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REVIEW

Optimal Techniques and Rehabilitation Protocols for Rotator Cuff Repair: A Literature Review

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Abstract: Rotator cuff pathology is present in nearly half the adult population over the age of 50 years and remains a leading cause of shoulder pain and dysfunction. These musculotendinous injuries may be the result of an acute trauma or chronic degeneration. Clinical examination involves inspection, range of motion, and strength assessment with special testing used to isolate the involved rotator cuff muscles. The classification of these injuries involves identification of tear size, thickness, morphology, and the presence of tendon retraction or muscular atrophy to guide clinical management. Magnetic resonance imaging is the primary imaging modality used to define these metrics unless contraindicated in select patients. Nonoperative management is largely reserved for partial thickness tears involving <1 cm full thickness tears. Surgical repair is indicated in the symptomatic patient with >25% of bursal or >50% articular surface involvement and those >1 cm in the sagittal plane. These are often managed with primary repair using single row, double row or transosseous equivalent techniques. In the event of irreparable rotator cuff tears with significant tendon retraction with or without fatty atrophy, partial repair techniques with augmentation, superior capsular reconstruction, and balloon spacers remain salvage options prior to consideration of reverse shoulder arthroplasty. Additionally, there remains debate on optimal postoperative rehabilitation protocol with recent literature supporting early passive mobilization and active range of motion at four to six weeks without compromise of tendon repair integrity that could serve to optimize both glenohumeral motion, accelerated recovery and strength optimization without an increase in re-tear rates. There is currently a lack of high-quality, long-term studies directly comparing surgical techniques and nonsurgical management, especially with follow-up beyond five years to assess durability, re-tear rates, and functional outcomes. This review aims to critically appraise the available evidence to guide optimal rotator cuff repair techniques and postoperative rehabilitation protocols.

Keywords: rotator cuff repair, rotator cuff tear, double row, transosseous equivalent, postoperative rehabilitation, surgical technique

Introduction

Rotator cuff pathology affects 30–50% of adults over the age of 50 years, representing a significant cause of shoulder pain and debility. These injuries may be acute or chronic, with degenerative tears affecting up to 54% of asymptomatic patients over the age of 60 years.[1] Risk factors for rotator cuff injury include those over 40 years of age, repetitive-use overhead athletes, and individuals who have experienced traumatic events including blunt impact or glenohumeral dislocation.[2,3]

Given the diverse etiologies, age groups, and patient populations affected by these tears, the use of classification systems is critical to guide clinical management, as they facilitate surgical indications and the selection of appropriate operative interventions.[4,5] These classifications include rotator cuff tear (RCT) size, location, shape, chronicity (fatty atrophy), as well as predictive models in the risk of healing failure. Within the framework of these classification systems, operative management is determined by the specific rotator cuff pathology and may include debridement, single or double row suture anchor repair, superior capsular reconstruction (SCR), tendon transfers, or reverse total shoulder arthroplasty (rTSA). Following surgical intervention, postoperative rehabilitation may be individually modified to consider tendon quality, host factors and repair technique with the primary goal of range of motion optimization while simultaneously allowing the musculotendinous repair to heal.

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Given the variability in clinical presentation, tear characteristics, and treatment strategies, further evaluation with detailed characterization is essential to effectively summarize the management of rotator cuff tears. As such, the purpose of this review is to provide updated evidence on the topic of surgical rotator cuff repair techniques and postoperative rehabilitation protocols that optimize glenohumeral joint motion while preserving tendon repair integrity.

Classifications and Indications

A comprehensive literature review was conducted using PubMed to identify relevant studies representing high levels of evidence, published in reputable peer-reviewed journals, and frequently cited within the field. An unbiased summary was prioritized, highlighting both the strengths and weaknesses of controversial topics. This approach ensured inclusion of the most influential and methodologically rigorous literature. RCTs vary widely in etiology, characteristics, and thus management. As such, the initial approach to management of these injuries begins with a detailed history and physical examination, often followed by radiographic study of the glenohumeral joint. Factors such as patient age, activity level, and bone quality are foundational to the initial management. When accompanied by common features of these injuries within the confines of well-established classifications, these factors guide indications for surgery and post-injury rehabilitation. These classifications tend to rely heavily on advanced imaging, primarily magnetic resonance imaging (MRI), although plain films are fundamental in evaluating other etiologies of shoulder pathology with ultrasound being an emerging adjunct for diagnostic efficacy and accuracy.[6]

Initial radiologic analysis should focus primarily on cuff tear tendinous location, most commonly in the supraspinatus and infraspinatus tendons.[7] One commonly used classification, the Ellman classification, is beneficial to characterize size (I – <3 mm or 25%, II – 3–6 mm or 25–50%, III – >6 mm or 50%) and location (A – articular sided, B – bursal sided, C – intratendinous).[8] The size and location has profound impacts on the indications for rotator cuff tear repair. For patients who fail non-operative management (corticosteroid injections [CSI], physical therapy [PT], nonsteroidal anti-inflammatory drugs [NSAIDs]) without systemic illnesses that preclude them from surgery, indications for surgery include both traumatic and chronic tears. Acute, full-thickness tears (Ellman grade 3) are widely accepted as an indication for surgical management.[9,10] Similarly, bursal-sided tears with >3mm in depth (Ellman grade 2B and 3B) as well as partial articular sided tears > 50% (Ellman grade 3A) are also common indications for operative intervention and repair.[9,10] Although the Ellman grading system is an exceptional means of communication, it lacks characterization of the chronicity and cuff tear shape, both of which are important considerations in the type of procedures offered and the likelihood of their success.

An adjunct to the Ellman classification is the Goutallier classification for rotator cuff arthropathy. Initially described in 1994 based upon review of CT scans, it has since been extrapolated and validated for the use of MRI to score the degree of fatty infiltration from stage zero (normal muscle without fat) to stage five (more fat than muscle within the muscle).[11–13] For patients with low stage Goutallier classification, the risk of re-tear is lower than those with higher staging offering insight into the success of rotator cuff tear.[14] As such, higher staging portends higher risk of re-tear and less likely indicate rotator cuff repair for other operative management, especially with the success RSA for these patients.

Although less described with regard to indications for or against surgery, tear shape (crescent, U-shaped, L-shaped) is more commonly involved in surgical planning and technique for rotator cuff tears as it often guides the type of repair and location of anchors.[15–18] Finally, more recent literature supports the use of a collection of the above classifications with the use of the Rotator cuff Healing Index (RoHI) score.[19] This scoring system is summative based upon various patient and tear attributes (age, anterior to posterior cuff tear size, cuff retraction, infraspinatus fatty infiltration grade, bone mineral density, and level of work or activity), which predict the risk of rotator cuff repair healing failure. Patients who score <4 have a 6% healing failure, with those scoring >5 having a 55% chance of healing failure, providing meaningful information that may lead patients to rTSA instead of rotator cuff repair where operative management is indicated.

The reliability and validity of rotator cuff classification systems vary depending on the specific system and imaging modality used. Interobserver agreement is generally high in distinguishing full-thickness and partial-thickness tears and location (articular vs bursal) of partial-thickness tears, with kappa values around 0.85, indicating excellent reliability. However, the reliability drops substantially when classifying the depth of partial-thickness tears, with kappa values as low as 0.19, reflecting poor reliability.[20] For full-thickness tears, classification by topography, the degree of retraction in the frontal plane, achieves moderate reliability (κ ≈ 0.54).[20] The geometric classification system (crescent, longitudinal, massive contracted, arthropathy) shows good to excellent intraobserver reliability (κ = 0.81–0.92) and moderate to good interobserver reliability (κ = 0.52–0.82), especially among experienced observers using MRI or MR arthrography.[21,22] Validated geometric and topographic classifications correlate well between MRI and arthroscopy; however, clinical outcome correlation is limited with the tear pattern inconsistently predicting postoperative function.[22] Rotator cuff classification systems are most reliable for basic tear characteristics (full vs partial thickness, tear size, and retraction) with decreasing reliability and validity in more complex or subjective criteria.

Given the implications of classifications on the indications and type of operative management, further review on the surgical techniques to manage these injuries will aid in understanding the importance of their use.

Surgical Technique

Partial Thickness Rotator Cuff Tears

Histologically, the rotator cuff tendon is divided into five individual layers which are of importance due to the articular surface having half of the tensile strength of the bursal interface.[23] This biological variation explains the epidemiologic findings of articular sided tear patterns as more prevalent than its bursal counterpart. Although the distinction of size is largely in regard to full thickness tears, partial thickness tears involving >25% of the bursal or >50% of the intra-articular aspect are considered for operative intervention. Biomechanical studies suggest partial tears of this magnitude have decreased intrinsic ability to spontaneously heal and alter strain trajectory during loading that ultimately lead to the propagation of the tear with repetitive use.[24] These factors support the surgical repair of symptomatic partial thickness RCTs to encourage healing and prevent further injury. For partial thickness RCTs greater than 50% in thickness (~3–6 mm), tear completion or transtendinous techniques are recommended, as they have shown good clinical outcomes.[25] In the case of poor tendon quality a conversion to a full thickness with either a single row or double row construct is reasonable.[26,27] In the event of a partial articular sided tendon avulsion (PASTA), tears may be repaired with a transtendinous technique.[28,29] However, current evidence suggests no significant difference in clinical outcomes when comparing full thickness conversion and transtendinous repair in partial thickness RCTs.[30,31] Additionally, the current American Academy of Orthopaedic Surgeons (AAOS) guidelines notes that repair of high grade, partial tears improves outcomes with no clear evidence to suggest either repair technique improves clinical outcomes in comparison to arthroscopic debridement alone.[32] Tsuchiya et al conducted a systematic review of level II–IV evidence studies analyzing 257 partial thickness RCTs tears for tear progression at an average follow-up of 34 months. They reported an overall rate of progression to a full-thickness tear at 0.26% per month. Interestingly, there were no significant differences in the rate of progression in the symptomatic and asymptomatic groups at 0.22% per month and 0.32% per month, respectively.[33] The study results suggest that although progression to full thickness tear patterns may be observed in short to intermediate follow-up, the rate is relatively low without corollary symptoms to guide management.

In the conversion technique, variation remains regarding the use of single or double row constructs. It is the senior author's opinion that partial thickness tears generally following the same trend of full thickness tears, with tears <1 cm may be treated with a single row repair, tears 1–3 cm being treated with either technique, and tears >3 cm predominantly managed with a traditional double row or transosseous equivalent (TOE) construct. There remains debate on the optimal timing and technique of surgical intervention in regard to partial thickness RCTs. A shared decision-making model should be employed to educate patients on the risk of tear propagation. Additionally, surgeons should carefully consider host factors, symptom severity and degree of partial tearing to determine whether debridement alone, transtendinous repair, or conversion to full thickness would be most appropriate in each unique case.

Full Thickness Rotator Cuff Tears

Small Sized Tears (<1 cm)

RCTs of less than 1 cm undergo considerable discussion in regard to nonoperative versus operative management. Several studies have demonstrated that physical therapy is a viable short-term option to alleviate symptoms without significant concern for rapid tear progression.[34] Ranebo et al, for example, has reported 29% of unrepaired

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tears experienced an increase in tear size >5 mm with no significant fatty infiltration during the 12-month observation period.[35] Thus, a trial of non-operative management is recommended for small, full thickness RCTs. For those small tears that remain symptomatic after a non-operative trial, operative intervention may be considered. Moosmayer et al published 10-year outcomes of a randomized control trial with 103 patients comparing nonoperative and operative management of small to medium sized RCTs and found superior results in the operative cohort in the long term due to tear progression leading to poor clinical outcomes.[36]

Evidence supports the natural history of unrepaired, full thickness (<1 cm) RCTs to progress in tear size of >1 cm in approximately 50% of patients.[37,38] Thus, there should be a shared decision-making process, especially in younger patients with more physically demanding occupations, as surgical repair may provide a more durable result in this cohort.[39] While surgical repair offers similar outcomes in comparison to physical therapy in the short term, the evidence supports continued concern for tear progression over the long term which may result in poorer outcomes and function.[34,36] The 2019 AAOS Evidence Based Guidelines for the Management of Rotator Cuff Injury reports, in the case of small and medium sized RCTs, that both physical therapy and surgical management resulted in a notable improvement in patient reported outcomes (PROs) for patients with symptomatic small to medium full-thickness RCTs. Additionally, they purport strong evidence that PROs improve with physical therapy in symptomatic patients with full-thickness RCTs with the understanding that RCT size, muscle atrophy, and fatty infiltration may progress over 5 to 10 years with nonsurgical management. The "strong recommendation" was made by synthesizing data from at least two high-quality randomized controlled trials with consistent results supporting the intervention. Specifically, Moosmayer et al[36] and Kukkonen et al[40] were referenced demonstrating that both physical therapy and surgical repair led to significant improvements in patient-reported outcomes such as the Constant score and the American Shoulder and Elbow Surgeons (ASES) score over 2–5 years, with no clinically meaningful difference between groups in the short to intermediate term.[2]

For all RCTs, the ideal repair construct must optimize suture-to-bone fixation, suture-to-tendon fixation, abrasion resistance and strength of suture, knot and loop security with restoration of the anatomic rotator cuff footprint.[41] The factors influencing these outcomes include biomechanical factors (single row versus double row), arthroscopic knot tying technique, angle of anchor insertion, suture anchor material and configuration for bony ingrowth, and suture wire or tape among others.[42] Although there appears to be a biomechanical advantage and decreased rates of re-tears with a double row construct for larger tears in regard to pain relief, range of motion, and cited PROs,[43] the effect is less pronounced in smaller tears in which a single row configuration has proven an effective approach for tears less <1 cm.[25,44] In tears of this size that fail nonoperative management or fall into the category of patients for initial surgical management, a take-down repair technique may be utilize primary repair may be utilized most often accommodating a single row construct based upon surgeon evaluation.

Medium Sized Tears (1–3 cm)

When the RCT tear exceeds 1 cm up to 3 cm, the literature supports primary tendon repair over physical therapy alone[34] in terms of shoulder function, pain, and patient-reported outcome measures.[36] Zhang et al[45] conducted a meta-analysis including eight Level I or II evidence studies with at least 2 years of follow-up to determine whether the arthroscopic double row technique produced superior clinical or anatomic outcomes in comparison to single row repair. They found that although American Shoulder and Elbow Surgeons (ASES) or University of California at Los Angeles (UCLA) scores were higher for double row constructs in tears measuring 1–3 cm, the differences did not reach statistical significance. Through evaluation of Constant, ASES, and UCLA scale systems and two independent reviewers' imaging assessment of rotator cuff integrity as 1) full thickness re-tear, 2) partial thickness re-tear, and 3) complete cuff integrity, their results suggest no significant difference in single versus double row repair for tear sizes smaller than 3 cm reporting between the two techniques. Although the authors reported a trend toward clinical significance for all tear sizes, this midrange tear size <3 cm largely relies on surgeon preference, patient comorbidities and tendon quality to determine the optimal surgical technique.

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Large Sized Tears (3–5 cm)

For large cuff tears, Zhang et al additionally suggested that the double row fixation technique increases postoperative rotator cuff integrity and improves the clinical outcomes, especially for full-thickness RCTs larger than 3 cm.[45] Traditionally, the gold standard in rotator cuff repair was an open approach was utilized with transosseous tunnels through the greater tuberosity;[46] however, an arthroscopic alternative was designed with a TOE or suture bridge repair option to biomechanically simulate the advantages of additional fixation to the double row repair technique in a minimally invasive manner. In the TOE technique, the medial and lateral row sutures are crossed over to the contralateral suture anchors in a bridged fashion with the aim to maximize the contact area of the tendon to the anatomic footprint of the greater tuberosity to optimize healing. The evidence supports a higher ultimate load to failure and resistance to both shear and rotational forces compared to the traditional double row alone.[47,48] TOE anchor-based repairs have shown satisfactory clinical and biomechanical results; however, these attributes have been coupled with increased cost, nonbiologic burden to the healing interface of the tendon, and new catastrophic failure modes including tendon transection, anchor pullout, and bone voids.[49]

Massive Reparable (>5 cm) and Irreparable Rotator Cuff Tears

It is important to distinguish between massive and irreparable RCTs as the two are not mutually exclusive. A massive tear has been defined as involvement of more than one of the rotator cuff tendons, greater than 5 mm in the sagittal plane or greater than two-thirds exposure of the anatomic footprint. Massive, traumatic RCTs do not have the biologic considerations of chronic tendon retraction and muscular degeneration limiting surgical options. In these cases, a primary repair may be attempted if addressed in a timely manner. Irreparable tears, however, may not necessarily be massive but depend on host factors and tissue quality to include those that have significant muscle atrophy, impaired tendon quality or a biological impediment to healing. Similar to large RCT, massive tears benefit from double row repair techniques.[45]

Technical challenges remain in the optimal repair technique in irreparable RCTs (iRCTs) with options including primary repair with graft augmentation, partial repair with or without bridging, SCR, tuberoplasty, tendon transfers, balloon spacer or rTSA. The technique depends on patient factors, degree of tendon retraction, fatty atrophy, and presence of pseudoparalysis.

Hughes et al conducted a systematic review including 83 studies and 3363 patients with iRCTs at minimum one year clinical follow-up. They evaluated debridement, arthroscopic and open repair, allograft bridging/augmentation, SCR, subacromial balloon spacer, and tendon transfer. Data points included range of motion, visual analog scale (VAS) pain score, ASES score, Constant score, rate of revision surgery, and rate of conversion to arthroplasty. All surgical options resulted in improvement in patient-reported outcomes with debridement having statistically significantly greater postoperative abduction and forward flexion motion, as well as better VAS pain scores, compared to the other treatment options. The SCR subgroup had the greatest improvement in ASES scores postoperatively. The overall revision rate was 7.2% among all surgical options, with the allograft bridging/augmentation group having the lowest rate of revision at 0–8.3%. The overall rate of conversion to arthroplasty was 7.2%, with debridement having the greatest rate of conversion at 15.4%.[50]

The current literature demonstrates substantial variability in the quality and level of evidence supporting different surgical techniques for massive, iRCTs that must be clearly acknowledged when interpreting comparative outcomes. Techniques such as debridement, arthroscopic and open repair, allograft bridging/augmentation, SCR, subacromial balloon spacer, and tendon transfer are supported by studies of differing methodological rigor, sample sizes, and follow-up durations. Bridging allograft reconstruction has some higher-level evidence, including randomized controlled trials,[51] but most other techniques lack robust comparative data and long-term follow-up with inconsistent definitions, patient selection, and heterogenous outcome measures. The authors caution the interpretation of these results given the short term follow-up, bias and inclusion of lower-level evidence studies; however, it does highlight a wide range of options for surgical management. Thus, it is imperative for surgeons to critically consider the individual patient and technical demands of the operation.

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Rotator Cuff Tear Shape

Although somewhat less reviewed in the literature, the rotator cuff tear shape portends an important consideration for intraoperative repair with variations in treatment reliant more upon technique of suture tensioning (force vector of tension and succession of anchor placement) than the number of anchors used. Treatment pattern often relies more heavily on surgeon experience and training.

Crescent Shaped

The crescent-shaped RCT is largely amenable to direct tendon to bone repair with mobility often to the anatomic footprint with minimal tension. These tear patterns tend to be concentric and localize close to the native cuff insertion and as such are repaired with single or double row constructs.[52]

U-Shaped

U-shaped variant often has more medial retraction and will result in a higher tension construct if attempts are made to repair directly to bone. Instead, this tear pattern is more amenable to marginal convergence in a side-to-side fashion, resulting in an inverted T-shaped repair prior to repair to the anatomic footprint. Marginal convergence may be accompanied by an interval slide depending upon the degree of tear medialization and required tendon excursion.[53]

L-Shaped

The L-shaped tear pattern is similar to the U-shape with the exception of one portion in the anterior or posterior portion of the tear being more mobile and amenable to direct osseous repair. It is critical to obtain a thorough arthroscopic evaluation to distinguish these similar but technically unique tear patterns. Following the repair of the more mobile component, the remainder may be repaired as a traditional U-shaped tear pattern again with side-to-side repair first followed by more standard tear to insertion repair.[52]

Debridement and Balloon Spacer

When evaluating the non-arthroplasty options in iRCTs, Hughes et al[50] reported that the debridement cohort exhibited statistically significant improvements in abduction and forward flexion and VAS pain scores. They showed similar improvements in internal and external rotation and Constant scores in comparison to other treatment options. Arthroscopic debridement alone may be considered in select patients understanding this has the highest rate of conversion to arthroplasty, reported at 15.4% in this study. Arthroscopic debridement and use of a balloon spacer remain salvage options that are less technically demanding than the aforementioned options. There are no long-term data regarding the balloon spacer to support its use over debridement;[54] however, short and mid-term results indicate promising outcomes even after the biodegradation process 12 months following the procedure, which is thought to the result of restoration of functional glenohumeral biomechanics from mimicking the rotator cuff function of humeral head depression and normalizing the native glenohumeral center of rotation.[55] The one Level I evidence study included in a systematic review and meta-analysis was published by Verma et al[56] and sought to evaluate the efficacy of a subacromial balloon spacer in comparison to an arthroscopic partial repair in patient with an irreparable, posterosuperior, massive RCTs. A total of 184 patients were analyzed across twenty hospital sites at a minimum of two year follow-up with statistically significant improvements in ASES scores in both groups with forward flexion being significantly greater in the balloon spacer cohort with shorter operative times. The authors concluded the balloon spacer to be a viable alternative to partial repair in patients with irreparable posterosuperior massive RCTs with an intact subscapularis. However, critical appraisal is required in the event of industry support of research efforts as a source of bias with further studies needed to corroborate findings.

Partial Repair

A partial repair aims to anchor the remaining tendon to a more medialized point from the anatomic footprint in order maintain semblance of motion, function and mitigate humeral head migration. In order to create a lower tension, a partial, arthroscopic repair is often accompanied by an anterior or posterior interval slide or marginal convergence with a consideration of an additional bridge technique. An anterior interval slide is performed by releasing the rotator interval,

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specifically the medial aspect of the capsule, preserving the lateral bridging fibers. This releases both bursal and articular sided adhesions securing the remaining supraspinatus tendon while the posterior interval slide involves releasing the interval between the supraspinatus and infraspinatus tendon to improve mobility. The constructs have been shown to provide a more tension-free construct. Additionally, a bridge technique may be performed with a partial repair where a graft may be shuttled through the partial repair construct and anchored to the anatomic footprint.[57]

Following preliminary approximation and mobilization to provide more tensionless tendon excursion through interval slide or marginal convergence, there is debate on the optimal augment of the partial repair to the anatomic footprint. Zhou et al[58] published a network meta-analysis including 17 studies with 2123 patients and 10 surgical techniques. They reported that latissimus dorsi transfer (LDT) with a partial repair may achieve improved clinical outcomes versus to LDT alone in comparison to rTSA, SCR, patch, partial repair alone, debridement plus biceps tenotomy, debridement alone, balloon spacer plus biceps tenotomy, and balloon spacer alone. An additional consideration is the role of the long head of the biceps as a humeral head depressor with its incorporation into the repair construct. This technique often involves releasing the transverse humeral ligament and translating the long head of the biceps tendon (LHBT) posteriorly on the greater tuberosity rotator cuff insertion. Additionally, Laprus et al[59] included 60 patients with iRCTs at an average of 62.5 years old and a mean follow-up of 34.5 months with reported better tendon healing and functional results with LHBT augmentation in comparison to partial repair alone. The re-tear rate was 43.3% in the partial repair LHBT augmentation cohort and 73.3% in the partial repair alone with no significant difference in range of motion, shoulder strength, Hamada classification, Simple Shoulder Test Score, or postoperative Goutallier stage. Conversely, Cuff et al[60] reported on a 34 patient case series of those who had an iRCT with maintained for active forward elevation >120 degrees and underwent partial repair with biceps tenotomy. The authors reported statistically significant improvements in the ASES and Simple Shoulder Test and a decrease in VAS pain scores with no change in range of motion at 5 year follow-up. However, 36% progressed in their Hamada classification with an overall failure rate of 29%, defined as ASES of <70, loss of active elevation >90 degrees, or revision to rTSA. Although this is a small patient case series, this study raises the question of the significance of the role of the LHBT in the longevity of partial RCTs.

A recent publication by Efremov et al[61] in *Arthroscopy* reported on an alternative surgical technique with in situ biceps tenodesis offering a more fascicle approach in creating an anteriorly positioned "jump graft" better suited for anterior based tear patterns requiring less manipulation of the LHBT with the goal of preserving its native position structural integrity. In a retrospective review of 39 patients at an average of 21 months follow-up, the authors reported statistically significant improvement in VAS, ASES and SANE scores with 66.7% (26 patients) achieving the minimally clinically important difference (MCID) for VAS, 84.6% (33 patient) for ASES, and 76.9% (30 patients) for the SANE score. They concluded the partial repair with LHBT in situ tenodesis to be an effective treatment in an iRCTs with improvement in PROM and ROM. These results were corroborated by a meta-analysis published by Thamrongskulsiri et al[62] reporting decreased rates of re-tear in the LHBT with no significant difference in clinical outcomes.

Although there is no consensus on the ideal augment to partial repair in iRCTs, improved clinical outcomes have been reported with efforts to maximize tendon excursion and minimize tendon tension including various options for dermal allograft bridge techniques, SCR or tendon transfer with emerging literature evaluating the contribution on the LHBT in the longevity of the partial repair construct.

Superior Capsular Reconstruction

SCR remains a viable option in the treatment of iRCT. In the event of pseudoparalysis,[63] the surgical options then largely become limited to SCR and rTSA. The definition of pseudoparalysis has been debated in the literature with features including an inability to initiative active elevation or shoulder shrug or active elevation less than 45 degrees This must be distinguished from pseudoparesis (<90 degrees of elevation), pain limitation, neurogenic causes or in the setting of acute injury. Of the joint sparing options, there is evidence to support SCR as a humeral head depressor over Latissimus dorsi tendon transfer (LDTT)[64] with graft options ranging from fascia lata, semitendinosus, Achilles, biceps, acellular dermal allograft, synthetic Teflon patch, and xenografts (acellular porcine dermal graft). LDTT was traditionally the graft of choice in irreparable posterosuperior iRCTs with literature supporting its use, with Kany et al reporting 10- to 20-year follow-up with significant improvements in the Constant score, Subjective Shoulder Value, and pain relief, although 12%

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of patients required conversion to rTSA.[65] However, there has been more recent use of the lower trapezius tendon transfer (LTTT) with the direction of contractile fibers most closely resembling that of the infraspinatus and reproducible correction of external rotation lag[66] with biochemical evidence that LTTT can significant decrease superior and anterior posterior translation and subacromial contact pressure improving shoulder kinematics.[67] Emerging literature supports synonymous use of LTTT and SCR resulting in improved clinical outcomes and native shoulder kinematics in comparison to either procedure alone.[68]

In summary, the surgical technique employed should aim to restore native, glenohumeral biomechanics through improved range of motion, strength optimization, and pain relief with individual considerations for host factors that dictate healing potential and postoperative expectations (Table 1). In partial bursal sided tears >3 mm (>25% in depth), intra-articular sided tears >50% in depth, surgical considerations for debridement alone, transtendinous techniques and take-down repair are viable options with single versus double row constructs varying based upon the size in the sagittal plane. In full thickness tears <1 cm, a trial of nonoperative management is recommended with surgical techniques supporting single row repair in select populations initially and those who fail nonoperative modalities. In full thickness, medium sized tears of 1–3 cm consideration for single row versus double row are largely surgeon dependent and patient specific; however, large and massive reparable tears are primarily managed with traditional double row or TOE techniques. In the iRCT, arthroscopic debridement or a balloon spacer may be viable options in select patients. Other options include partial repair utilizing interval release, marginal converge or bridge methods with graft augmentation, SCR with a multitude of graft options to depress the humeral head or tendon transfer, largely latissimus dorsi and lower trapezius with Achilles allograft. In cases of pseudoparalysis, consideration of rTSA remains a viable alternative in shared decision-making with appropriately indicated patients.

Postoperative Rehabilitation

Rehabilitation following rotator cuff repair seeks to balance two competing priorities: protecting the integrity of the surgical repair while optimizing postoperative shoulder mobility. Historically, standard protocols involved strict immobilization in a shoulder sling for 4 to 6 weeks, followed by a gradual progression of physical therapy to restore range of motion (ROM) and function. This approach was predicated on the assumption that prolonged immobilization would reduce tension across the repair site and thereby facilitate tendon healing. However, recent evidence has challenged this paradigm, suggesting that early mobilization – including minimal or no sling use – may promote faster functional recovery without increasing the risk of repair failure. In a randomized controlled trial by Tirefort et al[69] patients with small to medium RCTs who forwent sling immobilization demonstrated significantly improved external rotation and

Table 1 Surgical Management of Rotator Cuff Tears by Size in the Sagittal Plane

<table>
<tr><th>Size</th><th>Surgical Technique</th><th>Thickness</th><th>Shape</th></tr>
<tr><td>Small
(<1 cm)</td><td>PT vs single row</td><td rowspan="5">Symptomatic partial thickness tears involving >25% of the bursal or >50% intra-articular aspect are considered for operative intervention.

For partial-thickness RTC tears greater than 50% in thickness (3–6 mm), arthroscopic debridement, tear completion, or transtendinous techniques are recommended</td><td rowspan="5">The crescent-shaped is largely amenable to direct repair with mobility often to the anatomic footprint with minimal tension.

U-Shaped tears are best managed with marginal convergence in a side-to-side fashion, resulting in an inverted T-shaped repair.

The L-shaped pattern may undergo direct repair of one segment in the sagittal plane while the remainder may be repaired as a traditional U-shaped tear pattern mentioned above.</td></tr>
<tr><td>Medium
(1–3 cm)</td><td>Single row vs double row/TOE</td></tr>
<tr><td>Large
(3–5 cm)</td><td>Double row/TOE</td></tr>
<tr><td>Massive, reparable
(>5 cm)</td><td>Double row/TOE</td></tr>
<tr><td>Irreparable</td><td>Debridement, balloon spacer, partial repair ± augment, superior capsular repair, or tendon transfer</td></tr>
</table>

forward elevation at 6 and 12 weeks postoperatively compared to those immobilized in a sling. Ultrasound imaging at 6 months revealed no differences in tendon integrity between groups, suggesting that early mobilization did not compromise healing. While the study did not evaluate long-term outcomes, it raises important considerations regarding the necessity of sling use in select patient populations. Similarly, Sheps et al[70] conducted a randomized control trial that supported early mobilization, finding improvements in early postoperative ROM without an increase in re-tear rates. However, at 24 months, no significant differences in clinical outcomes, pain scores, or tendon healing were observed, indicating that the early gains in ROM may not translate into sustained long-term benefits. Nevertheless, for motivated patients seeking an earlier return to function and mobility, selective sling avoidance may offer a safe and effective option.

In tandem with sling weaning, accelerated physical therapy protocols have garnered attention. These regimens typically introduce passive range of motion (PROM) within the first 2–4 weeks postoperatively, followed by active-assisted (AAROM) and active range of motion (AROM) by 4–6 weeks. Compared to delayed protocols, early rehabilitation has been associated with superior ROM at 6 weeks and 3 months without increasing re-tear risk. Multiple studies have shown that early introduction of PROM results in improved forward flexion and global shoulder motion, suggesting enhanced short-term recovery. Despite these advantages, long-term comparisons between early and delayed rehabilitation consistently demonstrate equivalent outcomes in pain, functional scores, and repair integrity at 12 to 24 months postoperatively.[71]

Patient-specific factors play a critical role in determining the most appropriate rehabilitation strategy. Tear size, tendon quality, and repair configuration (eg, single vs double row repairs) may warrant different levels of postoperative protection. For example, patients undergoing repair of large or massive tears, or those with poor tissue quality, may benefit from prolonged immobilization to protect against gapping or early failure. Conversely, younger, healthier patients with isolated small to medium sized tears and robust tissue may tolerate early motion with minimal risk. Patient comorbidities such as diabetes, smoking, or poor bone quality, as well as adherence to postoperative restrictions, must also be considered when weighing the risks and benefits of early mobilization.

In addition to biomechanical and functional outcomes, psychological and quality of life factors are increasingly recognized as important considerations in rehabilitation planning. Sling use can contribute to sleep disturbances, anxiety, and overall dissatisfaction, particularly in the early postoperative period.[69] Moreover, older adults – especially women – may be more susceptible to adhesive capsulitis; minimizing immobilization may reduce this risk. PROs are beginning to reflect these aspects, suggesting that even if long-term function is equivalent, early mobilization may improve subjective recovery experiences.[72]

Economic and health system implications also warrant consideration. Expedited recovery of ROM may reduce the total number of required physical therapy sessions, decrease time away from work, and accelerate return to activities of daily living. These factors can have tangible effects on healthcare utilization and societal cost. As healthcare systems increasingly focus on value-based care, early rehabilitation protocols – if shown to be equally safe – may support cost-effective recovery pathways for appropriately selected patients.

Taken together, early sling liberation and accelerated physical therapy represent evolving components of postoperative care, each demonstrating modest short-term benefits in ROM without apparent compromise in structural healing. Yet the absence of sustained long-term advantages underscores the need for a patient-centered approach. These interventions may be most appropriate for individuals prioritizing early return to activity, provided they are carefully selected based on tear size, tissue quality, and compliance with rehabilitation protocols. Future studies with long-term follow-up are necessary to further delineate which subgroups may benefit most from early mobilization strategies.

Conclusion

This review highlights the need for further high-level evidence studies to better guide the surgical management and postoperative protocols that translate to improved outcomes in patients with rotator cuff pathology. Currently, the management of RCTs considers the patient-specific factors in regard to host comorbidities and patient postoperative expectations. Surgical techniques should consider aspects of the tear itself, including size, thickness, shape, mobility, and degree of retraction. The evidence suggests in symptomatic, partial bursal sided tears >3 mm (<25% in depth) and intra-articular sided tears >50% in depth surgical considerations for debridement alone that transtendinous techniques and take-down repair are viable options with single versus double row constructs varying based upon the size in the sagittal plane. In full thickness tears <1 cm, a trial of nonoperative management is recommended with surgical techniques supporting single row repair in select populations initially and those who fail nonoperative modalities. In full thickness, medium sized tears of 1–3 cm consideration for single row versus double row are largely surgeon dependent and patient specific; however, large and massive reparable tears are primarily managed with traditional double row or TOE techniques. In the irreparable tear, arthroscopic debridement or a balloon spacer may be viable options in select patients. Other options include partial repair utilizing interval release, marginal converge or bridge methods with graft augmentation, SCR, or tendon transfers. In cases of pseudoparalysis, consideration of rTSA remains an alternative option in shared decision making with patients. Emerging literature surrounds the significant of the role of the LHBT and whether tenotomy, tenodesis, or augmentation is the best use to increase longevity of a partial repair construct. Recent literature supports early passive mobilization and active range of motion at 4–6 weeks without compromise of tendon repair integrity that could serve to optimize both glenohumeral motion, accelerated recovery and strength optimization without an increase in re-tear rates.

Disclosure

The authors declare that they have no competing interests.

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