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Tendon transfers for massive rotator cuff tears

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- Massive rotator cuff tears (MRCTs) present a particular challenge due to high rates of retear that can range from 18 to 94%, failure of healing after repair, and potential for irreparability.
- Management of MRCTs must take into consideration the patient's characteristics, clinical examamination and expectation, number and quality of muscle tendons units involved.
- Conservative treatment, arthroscopic long head of the biceps tenotomy, cuff debridement, partial repair, and superior capsule reconstruction are viable solutions to treat selected patients.
- The goal of tendon transfers is to achieve stable kinematic by restoring rotational strength and force coupling of the shoulder joint.
- The ideal candidate is a young, motivated patient with small degenerative changes of the glenohumeral joint, a massive irreparable cuff tear, significant atrophy, fatty infiltration, and functional deficit.
- Patients with posterosuperior massive tears have impaired shoulder function with external rotation weakness and eventually lag sign If the teres minor is affected.
- Latissimus dorsi transfer is the most used with results lasting for long follow-up and lower Trapezius transfer is becoming a surgical option. For anterosuperior tears, there is still controversial if pectoralis major is the best option when compared to latissimus dorsi although this last has a similar vector force with the supraspinatus tendon.
- Complications associated with tendon transfers include neurovascular injury, infection, and rupture of the transferred tendon.

Keywords

- massive rotator cuff tear
- pseudoparalysis
- tendon transfer
- muscle atrophy
- fatty degeneration
- force vector

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Introduction

Among rotator cuff tears, massive tears (MRCTs) present a particular challenge due to high rates of retear that can range from 18 to 94%, failure of healing after repair, and potential for irreparability with the consequent low clinical results after surgical treatment (1). MRCTs have been defined either according to the number of tendons involved (two or more) (2) or according to the size of the tear (more than 5 cm) (3). According to the tendons involved, these tears may be classified as: (a) superior subscapularis (SST) (major) and supraspinatus, (b) supraspinatus and SST (major and minor), (c) infraspinatus, supraspinatus, and superior SST, (d) infraspinatus and supraspinatus, and (e) teres minor, infraspinatus, and SST (4). These tear patterns have a strong influence on shoulder function going from full range of motion (ROM) to a pseudo paralytic shoulder according to tear pattern (5). Some of the patients with a balanced chronic massive rotator cuff may turn out to have, after a traumatic event, an unbalanced acute on chronic tear due to a structural aggravation of the chronic tear.

In terms of onset, massive tears may be acute, chronic, or acute on chronic. The first is associated to a traumatic event on a young patient and is rare compared to the other two. If function is considered, massive tears may also be classified as functional or compensated and dysfunctional or non-compensated (6).

Clinical presentation of patients with massive cuff tears has a wide spectrum that goes from an almost asymptomatic shoulder to pseudo paralytic one. Pseudoparalysis was defined as active forward flexion less than or equal to 90° with full passive forward flexion, with loss of a stable glenohumeral fulcrum (7). When symptomatic, patients often have night pain and with motion above the scapular plane. Pain is considered dependent on the inflammatory status and of the integrity of the long head of the biceps tendon (LHBT) (8). Failure of conservative measures and quality-of-life impact may lead to a surgical option. Other symptoms include weakness and impaired ROM. As said previously, Collin *et al.* described that the tear pattern will more likely lead to a pseudo paralytic shoulder. These authors consider the superior two-thirds of the subscapularis that ends into a tendon in its attachment to the lesser tuberosity and the inferior third that remains muscular in its insertion as two separate units that balance the action of the two external rotators, the infraspinatus, and teres minor. In the present study, active ROM was significantly different between patients with type A (supraspinatus and superior SST) having ROM above shoulder level, whereas 80% of patients with type B (supraspinatus and complete SST) tears had a pseudo paralytic shoulder. This leads to the conclusion that tears involving the supraspinatus and superior half of SST can be compensated by other muscles and that this is not possible if all SST is involved. Other tear patterns such as type C (superior SST, supraspinatus, and infraspinatus) with 50% of patients with pseudoparalysis and type E (supraspinatus, infraspinatus, and teres minor) with 33% of pseudoparalysis demonstrate that dysfunction of three rotator cuff muscles is a risk factor for pseudoparalysis. However, the lowest mean active elevation and highest proportion of patients with pseudoparalysis were observed with complete tears of the SST, suggesting that the SST is more important than the infraspinatus and teres minor in shoulder elevation (5).

With the loss of the compressive humeral head centering forces produced by the rotator cuff, eccentric loads are placed upon the glenoid leading to cartilage damage and early osteoarthrosis (OA). Treatment should aim to restore as much as possible joint kinematics with reconstitution of the force couple and shoulder function, which theoretically could slow OA progression.

Management of MRCTs must take into consideration patient age, motivation and expectations, pain, the clinical exam, the type and onset of the lesion, the static upward migration, and arthritic changes of the humeral head. The decision of the best surgical approach, in case of failure of conservative treatment, also depends on the tendons involved and consequent ROM limitations, tendon retraction, muscle atrophy, muscle fatty degeneration, and the presence of a lag sign (9).

Massive tears clinical approach

Management of patient expectations must consider the most common outcome using suitable techniques. If pain remains the main symptom despite conservative measures, in spite of a good ROM, a surgical approach such as a long head of the biceps tenotomy or tenodesis might be indicated. On the other hand, a patient whose main complaint is weakness of the shoulder and but has good ROM is not a good candidate for surgical management (10).

A good clinical examination is mandatory. Passive and active motion evaluation should be performed. The presence of pseudoparalysis is a determinant of the decision algorithm. Assessment of individual tendon strength using clinical tests like bear hug (11) or press belly (12) signs will indicate a superior SST tear and a positive 'lift-off' test will point to a more extensive tear of this tendon (13). On the other hand, a positive Jobe sign associated with an external rotation weakness or lag sign indicates an insufficient posterosuperior cuff (9).

Imaging studies begin with a radiographic exam to assess humeral head migration and degenerative changes in the glenohumeral joint. Figure 1 An acromio-humeral distance shorter than 7 mm is considered indicative of a non-repairable rotator cuff tear (14) and degenerative changes can be classified according to Hammada (15). MRI is mandatory, if and when, a cuff structural assessment is important for patient management. Arthritic changes, superior head migration posterior static subluxation, glenoid wear, tendon quality, and retraction muscle atrophy and fatty degeneration are considered in decision-making and outlining prognostic factors. Fatty degeneration as described by Goutallier *et al.* (16) greater than two and atrophy greater than two as described by Thomazeau *et al.* (17) on the MRI are considered indicators of clinically poor results (Fig. 2) if a repair of the cuff is considered (18, 19).

Conservative treatment

The majority of MRCTs are degenerative tears in elderly patients that become symptomatic. Conservative treatments should aim to control pain, inflammation, and restore as much as possible ROM to permit the patient to perform daily living activities with minor discomfort. If ROM gaining is vital for patients' expectations, the surgeon must bear in mind that according to the type

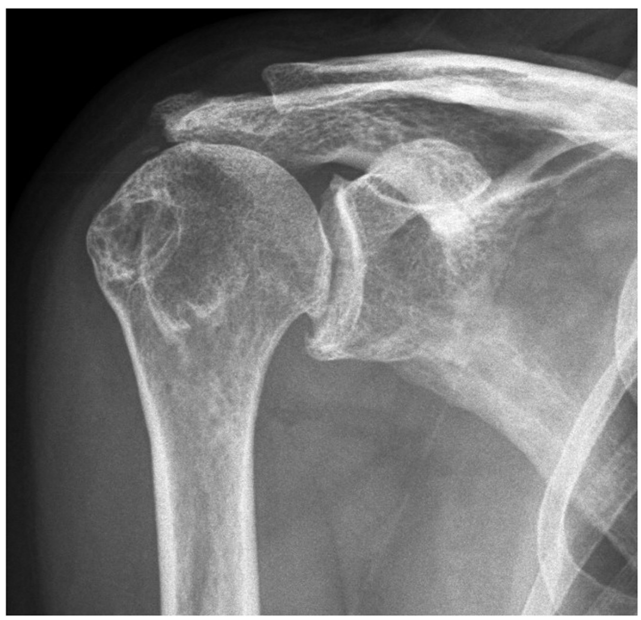

Figure 1
Humeral head migration and degenerative changes of the gleno-humeral joint.

Figure 2
Fatty degeneration and muscle atrophy are considered indicators for clinical poor results.

of rupture, as described by Collin *et al.*, it might not be possible to correct a clinical pseudoparalysis.

Pain control might be achieved with anti-inflammatory medication and in more intense cases with corticosteroid injections. Shoulder rehabilitation should aim to optimize the centering effect of the remaining cuff and to optimize periscapular function and lateral deltoid strengthening (20).

Surgical approach

MRCTs surgical treatment may have different goals according to patient needs and there are different arthroscopic approaches to the problem. Debridement and long head of the biceps tenotomy or tenodesis have been indicated in low-demanding patients whose pain is the major complaint and shoulder function is sufficient to fulfil their daily living activities (21). Reversed subacromial decompression (22) and 'interposition techniques' like subacromial balloon (23) and superior capsule reconstruction (SRC) (24) aim to give pain relief and ameliorate function by facilitating the slide of the humeral head under the acromion and in the last, lower the humeral head. Arthroscopic repair, or partial repair, may ameliorate function and control pain (25). The use of growth factors in massive rotator cuff tears is still not supported in the literature (26, 27), and stem cells and tendon augmentation aim to enhance tendon resistance and healing capacity (28, 29). LHBT has been introduced as a new and promising alternative for use in SCR in clinical and biomechanical studies, the main limitation being the fact that in most patients already having a spontaneous tenotomy, the tendon is also not available (30, 31). Finally, tendon transfer may restore power and function in non-repairable and dysfunctional tears (10).

Tendon transfers for massive cuff tears

Tendon transfers to deal with irreparable MRCTs had first been described for open surgery and more recently arthroscopic assisted or fully arthroscopic technics have been described. The goal is to achieve stable kinematics by restoring rotational strength and force coupling of the shoulder joint. Nevertheless, the expected strength of the transferred tendon unit is always weaker when compared to that of native function (32) and as scapulothoracic motion is a significant component of shoulder joint movement, and because some of the transferred muscle-tendon units originate from the thorax, lines of action, muscle lengths, and muscle forces are all dependent on scapulothoracic dynamics (33).

The ideal candidate is a young, motivated patient with small degenerative changes of the gleno-humeral joint, a massive irreparable cuff tear, with significant atrophy (>2 according to Thomazeau), fatty infiltration of muscle (>2 according to Goutalier), and functional deficit (34).

In order to achieve good results when considering tendon transfer reconstruction, certain important principles must be taken into consideration: a good understanding of anatomical relationships of the neurovascular bundles is vital for safe and effective transfers preserving muscle function, the transferred muscle must be elongated without compromising the donor site, the excursion and tension of the two muscles should be similar as the line of pull of both muscles, and the transferred muscle should acquire one of the functions of the recipient muscle (35). On the other hand, the tissue bed where the transferred tendon is supposed to glide must be free of oedema or scarring tissue, the tendon should function on a mobile and stable joint, the reimplantation site must be accurate with strong primary stability, and the surgeon must take care to use a meticulous technique in order to avoid unnecessary scarring of the tissue that will prevent tendon gliding (36, 37, 38).

Contra indications for tendon transfer are infection, a stiff joint, glenohumeral advanced arthritis, axillary nerve palsy, brachial plexus palsy or dysfunction affecting the muscle to be transferred, a posterosuperior tear massive tear associated with a non-reparable SST tear, and an anterosuperior massive tear associated with a non-repairable infraspinatus (36).

Complications associated with all tendon transfers include neurovascular injury, infection, and rupture of the transferred tendon.

Postero superior massive cuff tears

Patients with posterosuperior massive tears have impaired shoulder function with external rotation weakness. If the teres minor is affected, a lag sign in external rotation is expected. The tendon to be transferred and its point of attachment should be chosen according to functional impairment.

Latissimus dorsi tendon transfer (LDTT)

The Latissimus dorsi muscle (LD) is a large, fan-shaped muscle with a broad origin from the iliac crest, thoracolumbar fascia, and spinous processes of lower thoracic and lumbar vertebrae. It inserts medial to the pectoralis major (PM) and lateral and proximal to the teres minor (TM) on the humerus. Its neurovascular supply derives from the thoracodorsal artery and the thoracodorsal nerve, a branch of the posterior cord of the brachial plexus (39). The axillary and radial nerves are closest to the LDT insertion when the arm is flexed, and farthest when the arm is internally rotated. This fact is particularly important when harvesting the tendon from the humeral insertion.

Transfer of the LDT from the intertubercular groove on the anteromedial aspect to the posterosuperior greater tuberosity converts the original internal rotation/extension action of LD to external rotation/flexion force. These effects are different according to tendon insertion. If external rotation weakness is the main clinical sign, the transferred tendon should be inserted on the infraspinatus insertion. On the other hand, if flexion of the shoulder is impaired, an insertion over the great tuberosity on the supraspinatus insertion should be performed. In this position, LDT depresses and centralizes the humeral head, thus helping the deltoid to elevate and abduct the arm (33).

LDT transfer for massive cuff tears was first described by Gerber *et al.* The ideal candidate, for a latissimus dorsi transfer, is a young patient, with an anterior flexion of 90º and an infraspinatus pseudoparalysis. The SST tendon must be intact or have a repairable tear (40). Results are better in the first case. Non-repairable SST tear is a contraindication. Teres minor fatty degeneration has a negative influence on the results of the procedure (41). The open technique described by Gerber consists an axillary approach to harvest the LDT Fig. 3 and a trans deltoid approach to reattach the transferred tendon over the great tuberosity using suture anchors or transosseous sutures.

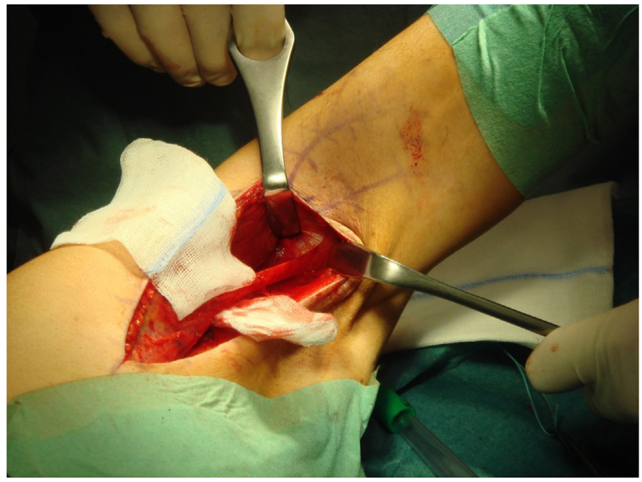

Figure 3
Axillary approach to harvest the LDT.

Techniques for arthroscopic-assisted latissimus dorsi transfer consist of an open harvest of the latissimus dorsi by an axillary approach and the arthroscopic-assisted transfer of the prepared tendon. The advantages of this procedure are that iatrogenic deltoid insufficiency can be avoided and the remaining posterosuperior rotator cuff as well as SST tears can be diagnosed and repaired. The passage of the tendon between the posterior deltoid muscle and the teres minor (TM) can be prepared and visualized with the arthroscope. Arthroscopic previous preparation of the acromial space, tendon remnants, and great tuberosity is performed. Viewing from the lateral portal, the tendon sutures, inside two silicon drain tubes, to prevent twisting of the tendon, are retrieved from the axillary incision through the posterior portal under direct visualization in the space between TM and deltoid (Fig. 4). The sutures are then moved out to the anterior portal, thus pulling the tendon over the tuberosity. The first anchor is inserted at the anterior aspect of the greater tuberosity, close to the articular cartilage, and the superior margin of the SST (Fig. 5). Two to three anchors are inserted fixing the tendon to the tuberosity until it is stable (42, 43). Tendon fixation using interference screws and tubulization of the tendon aiming to achieve a better primary stabilization and permit early rehabilitation has proven to have higher risk of rupture. The same with fixation of the tendon over the great tuberosity instead of on the infraspinatus native insertion (44).

Results of LDT transfer are better for primary cases than salvage procedures for patients with failed rotator cuff repair (45). A lower pre-op constant score leads to a post-op inferior score (46). Good clinical results are presented by several authors using open techniques. Additionally, significant improvements were noted in forward flexion, abduction, external rotation, and abduction strength, and

Figure 4
Sutures from the axillary incision are retrieved through the posterior portal under direct visualization.

these results are consistent at long-term follow-up (47, 48, 49). Arthroscopic-assisted techniques reported low risk of complications, and subjective shoulder value (SSV) improved from 26% preoperatively to 71% postoperatively with marked improvement in shoulder pain, strength, and better range of movement mainly in abduction (47, 50). Nevertheless, mid-term results showed 13% of RSA conversion and progression of OA in half of the patients, especially if teres minor showed significant atrophy and fatty degeneration (47).

Isolated or associated with LD, teres major transfer

Teres major (TM) originates from the posterior aspect of the inferior angle of the scapula and inserts medial to the LDT insertion on the humerus. Its vascular supply is derived from the circumflex scapular artery, a branch of the subscapular artery, and its nerve supply is from the lower subscapular nerve, a branch of the posterior cord of the brachial plexus (36). TM is an adductor and internal rotator. As being a short muscle, the TM is more prone to rupture or necrosis due to stress on the neurovascular bundle. This is one of the reasons why surgeons prefer to perform a combined transfer of the LD and the TM to achieve a more consistent external rotation, forward flection, and abduction when transferred to the insertion of the supraspinatus on the greater tuberosity (51, 52).

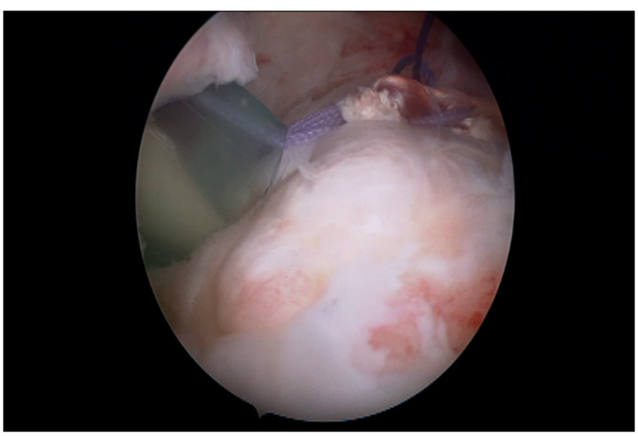

Figure 5
The first anchor is inserted close to the articular cartilage and the superior margin of the SST.

LD and TM tendon transfers were initially described for brachial plexus injuries by L'Episcopo in 1934 (53). Boileau *et al.* presented a modified L'Episcopo technique to restore external rotation in patients with massive rotator cuff tears and lag sign in external rotation submitted to reverse shoulder arthroplasty (RSA) (54). The tendons should be harvested at the beginning of the procedure and performed through a deltopectoral approach. After identifying the PM, a separation of the upper two-thirds of the tendon is performed to expose the LD and TM insertion. At this point, identification and protection of the radial nerve, which runs just medial and posterior to the LD, should be performed. The tendons are then harvested, and sutures are used to tag and mobilize the tendons using blunt dissection to avoid damaging the neurovascular structures. After these procedures, the surgeon must proceed with the RSA according to the technic. While using the trial implants, the tendons should be passed through the posterior aspect of the humerus to its lateral side by blunt dissection and using a curved clamp. Just before definitive implants are put in place, the tendons should be fixated to the lateral side of the humerus at the same level as the native insertions to achieve a correct length of the muscle-tendon unit and optimize active external rotation. Fixation can be achieved by bone drill holes and might be augmented with staples or suture anchors. The PM is reattached to its anatomic insertion and the wound closed.

More recently, the same author described the use of this same technic for patients with isolated loss of external rotation (ILER) (55). Having a full, or at least functional, forward flexion, despite a massive cuff tear, these patients do not benefit from an RSA. Nevertheless, ILER affects daily living activities as it prevents patients from reaching the face or the head, eating, or drinking with the elbow next to the body. To achieve these tasks, the patient must mimic an 'Hornblower sign' with the elbow far from the body with the shoulder flexed and the arm in internal rotation. LD and TM transfer were able to eliminate the 'Hornblower sign' in 50% of the patients and there was a slight gain in forward flexion. Nevertheless, the authors report that 80% of patients were satisfied due to hand control in space after the procedure (55).

Recently, a fully arthroscopic combined transfer of the LDT and TM has been described by Kany *et al.* (56). Performing a very demanding arthroscopic technique, the LDT together with the TM are transferred to the native insertion of de infraspinatus to balance the shoulder with the SST, avoiding, excessive tendon tension and the need for extensive dissection to obtain tendon excursion. For fixation, two knotless suture anchors are used. Cadaver training of this technique is strongly recommended as there are potential risks of radial and axillary nerve and circumflex vessels injuries. The authors have been using this technique for more than a year with no complications reported but, to our knowledge, results were not published.

Lower trapezius transfer

The LT muscle originates from T4 to T12 vertebrae and inserts into the medial portion of the scapular spine. The transverse cervical artery and the spinal accessory nerve constitute the neurovascular bundle (57). LT has a force vector in the same direction of the infraspinatus, thus theoretically making it a better option for tendon transfer in posterosuperior massive cuff tears (58). Nevertheless, the external rotation moment arm (ERMA) with LT transfer is larger than with LD transfers with the arm at the side, and at 90° abduction, LD transfer had a significantly higher ERMA than the LT transfer (59).

Transfer of LT lengthened with Achilles tendon allograft was first described to improve external rotation in patients with traumatic brachial plexus injury (60). LT transfers can be performed open or arthroscopic assisted. The tendon might be attached to the infraspinatus on a paralytic shoulder or into the native infraspinatus footprint in a massive rotator cuff tear. For this last, the LT augmentation with a graft is mandatory. Achilles' tendon allograft is the most used, but augmentation might also be achieved using semitendinosus tendon (61). In open technique, a medial vertical incision parallel to the scapular border is used, whereas, in the arthroscopic assisted approach, a horizontal incision is made just below the spine. After LT detachment and elevation from its insertion on the scapular spine and separation from the rest of the trapezius, protecting the accessory nerve, the LT tendon should be attached to the chosen allograft and inserted in the humeral head after being transferred into the subacromial space (62). When using arthroscopic-assisted techniques, the allograft is first attached to the humeral head using suture anchors or transosseous sutures and secondarily to the LT tendon. Tendon tensioning should be performed with the arm in full external rotation and 40–90° of abduction (63).

Clinically published outcomes after LT transfer have shown good results with a decrease in pain and a mean gain in forward flexion and external rotation of 37.5° and 34.3°, respectively (61, 64).

Middle trapezius (MT) transfer

Treatment of irreparable supraspinatus tendon tears (ISSTT) remains challenging especially in young, motivated patients. Recently after a cadaveric study where the feasibility of the MT tendon was tested (65), an arthroscopic-assisted technique was described to transfer the MT to the great tuberosity at the supraspinatus footprint (66).

Indications are irreparability of the supraspinatus with integrity or repairability of infraspinatus and SST tendons and degenerative changes lower than two according to Hamada classification.

The MT tendon is detached from its insertion on the acromion through a 5 cm incision just anterior to the spinoacromial junction and the tendon is passed to the previously prepared subacromial space with arthroscopic control. The tendon is fixated to the great tuberosity using suture anchors.

Anterosuperior massive cuff tears

Patients with anterosuperior massive cuff tears have rupture of the SST and of the supraspinatus tendon. It was considered after the studies of Collin *et al.* that the SST is more important than the infraspinatus and teres minor in shoulder elevation turning patients with a complete tear of the SST more prone to develop a pseudo paralytic shoulder.

Pectoralis major and minor transfer

Indications for pectoralis major transfers (PMT) are irreparable SST tear in young active patients with no osteoarthritis. Indications for pectoralis minor transfer (Pmi) are irreparable tears of the upper third of the SST with or without the involvement of the supraspinatus in young active patients with no osteoarthritis (67). From a biomechanical point of view, the PM has a different vector than the SST as this tendon muscle unit is located posterior to the chest wall while PM is anterior. PMT was first described by Gerber *et al.* According to these authors, the PM tendon is transferred from the anterior humeral shaft to the lesser tuberosity passing anteriorly to the conjoint tendon (68). Despite the biomechanical handicap, the same group presented satisfactory long-term outcomes for isolated SST tears despite the fact that active internal and external ROM decreased over time (69). Based on biomechanical considerations, a passage of the upper part of the tendon under the conjoint tendon was described. These authors reported reduced pain and improvement in both subjective and objective scores. Nevertheless, of the 12 patients in this study, only 4 had an anterosuperior tear (70). On the other hand, Gavriilidis *et al.* in a study group of 15 patients with anterosuperior cuff tears advise that patients should be informed only a partial active ROM gain and no significant improvement in strength should be expected (71).

Pmi transfer was first described for isolated SST tears with gain in forward flexion, a decrease of external rotation, and a constant score improvement of 51 points although the strength sub score did not rise significantly. The authors concluded that sub-coracoid transfer of the thin pectoralis minor muscle passes easier under the coracoid, then the PM and the force vector produced by Pmi transfer improves shoulder function and ameliorates pain (72). More recently, an arthroscopic-assisted Pmi transfer has been described for anterosuperior massive tears. The tendon is harvested with a chip of bone from the coracoid by an open incision. Using arthroscopy control, the lesser tuberosity is prepared, and the supraspinatus is partially repaired if feasible. As a second step, the Pmi tendon is passed, after a small coracoplasty and finger dissection under the conjoint tendon and fixated with knotless suture anchors (73).

Latissimus dorsi tendon transfer (LDTT)

LDTT has biomechanical advantages over PM to treat SST irreparable tears as their force vector is similar. After a feasibility cadaveric study, Elhassan *et al.* described primary open technique and later, an arthroscopic-assisted technic for LDTT either to the lesser tuberosity or to the anterior part of the supraspinatus if treating an anterosuperior massive tear (74, 75). The LDT is harvested using an anterior approach for isolated SST tears and a posterior approach is used for anterosuperior tears and in the arthroscopic-assisted technique. The tendon is passed anteriorly either open or under arthroscopic control and fixed using suture anchors. Outcomes studied improved in 80% of the patients although only 20% had a complete reversal of the lift-off test. Worse prognostic factors are irreparable supraspinatus tear, fixed anterior subluxation, anterior-superior sub-luxation, and arthritic changes. The authors conclude that LDTT is a valid and better alternative than PMT for massive, irreparable anterosuperior cuff tears approach (71, 72).

Conclusion

Massive rotator cuff tears are difficult to treat, especially in young and active patients. For anterosuperior tears, there is still controversy if PM is the best option when compared to LD although the latter has a similar vector force with the SST and gives good results not only in isolated SST tears but also in association with supraspinatus tears. Recently, MT transfer has been proposed for irreparable supraspinatus tears. For posterosuperior tears, LDT is mostly used with results lasting at long follow-up. LTT is becoming a surgical option despite the need for elongation as it provides better moment arms for abduction and external rotation in adduction.

ICMJE Conflict of Interest Statement
The author declares that there is no conflict of interest that could be perceived as prejudicing the impartiality of this work.

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