Tendon transfer for irreparable rotator cuff tears: indications and surgical rationale

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Summary

Background: treatment of symptomatic irreparable rotator cuff tears is extremely challenging because, at present, there are no ideal solutions to this problem. Many patients respond favorably to nonsurgical treatment. However, when conservative measures fail to improve the patient’s pain and disability, surgery should be considered. Methods: different surgical techniques are available and the choice of the most appropriate procedure depends on the presenting symptoms, age of the patient, functional demand, medical comorbidities, joint stability and presence of arthritic changes. The transposition of the surrounding muscles to replace the rotator cuff function represents a viable option in the treatment of younger patients without glenohumeral osteoarthritis and with severe functional limitation. Purpose: aim of this study is to give an overview of the currently available evidence regarding tendon transfer procedures for irreparable rotator cuff tears.

KEY WORDS: shoulder, rotator cuff, irreparable tears, tendon transfer.

Introduction

Rotator cuff tears (RCT) represent one of the most common cause of pain and disability of the shoulder. Epidemiological studies have shown that RCT occur more frequently after a certain age, with a prevalence ranging from 30 to 50% in patients older than 50 years¹, and that, in most of cases, they are progressive². Although the pathogenesis of RCT remains unclear, two main theories have been developed: the extrinsic theory and the intrinsic one³. In 1972 Neer⁴ developed the concept that RCT resulted from the extrinsic mechanical compression caused by a hooked acromion (subacromial impingement). However, recent evidence strongly suggests that most of RCT are caused by primary intrinsic degeneration of the rotator cuff⁵ which result from the combination of the natural process of aging, poor vascularity, altered biology and inferior mechanical properties⁶-⁸. In addition, a genetic component for the development of RCT has also been identified and theorized to be related to polymorphism of collagen genes⁹. Basing on these findings, some studies have suggested that RCT do not heal spontaneously and that they tend to grow larger over time¹,¹⁰,¹¹. The treatment of choice in symptomatic “cases” is the direct reattachment of the torn tendon to the footprint through either open or arthroscopic surgery. However, some tears can progress to the point of becoming irreparable. Several classification systems have been developed to describe RCT based on different parameters¹²-¹⁸ (Tab. 1). The term irreparable is often incorrectly used and ably interchanged with the term massive but not all massive tears¹⁰ (Fig. 1). It is possible to define irreparable tears as those that, because of their size and retraction, cannot be repaired primarily to their insertion on the tuberosities despite conventional techniques of mobilization and soft-tissue releases¹⁹,²⁰. Moreover, irreparable RCT typically present with atrophy and fatty degeneration of the respective muscles that lead to impaired muscle quality and thus to defective contrac-
Conservative measures fail to improve the patient’s pain and disability, surgery should be considered. Surgical options include arthroscopic débridement with or without partial rotator cuff repair, the use of rotator cuff allografts and synthetic grafts, arthroplasty and tendon transfer. Among these techniques, the transposition of the surrounding muscles to replace the rotator cuff function represents a viable option. The aim of this study is to give an overview of the currently available evidence regarding tendon transfer for irreparable RCT.

### Tendon transfer procedures: rationale

The choice of the most appropriate procedure depends on the presenting symptoms (pain and/or disability), age of the patient, functional demand, medical comorbidities, joint stability and presence of arthritic changes. The ideal candidate for a tendon transfer procedure is a young, active patient who does not have glenohumeral osteoarthritis but has severe disability related to weakness and loss of external rotation. The selection of the donor muscle-tendon unit is based on the structural deficit and impaired function. Although different muscle-tendon units have been proposed in the last decades, the most commonly used include the latissimus dorsi (LD) for posterosuperior RCT and the pectoralis major (PMa) for irreparable anterosuperior tears. The aim of tendon transfer is to restore the force couples of the shoulder. With LD transfer, the aim is to exert an external rotation force that allows for a more balanced state, even if direct repairs are structurally successful. Obviously in presence of an irreparable RCT, also the shoulder biomechanics is altered. In the normal shoulder, the deltoid and rotator cuff muscles work synergistically to maintain a balanced force couple around the joint in both the coronal and the transverse plane, with coactivation of agonist and antagonist muscles, as well as coordinated activation of the agonist and inhibition of the antagonist muscle. In particular, the deltoid and rotator cuff inferior to the humeral head equator maintain a balanced coronal force couple, while the subscapularis and infraspinatus/teres minor complex balance each other in the transverse plane. In this way, the rotator cuff acts as a dynamic stabilizer, resisting upward motion of the humeral head during contraction of the deltoid muscle. When there is an irreparable RCT, the stabilizing force couple is lost, allowing the humeral head to displace superiorly for the contraction of deltoid. This is associated with a loss of elevation and, in some cases, with superior shoulder instability. For this reason, acromiohumeral distance (evaluated on X-ray) represents another parameter that may be used to assess if a RCT is reparable. With some studies suggesting that an acromiohumeral distance of <7 mm is associated with decreased likelihood of reparation. Patients with irreparable RCT can present a variety of clinical manifestations. They may have no symptoms or mild symptoms, or they may be completely disabled and have severe pain. Pain is the most frequent symptom, particularly at night and during activities of daily living, and it is often combined with functional impairment. The management of symptomatic irreparable RCT is still controversial, and often the results are less favorable and predictable. Many patients with irreparable RCT respond favorably to nonsurgical treatment. When conservative measures fail to improve the patient’s pain and disability, surgery should be considered. Surgical options include arthroscopic débridement with or without partial rotator cuff repair, the use of rotator cuff allografts and synthetic grafts, arthroplasty and tendon transfer. Among these techniques, the transposition of the surrounding muscles to replace the rotator cuff function represents a viable option. The aim of this study is to give an overview of the currently available evidence regarding tendon transfer for irreparable RCT.
Glenohumeral joint and thus replacing the function of the posterior force couple. Aim of PMa transfer is to exert an internal rotation centering force there by replacing the function of the subscapularis. This is intended to function as the anterior force couple. Theoretically, restoration of the anterior and posterior force couples will allow the glenohumeral joint to pivot around a stable fulcrum. However, the critical function of the rotator cuff can never be fully replaced, and this balance in the force couple is rarely attained. The probable reason that the periscapular muscles cannot fully restore the normal function of the rotator cuff is their anatomic position and the resulting force vectors in relation to the anatomic positions of the native rotator cuff muscles. In particular, in both subcoracoid and supracoracoid transfers the PMa transfer is always anterior to the normal position of the subscapularis. Moreover, the LD transfer is always inferior and posterior to the infraspinatus and teres minor muscles. This results in the development of a non-physiologic vector across the glenohumeral joint, leading to abnormal kinematics.

**Tendon transfer procedures: techniques**

**Latissimus dorsi transfer**

The LD muscle is a large muscle, located along the dorso-lateral side of the trunk. The muscle has four points of origin, the spinous processes of the thoracic vertebrae (T7-T12), the inferior angle of the scapula, the iliac crest and the 9th to 12th ribs, and inserts to the medial edge of the bicipital groove of the humerus. LD transfer provides a large, vascularized tendon that closes the cuff defect and exerts an external rotational moment, allowing more effective action of the deltoid muscle. In its native location, the LD muscle contributes to internal rotation, retroversion, and abduction of the shoulder joint. The procedure is performed on the patient in general anesthesia in the lateral decubitus position and includes a superior approach and an axillary approach. The superior approach is performed with a 5-cm supero-lateral skin incision made immediately lateral to the acromioclavicular joint going through the rafe between the anterior and the lateral deltoid without detaching it from the acromion. The rotator cuff is exposed to ascertain that the rupture is irreparable and trying an extensive mobilization of the retracted musculotendinous units to attempt a direct repair of the residual tendon bands. Then, the axillary approach is performed through a 12 to 15-cm posterior skin incision that follow the lateral border of the LD, the muscle is identified and is released from the humeral shaft taking care to identify and separate the LD belly from teres major. After exploration of the neurovascular bundle, the LD is mobilized and is pulled through the plane between the infraspinatus-teres minor and the deltoid muscle. The transferred tendon is anchored to the greater tuberosity in the area of supraspinatus tendon insertion with the use of 2 double-loaded suture anchors (Threvo FT; ConMed, Largo, FL, USA) or with transosseous sutures/bone trough. Alternatively, a small osteotomy can be performed to enhance tendon healing. Any part of the torn rotator cuff are then sutured to the medial edge of the LD tendon. A post-operative period of 4-6 weeks of immobilization with the arm in...
slight abduction and externally rotated is required\textsuperscript{10,35,36,39}. Gentle passive range of motion in abduction can begin immediately, but internal rotation and adduction are restricted until 6 weeks after surgery. At 6 weeks the brace may be removed and active range of motion is started. Strengthening exercises can be started in the third month\textsuperscript{10,35,36,39}. When the LD tendon is transferred to the greater tuberosity, the muscle’s internal rotator torque is removed and the function of the muscle changes into an external rotator\textsuperscript{36}. This external rotation is accomplished by either a synergistically active tendon transfer or a tenodesis effect: electromyographic studies have suggested that in some cases the transfer is truly active whereas in others the patient cannot actively synchronize LD muscle activity with supraspinatus and infraspinatus muscle activity\textsuperscript{39,40}. In both cases, the improved balance between the anterior and posterior soft tissue structures of the shoulder is believed to be biomechanically important to serve as a balanced fulcrum\textsuperscript{33}. For this reason the subscapularis tendon and deltoid muscle origin must be intact in order to establish balanced force couples in the glenohumeral joint. Moreover, after transposition of the LD tendon, the muscle acts as a depressor of the shoulder. Depression of the humeral head, allows the deltoid muscle to contribute to the abduction and anteflexion of the shoulder more effectively\textsuperscript{35,36}. LD tendon transfers were firstly used in patients with brachial plexopathies in order to treat the lack of external rotation\textsuperscript{10}. This concept of using muscle transfer to improve shoulder external rotation was applied by Gerber et al.\textsuperscript{37} in the management of irreparable posterosuperior RCT.

In the majority of patients LD tendon transfer is very effective in reducing pain. However, the functional outcome is more variable\textsuperscript{35,39,41,42}. Proper patient selection is critical. Factors associated with poor outcome include muscle dysfunction (subscapularis, deltoid, teres minor) and osteoarthritis of the glenohumeral joint. In particular, Miniaci and MacLeod\textsuperscript{41} reported that fourteen out of seventeen patients who were treated with this transfer after a failed rotator cuff repair had a satisfactory result. Warner and Parsons\textsuperscript{42} reported a 73% overall patient satisfaction rate in a series of twenty-two patients treated with LD tendon transfer but a 27% re-rupture rate and significantly worse outcomes in patients who had a salvage procedure after a failed rotator cuff repair as opposed to a primary procedure. Iannotti et al.\textsuperscript{39} reported a 64% rate of satisfactory results in a series of fourteen patients and noted that female sex, poor preoperative shoulder function, and generalized muscular weakness were associated with an inferior clinical outcome. Gerber et al.\textsuperscript{35} reported after 10 years of follow-up an increase in the mean Subjective Shoulder Value from 29% preoperatively to 70%, an increase of the mean Constant score from 56 to 80% and an improvement of pain score from 7 to 13 points. Mean flexion increased from 118° to 132°, abduction from 112° to 123°, and external rotation from 18° to 33°. Poor results occurred in shoulders with insufficiency of the subscapularis muscle and fatty infiltration of the teres minor muscle.

**L’Episcopo procedure**

The procedure described by L’Episcopo in 1936\textsuperscript{43} had the scope to restore external rotation in patients with obstetrical plexus paralysis. A modified L’Episcopo technique has been proposed in 2002 by Hebermeyer et al.\textsuperscript{44} with the indication to restore loss of external rotation in patients with massive posterosuperior RCT. Operation is performed with the patient under general anesthesia in lateral decubitus using an axillary approach from the posterior border of the deltoid muscle to the axillary fold\textsuperscript{45}. The deltoid muscle is elevated to expose the plane between the long head of the triceps and teres major muscle, and to identify the axillary nerve in the quadrangular space that is delimited by the humerus (latterally), long head of the triceps (medially), subscapularis (on the top), teres major and LD (down). The combined insertions of the LD and teres major tendons are dissected from the humerus taking care not to injure the radial nerve. The two tendons are reattached with Mason-Allen sutures on the lateral proximal humeral shaft – approximately 180° lateral to the anatomical insertion – using a bone through or bone tunnels, as originally described by L’Episcopo or alternatively with suture anchors\textsuperscript{46}. Although the LD transfer is the preferred surgical approach in patients with massive and irreparable RCT, good restore of shoulder function have been described with L’Episcopo technique, even if the grade of cuff arthropathy progress significantly at final follow-up\textsuperscript{47}. An additional technique has been reported with satisfactory clinical outcomes for shoulder function by other authors who used only the teres major for infraspinatus muscle in irreparable RCT\textsuperscript{48}.  

![Image](https://via.placeholder.com/150)
Pectoralis major transfer

PMa originates from the anterior surfaces of the medial clavicle, the length of the sternum, the cartilage of ribs 2 through 7, and the aponeurosis of the external oblique muscle and inserts lateral to the bicipital groove. Its insertion consists of two distinct layers. The anterior lamina is the terminal portion of the clavicular head, while the posterior lamina originates from the sternal head. A variable third layer, the abdominal lamina, is derived from the aponeurosis of the external oblique muscle. PMa contributes to the general anesthesia in beach-chair position from the sternal head. A variable third layer, the ab-

Thus, the space for the transferred muscle between the pectoralis minor (PMi) and the conjoined tendon is entered by blunt dissection, as well as the increased bulk of the transferred musculotendinous unit, risks injury to the musculocutaneous nerve and brachial plexus. For this reason, split-tendon transfers are also frequently performed. If a partial transfer of the PMa is chosen, the two laminae are bluntly separated for selective transfer. This is achieved by retracting the clavicu-

This way, a transfer is used to rebalance the forces on the humeral head through an inferiorly directed force vector. If rerouted deep to the conjoined tendon, the PMa transfer is thought to also reduce subcoracoid impingement through a soft-tissue interposition effect that aids in pain relief. Care should be taken not to mobilise more than 8 cm from the lateral border of the muscle in order to protect the lateral pectoral nerve. The tendon is then transferred to the upper lesser tuberosity or the anterior aspect of the greater tuberosity depending on the length and excursion of the tendon (Fig. 5 A). The site of attachment is burr, providing a surface of punctate bleeding bone. The tendon is then secured to the tuberosity by use of transosseous sutures or bone anchors. Postoperatively, the shoulder is immobilized for 4-6 weeks in a rigid orthosis. Passive range of motion can be started after 4 weeks but it is restricted within a safe range determined intraoperatively in order to protect the transfer. Active range of motion is allowed after 6 weeks and strengthening exercise after 2 months. However, internal rotation against resistance is allowed only 3 months after surgery. The sub-conjoined tendon transfer has the theoretic advantage of producing a force vector that better simulates that of the native subscapularis tendon (Fig. 5 B). A second advantage of the subcoracoid transfer is that the transferred tendon produces a static soft-tissue interposition between the humerus and the coracoid process, minimizing anterior humeral translation and decreasing the risk of coraco-humeral impingement. One potential disadvantage of the subcoracoid technique is that surgical dissection, as well as the increased bulk of the transferred musculotendinous unit, risks injury to the musculocutaneous nerve and brachial plexus. Despite overlapping insertions, either the anterior or posterior lamina can be elevated while leaving the other intact on the humerus. Different studies reported outcomes after PMa transfer for irreparable anterosu-

Figure 5 A, B. A) Pectoralis Major (PMa) released and pulled out (white arrows); B) PMa passed beneath the conjoined tendon and fixed to the lesser tuberosity of the humerus (black arrows). PMa: pectoralis major.
perior RCT \cite{34,49,50,53}. Jost et al. \cite{50} reported excellent mean relative Constant score (79\%) after PMa transfer. This study also showed that the ability to repair the supraspinatus improved the outcome compared with concomitant irreparable supraspinatus tears. Resch et al. \cite{34} were the first to report the technique of subcoracoid transfer of the PMa to the lesser tuberosity. In their group of 12 patients with a minimum follow-up of two years, the mean Constant score improved from 22.6 points preoperatively to 54.4 points postoperatively and most of the patients had marked improvement of pain. In addition, four of the patients with preoperative instability regained stability after surgery. Galatz et al. \cite{53} reported satisfactory results after subcoracoid transfer of the PMa tendon in 11 of 14 patients with a massive RCT with improvement in pain and function (ASES scores improved from 27.2 to 47.7). In a more recent study, Gavriilidis et al. \cite{49} described their experience of 15 patients treated after 37 months of follow-up. The authors reported an improvement in Constant score from 51.73 to 68.17. Patients were also monitored by MRI to verify the integrity of the transferred tendon and an intact transferred tendon was described in 70\% of patients \cite{49}. On the contrary, different authors reported that patients with instability and anterior subluxation have the least predictable pain relief and worse functional outcomes \cite{50,53}.

**Pectoralis minor transfer**

The PMi is a thin triangular muscle lying deep to the PMa. It originates from the 3rd, 4th and 5th ribs near the costal cartilages. Its fibers ascend laterally and converge in a flat tendon that attaches to the medial border and upper surface of the coracoid process of the scapula. The axillary vessels and brachial plexus lie posterior to the muscle. The PMi pulls the scapula anteriorly and inferiorly toward the ribs (abduction and depression respectively) leading to a dorsomedial movement of the inferior angle of the scapula. This movement is both helpful when retracting the elevated arm and as well as moving the arm posteriorly behind the back. Given a fixed scapula the PMi also elevates the 3rd to 5th ribs and expands the rib cage. For this reason, it can also serve as an accessory muscle during inspiration \cite{54}.

PMi tendon as a graft to treat irreparable subscapularis tears was first used by Wirth and Rockwood \cite{55} who even tried to use the coracohumeral ligament, which is continuous with the coracoid insertion of the PM \cite{56}. Inclusion criteria for a PMi transfer are as follow: irreparable RCT involving the upper two-thirds of the subscapularis tendon \cite{57} (Fig. 6 A); complete supraspinatus tear; and MRI evidence of fatty degeneration (grade III according to Fuchs et al.\cite{18}) of the supraspinatus and upper subscapularis muscles \cite{58}. All patients are operated under general anesthesia in a beach-chair position using the same standard deltopectoral approach described for PMa tendon transfer. After careful debridement of the subscapularis footprint and of the interval between the coracoid and the humeral head, the PMi tendon is detached from the coracoid with a bone fragment to foster the healing process and to avoid muscle wasting (Fig. 6 B). Two stay sutures placed over the osteotomy are used to drag the PMi tendon, which usually reaches the lesser tuberosity without excessive tension, under the coracoid. The PMi is accurately released, taking care to identify and protect the musculocutaneous nerve, and then sutured in areas 2 and 3 as described by Arai et al.\cite{59} using 2 double-loaded suture anchors (Threvo FT; ConMed, Largo, FL, USA) (Fig. 7). The bellies of the inferior subscapularis and of the PMi can be joined horizontally with 2 free sutures and the biceps tenodesed or tenotomized. After the operation, the shoulder is immobilized in a sling for 6 weeks, active elbow flexion and extension are allowed with the arm at the side; at 6 weeks, the sling is removed and passive mobilizations in forward flexion and passive external rotation are permitted \cite{31,60}. After 8 weeks all range-of-motion (ROM) restrictions were lifted, strengthening is initiated at 3 months \cite{31}.

**Overview**

Tendon transfers are complex surgical procedures that require a long period of rehabilitation. They do not restore normal shoulder function and kinematics but can rather be considered as a salvage procedure. The functional outcomes and pain relief that can be achieved after surgery strictly depend on patient. The best candidate for a tendon transfer procedure is a young patient with irreparable RCT, no sign
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Donor tendon depends on the location of the RCT. The choice of sutures. CT: coracoid tendons. Inferior subscapularis and PMi joined horizontally with free sutures. CT: coracoid tendons.


References


