Surgical Management of Irreparable Massive Rotator Cuff Tears – Current Concepts
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Abstract
The treatment of irreparable massive rotator cuff tear is a challenge for shoulder surgeons due to myriad of options presently available. The conservative methods are usually associated with suboptimal outcomes. The present review aims to discuss the current evidence for treating irreparable massive rotator cuff tears and propose an algorithm for the decision making.

Keywords: Irreparable, massive, rotator cuff tears, tendon transfer, superior capsular reconstruction,

Introduction
The treatment of irreparable massive rotator cuff tears (IMRCT) possesses a challenge for shoulder surgeons across the globe, with limited consensus regarding the ideal management. Massive Rotator cuff tears (RCT) comprise 40% of all cuff tears, with a re-tear rate of up to 78% [1-3].

Definition
The literature is filled with definitions of irreparable and massive rotator cuff tears. One should remember that while a massive rotator cuff tear can be at times reparable, an irreparable rotator cuff tear is usually always massive. The IMRCT has been defined by many studies as a full-thickness tear involving either two or more tendons and/or a tear with a retraction of >5 cm in coronal plane [4-9] and/or a tear with >67% tuberosity exposed in sagittal plane [10] and/or a fatty muscle infiltration of Goutallier grade >3 [7-15]. More recently, Mayo clinic coined the term functionally irreparable rotator cuff tears, where some cuff tears would reach the anatomical footprint but still not heal [16].

Goals of the treatment
The primary goal of RCT surgery is to eliminate pain and restore function.

Partial repair
The concept of partial anterior and posterior cuff repair by margin convergence to restore the force couples and leave a functional tear was introduced by Burkhart et al. in 1994 [17]. A recent systematic review on partial repair of massive rotator cuff tears in 11 studies (one level I and II each, while 6 level III and 3 level IV) concluded that although the functional re-tear rates after surgery were 48.9%, there was a significant short- to mid-term improvement in clinical and functional outcomes postoperatively [18]. Moreover, the re-surgery rate has been found to be around 2.9% after partial cuff repair. Mizuki et al. [19] have proposed a technique of extreme medialized repair in which a medialized suture bridge repair can be achieved by resecting 5–10 mm of the cartilage and the humeral head to create a cancellous bone surface. It can also be performed for >grade 2 fatty infiltration. However, there are no long-term results available yet.

Recommendation
Elderly patients with low demands, pre-operative <2 fatty infiltration overall, no fatty infiltration of teres minor, a lower American Shoulder and Elbow Society score, and a higher visual analog scale score, patients with night pain show better mid-term outcomes. Adjuvant procedures such as subacromial decompression, intra-articular synovectomy, some amount of suprascapular nerve decompression, maintaining the force couples, and an overall reduction in the pain stimulating activities due to the procedure might contribute to the better outcomes in spite of high re-tear rates.

Interposition Grafts
A myriad of patch augmentation techniques have been proposed to achieve better healing, increase the strength of repair, avoid complications related to re-tears, and eventually achieve better functional outcomes as compared to other modalities. These patch augmentations have been classified based on their derivative sources into xenograft, synthetic graft, allograft, and finally autograft.

Xenograft
A variety of xenografts have been proposed with debatable results. Earlier studies have shown re-tear rates of as high as 91% and a sterile inflammatory response of 20% with small intestine submucosal patches [20-22]. Other studies [21,23-25] on porcine dermal grafts have shown either comparable outcomes with no augmentation or have shown a re-tear rate of up to 33.9% in patients with large tears. However, only one study by Avanzi et al. [24] on small and medium tears...
is level I, while others are level III studies. Gupta et al. [26] in their level IV study have used porcine extra cellular matrix patch (Connexa, Tornier, Warsaw, IN) for irreparable tears with a healing rate of 73% at the end of 2 years with good clinical outcomes. Moreover, Bokor et al. [27] have used a Bovine Tendo Achilles type I collagen patch (Regeneten, Smith n Nephew, USA) and have shown a 100% healing rate at the end of 1-year magnetic resonance imaging follow-up.

**Synthetic grafts**

Synthetic grafts have been tried, which are made up of polyester [28-31], polypropylene [32], polyurethane [33], poly4hydroxybutyrate [34], polytetrafluoroethylene [35], and even 3D scaffold with varying results. The majority of these studies are level IV or level III evidence. However, Ranebo et al. [28] had a failure rate of 75% with the polyester graft at 20-year follow-up and Shephard et al. [35] had 80% intact cuffs at the end of 10 years.

**Allografts**

Numerous types of acellular dermal allografts [35-38] have been tried for massive and even revision cuff tears, with a success rate of as high as 87.5% and significant improvement in short and midterm clinical and functional outcomes. A recent case series has shown 41% acceptable short-term results with human dermal allografts combined with PRP and bone marrow aspirate [39].

**Autografts**

Although less commonly used than allografts, facia lata autografts have shown an intact graft rate of as high as 79.2% and a re-tear rate of 10% in midterm follow-ups for irreparable cuff tears [40-43]. High post-operative complication rates at the donor site but improved midterm functional outcomes have been observed using quadriceps tendon graft [43] Two studies have used humeral periosteal flaps. While Schiebel et al. [44] had a re-tear rate of 20% with improved short-term outcomes, Holwein et al. [45] recently had unsatisfactory outcomes with no healing at the operated site. However, heterogeneity among these studies could be a reason for such varying results.

**Recommendation**

Although using an autograft like fascia lata or even a long head of biceps (LHB) might be a viable option, a recent meta-analysis [46] has shown small an improvement in PROMS and a moderate reduction in re-tear rate for synthetic and human allograft questioning the use of these patches at present. Another recent systematic review [47] has questioned the longevity of these grafts. However, the human dermal allograft could be used potentially in young, active adults.

**Superior Capsule Reconstruction (SCR)**

Ever since Mihata et al. [6] popularized the concept of SCR in postero-superior irreparable RCT using facia lata autograft, there has been a 300% surge in the literature describing his technique with some modifications [5]. He reported a 94% reversal in severe pseudoparalysis and the elimination of external rotation lag in their series of 100 consecutive patients with a mean follow-up of 60 months [5]. When compared to options such as dermal allograft of single (3 mm) or double layer (6 mm) thickness versus fascia lata (6–8 mm), showed improved clinical and functional
outcomes and better forward elevation, external rotation, and acromiohumeral distance with fascia lata graft [48, 49]. A retear rate of 5–32% was seen with fascia lata while a retear rate of 20–75% was seen with different dermal allografts. Few level IV case series [50, 51] have shown improved outcomes using long of biceps tendon (LHBT) for SCR with a healing rate of nearly 92%. El-Shaar et al. [52] in their cadaveric study have reported stronger biomechanical stability and resistance to superior migration with LHBT as compared to fascia lata graft. Another cadaveric study by Krishnan [53] et al. has shown equivalent results between LHBT and human dermal grafts in SCR. Thus, LHBT can be a good alternative for SCR once long-term randomized trials are conducted.

Semitendinosus autograft in V-shaped configuration by Rosales-Varo et al. [54] and box-shaped configuration by Milano et al. [55] have also shown good short-term outcomes and increased acromio humeral distance. Another cadaveric study by Croom et al. [56] has shown a reduction in superior head migration and better biomechanics with patella tendon allograft. Kim and Nam [57] have proposed the use of a Tendo Achilles bone allograft for SCR with favorable outcomes.

**Recommendation**

The autograft would be a better option considering the ease of availability, the cost involved, and the lack of foreign body reaction. The present indications for a SCR would be young active adults with irreparable cuff tears with no glenohumeral arthritis and moderate or severe pseudoparalysis. However, the ideal graft thickness of 6–8 mm, margin convergence repair of the graft with infraspinatus posteriorly and subscapularis anteriorly, fixation of the graft in 15°–45° of abduction for proper tension, and acromioplasty as an adjuvant procedure should be taken into account to achieve a successful outcome.

**Tendon Transfers**

Tendon transfers help in restoring force couples by improving joint function in young active individuals with irreparable (especially posteroinferior) cuff tears, significant fatty infiltration, and no joint arthritis.

**Latissimus dorsi**

Gerber popularized the Latissimus dorsi transfer (LDT) from lesser to greater tuberosity, making it an effective external rotator and counterbalancing the anterior forces by the deltoid and intact subscapularis [58, 59]. Various short-, mid, and even long-term studies [13, 60, 61] have shown good to excellent results with open as well as arthroscopic-assisted LDT with a failure rate as low as 10%. The complications described are retaining the transferred tendon, tendon rupture, and progression of the glenohumeral arthritis [62, 63].

More recently, LDT has also been used for isolated irreparable isolated subscapularis tears [64, 65]. Latissimus dorsi originates posterior to the chest wall and is an active internal rotator, similar to the subscapularis. Moreover, LDT has a higher potential for excursion with no risk of affecting axillary, radial, or musculocutaneous nerve making it a safer alternative to its other counterparts [65, 66]. Mun et al. [65] had good short-term functional and clinical scores with no re-tear or neurologic injury.

**Lower trapezius**

Although originally described to achieve external rotation in brachial plexus injury, the lower trapezius tendon transfer (LTTT) has gained popularity because biomechanical similarities between it, and infraspinatus and teres minor. Furthermore, it has been shown to provide better kinematic restoration with the arm by the sides as compared to other options such as LDT and teres major transfer (TMT) [67-69]. However, difficulty in harvesting the LTT, suboptimal excursion, the need to attach the allograft, and issues related to the same such as graft twisting and breakage at the LTT allograft junction, inadequate tuberosity fixation, and insufficient graft tensioning are potential risks while doing a LTTT [14,68]. A recent review by Desai et al. found an overall complication rate of 18% with seroma formation, tendon rupture, and deep infection being the most common causes associated with LTTT [70].

**Pectoralis major**

Wirth and Rockwood [71] proposed the pectoralis major transfer (PMT) in irreparable anterosuperior tears, primarily involving the subscapularis muscle. The PMT partially restores the subscapularis function by restoring the anterior force couple. A variety of PMT techniques have been proposed, namely transferring the entire tendon versus split and directing the tendon above or beneath the conjoint tendon [72-74]. Theoretically, passing the PMT underneath the conjoint tendon provides an anterior buttress between the coracoid and humeral head, providing a dynamic buttress force [75, 76]. A rare risk of musculocutaneous and axillary nerve palsy has been reported in the literature [62]. A level IV review [77] with a follow-up of 20 years concluded that PMT provides good to excellent clinical results delaying the need for reverse total arthroplasty surgery.

**L’Episcopo procedure**

Boileu et al. [78] popularized the concept of combined LDT and TMT to restore active external rotation in patients with horizontal imbalance secondary to deficient infraspinatus and Teres minor. Various mid-term and long-term studies [78, 79] have demonstrated good clinical and functional outcomes and better external rotation with arm by the sides and even in abduction. The concept of this transfer is based on the principle that two internal rotators, namely LD and TM, are converted to external rotators. This is further based on the fact that, in a unique population with isolated loss of external rotation, four muscles-subscapularis, PM, LD, and TM internally rotate the arm, overpowering and disturbing the horizontal force couple balance. The progression of arthropathy ranged between 38% and 55% in both studies [78].

**Recommendation**

Good to excellent outcomes can be achieved with tendon transfers; however, the choice of the ideal tendon transfer remains debatable to date. While LDT is a viable, reproducible, and time-tested option, LTTT has shown to have equal or superior outcomes biomechanically, but with a need for additional graft and its related complications for posteroinferior irreparable tears. PMT partially restores the anterior force couples with good to excellent results, whereas LDT can be a promising graft for irreparable subscapularis tears. The L’Episcopo procedure can be a good option in patients with isolated loss of external rotation without loss of forward active elevation, intact subscapularis, and no arthritis.
Arthroscopic Debridement (AD)/ Biceps tenotomy/ Acromioplasty/Tuberoplasty
AD is a time-tested procedure with acceptable improvement in outcomes in low-demand patients, with failed conservative trial [77, 80]. Various level IV systematic reviews [77, 80-82] have concluded that AD in adjuvant to other procedures such as subacromial decompression, biceps tenotomy/tenodesis, tuberoplasty, or bursectomy without RCT above 65 years of age shows improvement in pain scores; however, the return of strength remains questionable. Patients with intact deltoid muscle function and coracocromial arch tend to do better than patients with pseudoparalysis and severe cuff tendon arthropathy.

The LHB being the final superior head migration restraint is often a source of pain because it undergoes various stages such as synovitis, subluxation, or dislocation and eventually rupture. Various studies [80, 81] have compared debridement with and without tenotomy and concluded that these procedures give comparable short and midterm results; however, they do not alter the long-term progression of the disease. The same has been confirmed by recent systematic reviews [82-84]. A recent review by Descamps et al. [84] compared the results of isolated LHB tenodesis/tenotomy versus partial repair with LHB tenotomy/tenodesis and concluded that both procedures can give acceptable outcomes, but patients undergoing partial repair do better in midterm follow-ups.

Burkhart [85] proposed the concept of suspension bridge wherein the superior migration of the head is prevented when teres minor and subscapularis are intact. While these patients shall respond well to acromioplasty and AD, patients with a loss of suspension bridge will do well with tuberoplasty [86].

Recommendation
At present, level III and IV studies do recommend AD with adjuvant procedures like LHB tenotomy/tenodesis and, or acromioplasty or tuberoplasty for low-demand patients above 65 years of age with minimal rotator cuff arthropathy and pain being the primary complaints. However, there is minimal improvement in terms of strength.

Subacromial Balloon Spacers
Savarese and Romeo [87] in 2012 described a biodegradable subacromial balloon spacer for irreparable cuff tears (InSpace, OrthoSpace, Inc., Caesarea, Israel). It is a copolymer poly-L-Lactide-co--caprolactone that degrades over a period of 12 months. Few short-term studies [88-91] have shown improvement in constant scores, around 80% patient satisfaction rate, improvement in acromio-humeral index, and even similar midterm results when compared with debridement alone versus balloon spacer insertion. Kunze et al. [92] in their recent level IV systematic review and meta-analysis of laboratory studies concluded that the balloon spacers provide adequate improvements in humeral head position at 0°, 30°, and 60° of shoulder abduction. Moreover, they concluded that the use of more than 40 mL of normal saline infusion may lead to supraphysiologic anteroinferior humeral translation. A recent meta-analysis and systematic review by Sandler et al. [93] over 1000 patients compared the results of subacromial balloon spacers with AD concluded that lesser operative duration, better post-operative outcomes, and longer time for conversion to reverse total shoulder arthroplasty (RTSA) make AD a better option than subacromial balloon spacers.

Recommendation
Further long-term randomized studies are required to consider balloon spacers as a line of management. At present, the ideal indications of spacer use are yet to be defined. However, their efficacy in patients with complete loss of anterior and posterior cable, an irreparable subscapularis tear, patients with arthritis, and pseudoparalysis remains questionable.

RTSA
While hemiarthroplasty has been the treatment of choice for a long, the treatment of irreparable cuff tears has changed ever since the original Grammont design was proposed in 1985 [94]. There has been a constant evolution in implant designs and even the indications for RTSA more so in patients without glenohumeral arthritis, since past decade [94-96]. The extended indications for RTSA are committted proximal humerus fractures, especially in elderly with poor bone stock and patients with pseudoparalysis without arthritis [95]. Various mid-term and long-term studies have reported improved functional and clinical outcomes and even patient satisfaction rates as high as 90% [97-99]. Few systematic reviews [96, 100] have reported overall improvement in forward elevation, external rotation, and pain. While the complication and revision rates were reported to be 50% and 33% [101], the same has decreased to 17% and 10%, respectively, in a recent systematic review [102]. The same could be attributed to the improvement in implant designs and techniques. The complications following RTSA comprise scapular notching (can be decreased by increasing the lateral offset and inferior tilt of 0°–10°), prosthetic instability (can be decreased by adequate soft tissue tensioning, inferior glenosphere inclination, repair of subscapularis), acromion and scapular stress fractures, heterotrophic ossification, infections, and neurological issues. To avoid complications related to external rotation lag postoperatively, Boileau et al. [103] have proposed combining the L’Episcopo procedure along with RTSA for favorable outcomes.

Recommendation
The present literature supports the use of RTSA in low-demand elderly patients with pre-operative loss of function, even without arthritis. However, the role of RTSA in younger individuals (<60 years), higher pre-operative functional scores, and patients with neurological dysfunction still remains controversial.

Conclusion
The present literature supports joint preserving procedures over salvage and replacement options. However, the treatment should be tailored based on patient factors such as age, sex, and demands; cuff factors such as number of tendons involved, grade of fatty infiltration, muscle power and quality, and presence of glenohumeral arthritis; and surgeon-related factors such as training and experience and familiarity of one technique over another.
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Conflict of Interest: NIL
Source of Support: NIL

How to Cite this Article