of choice for cuff tear arthropathy for a long time; however, rTSA has recently been shown to yield better results concerning pain relief and function.[76] Anatomic total shoulder arthroplasty is not commonly considered for patients with massive rotator cuff tears because of concerns about instability and secondary loosening of the glenoid component.[35] Additional indications for rTSA include comminuted proximal humeral fractures in elderly patients with poor bone quality and revision arthroplasty.

Clinical outcomes

The results of studies reporting outcomes of patients who underwent rTSA for massive rotator cuff tears are summarized in Supplementary Table V.[9,28,33,34,67,76,97,106,112,123,124] Reported rates for complications and revisions after rTSA have been as high as 50% and 33%, respectively.[124] Recently, lower complication rates (7%) and revision rates (5.3%) have been reported.[50] It is important to assess the integrity of the teres minor preoperatively as Simovitch et al reported inferior outcomes in patients with stage 3 or stage 4 fatty infiltration.[111] Furthermore, Boileau et al noted that when the

preoperative function of the teres minor was impaired as determined by the Hornblower sign, postoperative active external rotation decreased significantly.[8]

Special concerns apply for young and active patients. Both Ek et al[28] and Sershon et al[106] recently reported substantial improvement in terms of pain relief, function, and satisfaction in patients younger than 65 years[28] or 60 years[106]; however, high complication rates of 37.5%[28] and 25.0%,[106] respectively, occurred. Guery et al reported a survivorship 10 years after rTSA of 58%, therefore recommending that rTSA be reserved for patients older than 70 years with low functional demands.[51] This statement was supported by Favard et al, who reported a deterioration both clinically and radiologically over time, therefore recommending caution with indication for reverse shoulder arthroplasty, especially in younger patients.[33]

Conclusion

The management of patients with massive rotator cuff tears remains challenging. A thorough knowledge of treatment options and indications is crucial to achieve the best outcomes for patients. Surgical advances including patch augmentation have improved the treatment of massive rotator cuff tears; however, long-term studies are needed to identify prognostic factors and ideal techniques and to optimize selection of patients.

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Supplementary data

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