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Tendon transfers for irreparable rotator cuff tears: An update

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Shoulder dysfunction in the setting of irreparable rotator cuff tears (RCTs) can be treated successfully with different types of tendon transfer:

- Latissimus dorsi transfer for irreparable posterosuperior RCTs works best for young, active patients with an intact subscapularis, no pseudoparalysis or previous surgery, and a functioning teres minor.
- A more anatomical transfer for irreparable posterosuperior RCTs is a lower trapezius transfer, and early results are promising.
- Isolated irreparable tears of the subscapularis can be successfully managed with pectoralis major tendon transfer with a concentric humeral head. However, restricted external rotation (ER) may occur, depending on technique.
- Pectoralis minor transfer can successfully address combination irreparable tears of the upper border subscapularis and the supraspinatus without significant loss of ER.
- Rotator cuff arthropathy with ER lag benefits most from a reverse total shoulder arthroplasty and a combination latissimus dorsi and teres major transfer (LDTMT) regardless of patient age.

Keywords: tendon transfers; shoulder; irreparable; latissimus dorsi; rotator cuff arthropathy

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Tendon transfers of the shoulder can be technically challenging, but if performed well can significantly improve the quality of a patient's life. Surgical skill is essential, but just as important is proper patient selection. Despite advances in surgical techniques and equipment, failure to heal may occur after rotator cuff tear (RCT) repair and may not be amenable to revision surgery. This review, structured in three sections, is designed to investigate current literature on transfers, over the last five years, on irreparable posterosuperior RCTs, anterosuperior RCTs and transfers with reverse total shoulder arthroplasty (RTSA).

The following sections describe several different transfers in detail; however, a brief anatomical refresher regarding innervations of the muscles involved is in order. Essentially, four muscles comprise the rotator cuff: the supraspinatus, the infraspinatus, the teres minor and the supscapularis. The supraspinatus and infraspinatus muscles are innervated by the suprascapular nerve. The teres minor muscle is innervated by the axillary nerve and the subscapularis muscle by the upper and lower subscapular nerves. The latissimus dorsi muscle is innervated by the thoracodorsal nerve and is the largest muscle in the back, and functions as an adductor, extender and internal rotator of the arm. The trapezius muscle has three sets of fibres and is innervated by the spinal accessory nerve or 11th cranial nerve. The teres major muscle is innervated by the lower subscapular nerve and, like the latissimus, is an adductor and internal rotator of the arm. The medial pectoral nerve innervates both the pectoralis major and minor, and the lateral pectoral nerve innervates just the pectoralis major.

Irreparable posterosuperior RCTs

Reports of massive posterosuperior rotator cuff repair failures range from 21% to 91%[1,2,3] and revision failure rates are significantly higher.[4] Recurrent tears typically occur within the first six months following primary fixation.[5,6] Symptoms of re-tear at two years include: impaired overhead function, increased pain, limited passive movement, loss of strength, and lower overall satisfaction with shoulder function.[4] Complications also arise when performing revision rotator cuff repairs.[7] Fortunately, when a posterosuperior RCT tear is deemed irreparable, there are several options for the patient.

Gerber originally defined an irreparable posterosuperior RCT as the inability to achieve fixation in $\leqslant 60°$ of abduction despite adequate releases.[8] This also includes at least stage 3 fatty infiltration of the supraspinatus and infraspinatus, an acromiohumeral distance of < 7 mm on imaging[8] or static migration of the humeral head.[9] Excluding shoulder arthroplasty, options considered for irreparable recurrent tears are debridement with possible partial repair, augmentation with scaffolding, or tendon transfers.[10] There are several possible major tendon transfers for irreparable posterosuperior RCTs. These include the latissimus dorsi transfer (LDT) with or without the teres major (LDTMT) and the lower trapezius transfer (LTT).

LDT

The earliest and most studied transfer is the LDT, originally described by Gerber in 1988.[8] It has the potential of a 33 cm excursion when fully released from surrounding attachments.[11] The intention in performing a LDT is to restore humeral head depression and external rotation (ER) in the young, active population without glenohumeral (GH) arthritis or significant static migration of the humeral head. It essentially reconstitutes the posterior force couple.[9] As with most surgeries, there is appropriate patient selection with respect to demographics, the physical exam., and radiographic imaging.

Approximately 70% of LDTs are performed on men. However, there is no objective outcome difference regarding gender.[12] Namdari et al[12] suggested that it is difficult to assess whether hand dominance and occupation are clinically significant, as corresponding reports were underpowered and inconsistent. While no age cap has been described, a recent systematic review noted a mean age of 59 years for LDT.[12] LDTs in the presence of prior rotator cuff repair have resulted in poorer patient outcomes,[13,14,15,16,17] especially with reference to post-operative constant scores.

Physical examination of the patient is critical. The subscapularis tendon should be intact and functioning, as forward elevation drastically decreases with insufficiency.[18,19,20] Additionally, GH stability increases with an intact subscapularis in the setting of an LDT.[21] Positive drop-arm[22] and ER lag tests[23] are typical findings. Supple shoulder movement is essential – specifically, passive forward flexion (FF) and abduction $\geqslant 80°$.[24] A pseudoparalytic shoulder has been demonstrated to correlate with poor outcomes.[25] Axillary nerve lesions and deltoid insufficiencies are contra-indications.

Imaging plays a role in the decision-making process. Standard shoulder radiographs and MRI are common modalities. The patient cannot have radiographic indications of GH arthritis, and limited, Hamada stage 1 or 2, rotator cuff arthropathy.[19] This implies no acetabulisation of the acromion.[26] The irreparable supraspinatus and infraspinatus tendons are typically torn with retraction to the level of the glenoid (Patte stage 3),[27] with fatty infiltration Goutallier grade 3[28,29] and/or significant atrophy.[30] Subscapularis tears with grade 3 or higher Goutallier atrophy,[28,29] and/or $\geqslant$ 50% tear of the upper border[31] should also be excluded.[19] Atrophy of the teres minor assessed pre-operatively by MRI was performed by several authors.[32,16,17] It was concluded that fatty infiltration of Goutallier grade 3 or higher was associated with worse post-operative outcomes and decreased active ER.

Many studies have evaluated the application of the two-incision technique popularised by Gerber.[8] In the two-incision technique, a superior incision is made over the acromion. The deltoid is removed with a small piece of bone and reflected laterally. A humeral head devoid of posterosuperior tendon attachment is exposed, and assessment of the remaining torn rotator cuff is performed. If any remaining rotator cuff can be incorporated into the transfer, it will be added. After preparation of the humeral head is performed, a second incision is made in the axilla. This incision starts in the mid-body of the latissimus dorsi and extends superior toward the axilla and then slants obliquely after the armpit. Careful dissection is necessary to find where the tendon inserts into the humerus. It is cut sharply off the humerus and a non-absorbable suture is placed in a Krakow fashion. The tendon is passed between the deltoid and the teres minor and is secured on the greater tuberosity as far anterior as possible.[8] Gerber published his 10-year follow-up showing durability of the reconstruction, with 74% good to excellent results and maintenance of subject shoulder values and constant scores.[33] El-Azab et al confirmed this finding as well, demonstrating long-term failure rates of 10% and conversion to reverse shoulder arthroplasty (RSA) at 4%.[19] Although the tenodesis effect may lose strength over time, it is possible to delay RSA after LDT.[34] Complications include stiffness, traumatic failure of the transfer, resolving nerve dysesthesia and deltoid re-attachment failure.[33]

Techniques for LDT are evolving. Habermeyer[35] described a single-incision approach that uses a more posterior attachment of the transfer into the humeral head. Hertzberg et al[11] demonstrated that securing the transfer at the insertion of the infraspinatus improves rotational movement when compared with other locations. Instead of making an incision down the arm, the single-incision technique uses a V-shaped incision and direct visualisation of the posterior humeral head. One downside to this approach is that the anterior humeral head cannot readily be evaluated and thus small underlying subscapularis tears cannot be repaired. The published results were comparable with the Gerber two-incision technique regarding constant score, FF and ER. Recently, there have been advances in arthroscopically-assisted LDT.[36,37,38,39] In a multi-centered study, Grimberg et al[37] demonstrated results equivalent to historical open two-incision approaches. They concluded that the one-incision arthroscopically-assisted approach provided better mechanical resistance to traction. Additionally, Gerhardt et al[40] did a five-year follow-up for the modified L'Episcopo[41] single-incision technique which transferred both the latissimus dorsi and teres major. They demonstrated maintenance of constant scores at five years. However, there was persistent progression of cuff arthropathy. The LDTMT is popular when performed in combination with RSA for a positive ER lag sign.[42]

Teres major transfers

Isolated teres major transfers (TMT) for irreparable posterosuperior RCTs are not well represented in the literature. It was designed as a transfer for infraspinatus deficiency.[43] This technique is performed using a two-incision technique similar to the previously described LDT

by Gerber. The teres major is isolated from the scapular origin from the latissimus dorsi. It is traced laterally to the humerus and removed with a strip of periosteum. Then it is passed under the deltoid and secured to the greater tuberosity. Interestingly, this transfer typically has an intact supraspinatus. If the supraspinatus is in jeopardy, it could be paired with a trapezius transfer. In 1998, Celli et al[43] were the first to publish results on this technique. Their case series of six patients demonstrated patient satisfaction with the operation. The same group published the long-term results of 20 patients with maintenance of improved post-operative constant scores.[44] A recent study was performed to evaluate the neurovascular responsibility to the muscle.[45] It was found that the lower subscapularis nerve innervates the teres major in over 85% of cases, with the difference supplied by the thoracodorsal nerve. The vascular supply inserts directly into the muscle within 2 cm of the nearby nerves, in the middle of the muscle belly. Often shorter in length than local nerves, the vascular structures tend to be the limiting factor when performing a TMT. In a biomechanical study, Steenbrink described improvement of post-operative activation when compared with LDT,[46] concluding that TMT was a superior anatomical transfer.

More recently, Henseler et al published short-term results of TMT transfers.[47] At two years, patients had improved FF, ER, visual analogue scale (VAS), and constant scores. Mansat et al[48] evaluated 12 TMTs with a mean of six years follow-up with similar results to Henseler. Similar to the LDT, negative prognostic factors included previous surgery and RCTs involving the subscapularis. Isolated infraspinatus involvement and a functional teres minor were positive prognostic factors. Further, Mansat et al described the following recommendations for TMT: the patient should be under the age of 55 years with a proper understanding of the condition and treatment, and an intact subscapularis and anterior supraspinatus cable.

LTT

LTT is a recently described modality for intervention of irreparable posterosuperior RCTs, and is a popular procedure for paralytic shoulders lacking ER.[49-52] Similar to TMT, LTT has not been well described in the literature. In this technique, a two-incision approach is performed as well. The first incision is made similar to the LDT, a sabre incision with deltoid take-down to expose the humeral head. The second incision is based 1 cm medial to the scapula. The lower trapezius attachment to the scapula is released and an Achilles allograft is used to augment for length. A subcutaneous tunnel is created from the medial incision to the lateral incision deep to the deltoid. A tendon wrap can be used to aid in gliding of the transfer. The transfer is secured to the footprint of the supraspinatus and upper border of the infraspinatus.

Most studies are anatomical or biomechanical. The lower trapezius tendon can be safely harvested without injury to the spinal accessory nerve or the muscle fibres of the middle trazepius.[53] In a cadaveric study, Omid et al concluded that the LTT was superior to LDT for restoration of GH mechanics and joint reaction forces.[54] Hartzler et al[55] found that LTT had improved ER with the arm at the side compared with the LDT. In a poster presentation at the 2014 American Association of Orthopaedic Surgeons,[56] Galatz presented her series of 12 patients at a mean of 18 months follow-up. Significant improvement was noted in American Shoulder and Elbow Surgeons and VAS scores, FF, and ER. In total 75% of those examined with ultrasound demonstrated an intact transfer. The ER was noted to be better than historically noted for a LDT. In a recently accepted manuscript, Elhassan et al[57] followed 32 patients for a minimum of two years and found greater outcomes correlated with pre-operative FF > 60°.The most common complication of the transfer was a seroma owing to the necessary subcutaneous tunneling of the transfer.

Irreparable anterosuperior RCTs

Anterosuperior RCTs, more specifically subscapularis tears, occur far less commonly than the aforementioned posterosuperior RCTs.[58,59] An MRI study of over 2000 RCTs demonstrated an incidence of 2% for subscapularis tears.[60] This number can be as high as 13% for isolated subscapularis tears and 37% of the time in combination with a supraspinatus tear.[61] The subscapularis is essential for proper function of the shoulder as it is the primary internal rotator and anterior dynamic stabiliser.[62] Patients with subscapularis RCTs typically present with anterior shoulder pain, internal rotation weakness, and dysfunction. Diminished strength can be assessed with multiple tests including the belly-press,[63] bear hug,[64] and lift-off.[65] While the repair of acute tears of the subscapularis muscle typically do well,[66-70] the outcomes of chronic tears with fatty infiltration, Goutallier grade 3 or greater, are not as promising.[58,71-73]

Excluding shoulder arthroplasty, several options for irreparable anterosuperior RCTs have been studied, including: pectoralis major transfer (PMT), pectoralis minor transfer (PMnT), latissimus transfer and teres major transfer.

PMT

The purpose of a PMT is to stand in for the subscapularis by exerting an internal rotation centering force.[9] Wirth and Rockwood originally described the PMT in 1997.[72] The PMT was performed anterior to the conjoined tendon and resulted in a high satisfaction rate at five years of follow-up. Resch et al[71] adapted this technique to transfer only the superior two-thirds of the tendon under the conjoined tendon. Subsequently, Warner transferred the inferior sternal head attachment under the clavicular head but anterior to the conjoined tendon to avoid injury to the musculocutaneous nerve.[74]

Biomechanically, subcoracoid placement of the transfer is superior.[75] However, there have been no comparative studies to date. Galatz et al[76] demonstrated a subcoracoid

transfer with over 75% satisfaction at almost 18 months with improved ASES and VAS scores. Elhassan et al evaluated patients treated with Warner's technique and found that those with a pre-operatively concentric humeral head had better outcomes.[77] Other recommendations include: age < 65 years (ideally < 40),[77] intact or reparable posterosuperior RCTs, and minimal GH arthritis.[78] It was noted that if the subcoracoid transfer is successful, ER loss up to 25° can be expected owing to a tenodesis effect.[71]

PMnT

Supracoracoid PMT can leave patients with a positive belly-press and lift-off test.[79] Investigators looked at other interventions including a PMnT.[72,80] Wirth initially described this transfer in 1997 while reporting outcomes on both PMT and PMnT. Paladini used a subcoracoid PMnT with a small cortical piece of the coracoid for subscapularis tears of the superior two-thirds concomitant with irreparable supraspinatus tears. Two-year follow-up of 27 patients demonstrated significant improvement in constant score and FF. In total 78% returned to their activities of daily living. Interestingly, there was only an ER loss of 11° and a 22% presence of a belly-press test.

LDTMT

Cadaveric studies have been conducted in an effort to identify a more anatomical tendon transfer modality. Elhassan et al[81] investigated the potential of LDT, TMT and LDTMT for anterior deficiencies. They concluded that a LDT or the TMT would be a viable safe option for transfer to the lesser tuberosity. *In vivo* studies must be conducted to determine the anatomical plausibility of these techniques.

Transfers for RTSA

Modern RTSA has provided surgeons with the ability to improve shoulder dysfunction in the setting of irreparable RCTs in the elderly.[82,83,84] While the deltoid is the primary elevator of the arm, ER will be lacking if pre-operative evaluation demonstrated a positive Hornblower's or ER lag sign.[82,85-87] The incidence is approximately 10%.[87] In an effort to restore ER, transfers using previously covered techniques have been studied, including LDT and LDTMT.

LDT

Gerber first described the two-incision LDT for RTSA in 2007.[88] Early results were promising; however, durability of the transfer was unknown. Puskas et al[89] evaluated 32 of Gerber's shoulders at intermediate-term follow-up and found excellent outcomes at five years with maintained ER. Surprisingly, the status of the teres minor had no effect on the outcome. It was concluded that patients with a pre-operative ER deficiency would benefit from a LDT in the setting of a RTSA.

LDTMT

In line with Gerber, Boileau published early results for his single-incision modified L'Episcopo technique where a LDTMT was performed.[90,91] Boileau then prospectively evaluated 17 of his patients for at least one year after performing the aforementioned LDTMT.[92] It was determined that the single-incision approach was easier, had fewer complications, and provided greater ER owing to addition of the TMT. Boughebri et al[87] re-affirmed these results with a minimum two-year follow-up investigation. Of note in both types of transfers (LDT or LDTMT), advanced age did not preclude the ability to perform either procedure.

Conclusion

Irreparable RCTs, Goutallier grade 3 or higher, can be debilitating. However, brilliant minds have developed techniques to improve quality of life and function. For posterosuperior RCTs, lacking the ability to raise and externally rotate the arm, the LDT remains the most time-tested transfer. LDT outcomes are satisfactory; however, LTT transfers are a promising new frontier and should be considered. Isolated subscapularis deficiencies seem to be well treated with PMT. In the presence of an irreparable supraspinatus and anterior supraspinatus one can consider the PMnT. When presented with rotator cuff arthropathy and an ER lag, the single-incision LDTMT appears to be the 'go to' transfer, as it improves ER with fewer complications compared with the isolated LDT.

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