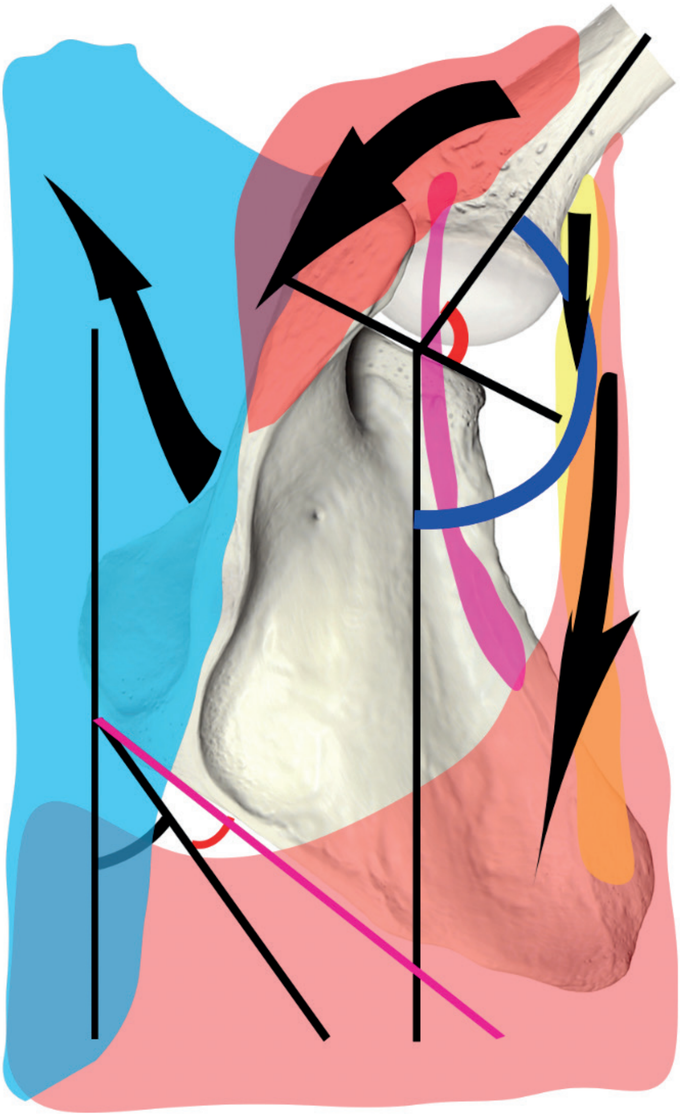
Latissimus dorsi transfer for massive irreparable rotator cuff tears



Navin Gurnani

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The research in this thesis was embedded in Amsterdam Movement Sciences Research Institute, at the department of Behavioural and Movement Sciences, Vrije Universiteit Amsterdam, the Netherlands

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LATISSIMUS DORSI TRANSFER FOR MASSIVE IRREPARABLE ROTATOR CUFF TEARS

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1

General introduction and aim of the thesis

INTRODUCTION

Chronic rotator cuff tears (RCT) may be repairable or beyond repair. Several surgical procedures have been proposed to treat either type of tear. The latissimus dorsi transfer (LDT) is a viable treatment option for a massive irreparable posterosuperior rotator cuff tear (MIRT). Good long-term outcomes can be achieved, however, they are not always consistent. Controversy remains concerning patient selection and the mode of function of the transfer. The primary aim of this thesis was to gain insights into the mechanical role of the LDT and its effect on shoulder kinematics. In turn, it might increase our knowledge of muscle activation strategies in the setting of a cuff tear and after an LDT.

Physiologic shoulder kinematics and muscle activation

Shoulder motion is complex because movement takes place across several joints. The involved shoulder girdle joints are the sternoclavicular (SC) joint, the acromioclavicular (AC) joint, the glenohumeral (GH) joint, and the scapulothoracic (ST) joint. The ST joint is not a true joint, but more an articulation between scapula and thorax. The entire shoulder girdle is only attached to the axial skeleton at the SC joint, therefore, permitting a large mobility. [14]

In the first 30-60 degrees of elevation, the scapula seeks stability relative to the humerus, which is highly variable and characteristic for each individual. This is termed 'the setting phase' of the scapula. Hereafter, elevation is divided into GH and ST motion, with a constant ratio of 2:1 coined the scapulohumeral rhythm. [35, 58] Shoulder elevation occurs through a mechanism in which the humeral head is positioned by a closed chain formed by the thorax, scapula, and clavicle. In full shoulder elevation, the scapula rotates 60 degrees upward, indivertibly involving the SC and AC joints. [35, 56] Rotation, elevation/depression, retraction/protraction, and tilting are necessary motions at the SC and AC joints to achieve scapular rotation leading to maximal shoulder elevation. These joints, together with their extra-articular ligaments also constrain scapular motion. Therefore, the scapulohumeral rhythm is the result of movement at four joints. [35, 39]

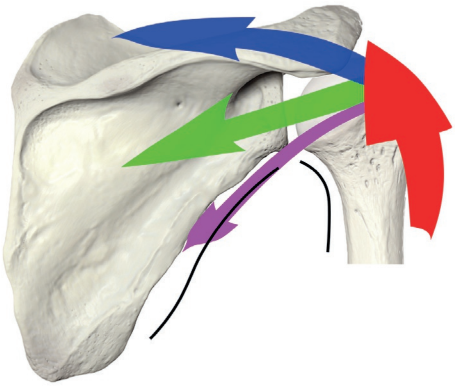
The scapula serves two important purposes in shoulder elevation. Firstly, maintaining the glenoid fossa in an optimal position to receive the articular surface of the humeral head. [35] Secondly, maintaining the optimal length/tension relationship of the acting muscles on the proximal humerus. This minimizes active and passive insufficiency of scapular muscles that act upon the humerus. [35, 39] For example, in humeral elevation, the action of the deltoid will lead to downward rotation of the scapula, subsequently leading to active insufficiency of the deltoid. Upward rotation of the scapula produced by the serratus anterior and trapezius force couple will prevent this downward rotation and maintain an optimal length/tension ratio for the deltoid. [39]

The scapula is fully dependent on muscular activation for scapular stability during shoulder elevation. [5, 35, 39, 62] These muscles act mainly as force couples, which are muscles that are paired to control the movement or position of the scapula. [35, 39, 82] The appropriate force couples for scapular stabilization include the upper and lower portions of the trapezius muscle working together with the rhomboid muscles, paired with the serratus anterior muscle. The appropriate force couples for acromial elevation are the lower trapezius and the serratus anterior working together, paired with the upper trapezius and rhomboid muscles. [5, 43, 62]

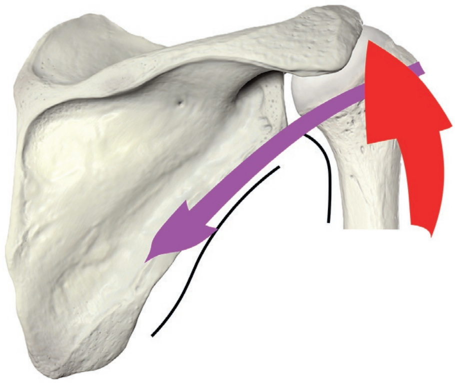
The large ball and small socket make the inherent bony GH joint highly mobile, with little constraint. The primary role of the rotator cuff is to stabilize the GH joint by compressing the humeral head against the glenoid during various shoulder motions, called concavity compression (Figure 1). [14, 84] Another role of the rotator cuff is to precisely coordinate a desired shoulder motion with the periscapular muscles, as they can have a synergistic or neutralizing effect on the prime mover. The prime mover(s) are the largest muscle(s) contributing to a specific shoulder motion. [54] For example, when solely internal rotation is required in the shoulder, the deltoid and cuff neutralize the adduction force of the latissimus dorsi (LD). The subscapularis muscle will co-contract for maximal internal rotation force. [65]

In terms of GH stability, the glenohumeral ligaments in extreme range of motion, labrum, and negative intra-articular pressure add to stability by decreasing humeral head translations in active elevation. However, their stabilizing properties in active elevation seem limited when compared to concavity compression by the rotator cuff. [34][69][17][36]

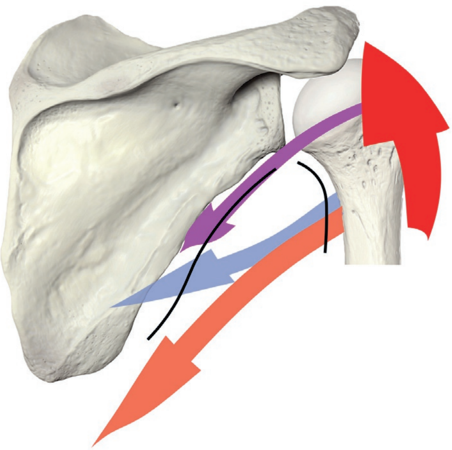
Figure 1 Concavity compression



A) Normal shoulder



B) Massive rotator cuff tear



C) Compensated rotator cuff tear

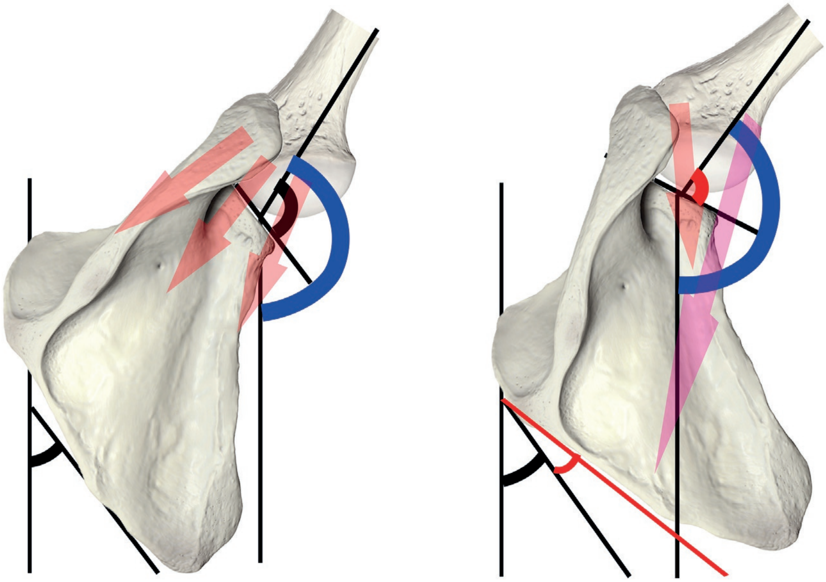
Arrow	Muscle
Red:	Deltoid
Blue:	Supraspinatus
Green:	Infraspinatus
Purple:	Teres minor
Grey:	Teres major
Orange:	Latissimus dorsi

A) Normal concavity compression from the rotator cuff
B) Decreased concavity compression after massive rotator cuff tear and superior humeral head migration
C) Compensated concavity compression by the shoulder adductors in a massive rotator cuff tear

Kinematics and muscle activation after a chronic rotator cuff tear

The concavity compression and muscle force of the rotator cuff decrease with increasing tear size (Figure 1). [70] In smaller superior cuff tears, increased activity of the deltoid in active elevation is observed to compensate for the lack of supraspinatus muscle force. [75, 85, 89] In turn, this induces an increased superior sheer force about the GH joint, which can be neutralized by the increasing glenoid-directed forces from the largely intact cuff. [75]

Figure 2 Kinematics and muscle activation



A Physiological B Rotator cuff tear

A) Normal physiological shoulder, intact rotator cuff muscles in red arrows, and normal shoulder kinematics.
B) Rotator cuff tear involving supraspinatus and infraspinatus muscles, the red arrow is the remaining teres minor and the pink arrow the shoulder adductors. The red angles show an increased scapulothoracic and a decreased glenohumeral motion.

A higher ST contribution in shoulder elevation is reported when a tear progresses to the infraspinatus muscle (Figure 2).[26, 31, 48] Together with this change in kinematics, increased activity of the remaining cuff, deltoid, biceps brachii, teres major, LD, pectoralis major, trapezius, and serratus have been observed. [18, 29, 30, 41, 74] These muscles work in concert to create a stable GH fulcrum by (partially) restoring the concavity compression and making active elevation possible. The deltoid has to work harder to lift the shoulder with the torn posterosuperior cuff. Upward scapular rotation increases deltoid muscle length and muscle force. [48] However, with this extra superior pull, the deltoid induces an upward-directed sheer force on the humerus. To minimize superior GH translation, the remaining cuff muscles increase their activity to maximize concavity compression. [75] In larger cuff tears this compression is insufficient and the adductor muscles, i.e. LD and teres major add their downward directed force to counteract the sheer forces of the deltoid (Figure 1). [76] The increased scapular upward rotation works favorable for the adductors to generate a more glenoid-directed force in active elevation. Thus, in active elevation, upward scapular rotation is somewhat better for generating increased deltoid force and centralizing glenoid-directed adductor forces in patients with an MIRT. This compensation mechanism could be responsible for asymptomatic shoulder elevation in these patients. However, once the cuff tear increases beyond the inferior coronal force couple of the GH joint, the compensation mechanism is insufficient to maintain active elevation. [2][16] [70]The coronal force couple is a balance between the deltoid and inferior cuff, i.e. lower subscapularis and infraspinatus/teres minor muscles. [6][35] Once this balance is disrupted, full active elevation is lost which could progress to a pseudoparesis or pseudoparalysis. [2][81][19] The chronic superior translation of the humeral head will eventually lead to cuff arthropathy with glenohumeral arthritis.

Etiology and natural progression rotator cuff tear

Chronic rotator cuff tears (RCT) lead to a significant decrease in quality of life with a large economic burden. [71] This shoulder pathology constitutes a significant public health issue, as it accounts for one of the most common upper-extremity conditions in people over 50 years old. [52, 71, 80]

Rotator cuff tears and degeneration have a multifactorial etiology with intrinsic and extrinsic factors. Tendon degeneration ranging from tendinopathy to full-thickness tearing is considered part of the natural aging process of tendons. [13] In a systematic review, rotator cuff abnormalities were observed in 9.7% of patients younger than 20 years which increased to 62% in patients older than 80 years. [42] Once torn, progression of the tear is observed in symptomatic and asymptomatic patients and is more frequently seen in the older population. A 2- and 5-year risk of tear progression in partial-thickness tears was 11 and 35%, for full-thickness tears this increased to 22 and 50% respectively. [40] Tear enlargement was also associated with arm dominance, suggesting that activity level plays a role. Smaller tears (<1.5cm) have less likelihood of tear progression over time when compared with larger tears. The presence of tear enlargement is associated with pain development. [57] Apart from age, the intrinsic tendon quality is affected by the presence of hypercholesteremia, smoking status, and genetic factors. [77] This has been associated with loss of elasticity and accelerated tendon degeneration, subsequently leading to tearing of the rotator cuff or progression of tear size. [77]

The rotator cuff is subjected to numerous complex tension loads in the day-to-day activities while using the shoulder. The elasticity of the cuff tendons enables it to tolerate tensile forces. However, mechanical loads applied at high frequency or intensity have the potential to injure the tendon structure as seen in patients performing heavily loaded overhead activities. [77]

The previously reported subacromial impingement syndrome is a common cause of shoulder pain. First described by Neer in 1972 to describe the trauma to the supraspinatus tendon encountered as it passes below the coracoacromial ligament and the anterior one-third of the acromion. [65] A more curved acromion could lead to external impingement by decreasing the actual space in the subacromial space. The coracoacromial ligament was thought to be responsible for compressing forces on the rotator cuff during shoulder flexion, however, this is found to be physiological. [77] A histological study shows that the curved acromion is more likely acquired (traction spurs coracoacromial ligament) than congenital. [73] Presently, it is assumed that the acromial changes are secondary to inadequate stabilizing forces of the rotator cuff and thickening of the tendon found in rotator cuff degeneration. Secondary or external impingement could be seen with altered glenohumeral abnormalities, muscle imbalance, weakness, glenohumeral instability, or osteoarthritis. [68]

The healing capacity of rotator cuff tendon tears is limited due to the continued loads/ forces acting on the GH joint and its scarce tendinous vascular supply. Once the tear process has started, it usually propagates over time. [34, 77] Insufficiency of one or more of the cuff tendons increases strain on other adjacent glenohumeral static and dynamic stabilizers during shoulder motion. [4][37] Tear progression mainly starts in the anterior supraspinatus tendon, extending into the infraspinatus and subscapularis tendon. Over time with ongoing propagation of the tear, the transverse force couple for maintaining GH joint stability during shoulder motion is lost. In the long term, this instability can turn into cuff tear arthropathy, defined as GH joint arthritis with a large rotator cuff tear.

Clinical presentation and imaging

Clinical symptoms do not always correlate with tear characteristics. However, if symptomatic in one shoulder, patients have a 35 % chance of having an asymptomatic tear in the contralateral shoulder. Asymptomatic patients are considered to have a well-balanced shoulder and an intact transverse force couple. [7] However, with a large tear and a disrupted coronal force couple, severe shoulder pain with a clinical pseudoparalysis in the shoulder can exist. [25] In the literature, the terms pseudoparesis and pseudoparalysis are used interchangeably. [81] A true pseudoparalysis is a complete loss of active shoulder elevation, usually with an anterosuperior escape, with a full passive range of motion, and active shoulder elevation will not improve after a subacromial lidocaine injection. Pseudoparesis is a partial loss of active elevation with a maximum elevation of 90 degrees and a full passive range of motion; these patients will improve activation elevation after a pain-inhibiting subacromial lidocaine injection. [81] Nightly pain, pain while sleeping on the shoulder, and loss of strength are also common complaints.

When assessing patients with shoulder pain, plain radiographs are usually conducted, but are of limited use to identify the presence of smaller rotator cuff tears. However, acromial morphology and degenerative osteophytes arising from the AC joint can be readily evaluated using antero-posterior projection and scapular Y radiographs. The Bigliani classification describing acromial morphology or acquired-changes could be associated with rotator cuff disease. [1] The Hamada classification is based on radiographs as well, and serves to determine the degree of the rotator cuff arthropathy on antero-posterior radiographs; proximal humeral migration correlates with larger rotator cuff tears which occur at a later stage of the disease. [27]

To diagnose a rotator cuff tear and its reparability an MRI is more commonly ordered. Cofield proposed a classification for rotator tears according to size in the coronal plane with MRI. Small is a tear size of less than 1 cm, medium is 1-3 cm, large is 3-5 cm, and more than 5 cm is considered massive. [20, 50] Smaller tears are associated with better tendon healing after repair when compared to larger tears. [55, 71]

Tendon quality of chronic and acute tears can be significantly different with similar tear sizes. A chronic rotator cuff tear has increased tendon degeneration, which is muscle atrophy, tendon retraction, and fatty infiltration. [4, 71] In contrast, acute tears lack intrinsic tendon degeneration. These tears readily reach the footprint when arthroscopically repaired and have better healing rates due to their good tendon quality. Patients with chronic large tears show more medial retraction of the tendon, which may cause traction on the suprascapular nerve which in turn can accelerate degeneration of the muscle. [4, 34]

As mentioned before, cuff degeneration is characterized by the development of fatty infiltration, muscle atrophy, and medial retraction of the torn tendon. The Goutallier grading system for fatty infiltration, which was originally developed using CT in 1989, was modified by Fuchs using MRI. This grading system classifies tendon degeneration by the degree of fatty infiltration in the affected torn cuff muscle(s). [59] The Goutallier stage ranges from 0-4 with more fatty infiltration in the torn cuff muscle with increasing stage. Higher retear rates after primary repair have been reported with increased stages of fatty infiltration. [24, 59] Cho and Rhee et al reported tendon healing to be 92.5% for stage 0, 88.3% for stage 1, 52.9% for stage 2, 38.5% for stage 3, and 0% for stage 4. [11] Similar percentages were found by Chung et al reporting on fatty infiltration and cuff healing after repair. [12] Some studies show that a stage 2 or greater fatty infiltration of the infraspinatus is enough to negatively affect tendon healing after repair. [24, 53]

Atrophy of the rotator cuff muscles correlates highly with tear size and fatty infiltration, and therefore also affects tendon healing after primary rotator cuff repair. [77, 79] The occupation ratio method developed by Thomazeau is used to calculate the supraspinatus muscle volume in its fossa, with the sagittal oblique MRI. [79] A simpler and more practical way to assess atrophy of the supraspinatus is by using the Tangent sign on sagittal oblique MRI.[78] [46][91] The Tangent line is drawn from the coracoid to the scapular spine on the sagittal oblique films. In (near) normal cases, without any muscle atrophy, the supraspinatus muscle belly should cross the line superiorly. Similarly, the technique of estimating atrophy of the subscapularis and infraspinatus muscle with lines is incorporated in the Warner classification.[86]

Medial tendon retraction is yet another aspect of rotator cuff tendon tear degeneration that can be graded according to the Patte classification with the coronal MRI images. Increased tendon retraction is correlated with chronicity, larger tear size, fatty infiltration, and atrophy. [59, 72] Due to the chronic existence of the tear, the torn muscle has gone through degenerative changes with loss of elasticity and medial tendon retraction. In turn, making anatomical repair to the footprint on the greater tuberosity difficult or even impossible. [90]

To repair or not to repair?

The goal of the initial non-operative treatment of a symptomatic RCT is to activate the compensatory mechanism to increase shoulder elevation and reduce pain conservatively. This can be achieved successfully by physical therapy with or without subacromial lidocaine/steroid injections. [71] However, tear progression should be monitored to avoid a symptomatic massive irreparable tear in younger patients.

When conservative management of the RCT fails, operative treatment may be considered. However, not every cuff tear is repairable. In the case of a massive (>5cm antero-posterior length) cuff tear, Goutallier stage 2 or more, and a positive Tangent sign make successful primary repair less likely. [12, 24, 45] This combination of rotator cuff tear characteristics commonly involves the supraspinatus and infraspinatus tendons and is considered an MIRT.[3] If left untreated, natural tear progression will extend to the subscapularis and teres minor tendons. [4, 70] The prevalence of an MIRT ranges from 10-40 % of all rotator cuff tears, with a re-tear rate of up to 90% after primary repair. [3, 26, 71, 77] Interestingly, tendon re-tear after repair does always have to correlate with worst clinical outcome. [8] In these cases, the coronal forces around the glenohumeral joint are sufficiently restored to accommodate asymptomatic active shoulder motion again. However, the longevity of maintaining this asymptomatic shoulder motion is questioned due to the progression of the re-tear and development of cuff tear arthropathy. Recent studies show that an intact and well-healed rotator cuff repair has a more favorable clinical outcome when compared to a non-healed repair. [9, 28, 44] Therefore, a repair with an unlikeness of tendon healing should be limited.

If the cuff is repairable, numerous surgical techniques and concomitant procedures have been reported for primary repair. Successful surgical repair of the rotator cuff will lead to restoration of the transverse and coronal force couple around the GH joint, restoration of shoulder kinematics, and shoulder muscle activations pattern. [45, 49]

In contrast, massive irreparable cuff tears are more challenging to treat. [63, 87] Treatment options for an MIRT include: physical therapy, debridement, partial repair, long head of the biceps tenotomy, subacromial balloon placement, superior capsular reconstruction, deltoid flap, muscle transfer, and reverse shoulder arthroplasty. [51] Due to its limited longevity, a reverse shoulder arthroplasty is nowadays generally reserved for the older population. Although reasonable long-term results have been published in younger age categories, [67] a reverse shoulder arthroplasty does not restore full range of shoulder motion and is considered to be an end stage solution for an MIRT.[51] A subacromial balloon is a biodegradable substance, which is inserted in the subacromial space. This balloon acts as a spacer between acromion and proximal humerus, which initially yielded good clinical results. However, a large multicenter study comparing the balloon to a simple debridement of the shoulder showed favorable results for the debridement over the balloon. [38, 60] A deltoid flap, which has good short-term clinical results, has inferior long-term results and might make a reverse shoulder arthroplasty at a later stage challenging. [51] A superior capsular reconstruction has also been proposed for an MIRT, the technique requires an autograft or allograft to reconstruct the superior capsule. The short-term clinical outcomes seem promising, but studies reporting on long-term results of the technique are still lacking. [88] Moreover, inferior outcome has been reported for tears that extend beyond the infraspinatus tendon.[88]

Muscle transfer surgery is a well-known option for an MIRT with good clinical outcomes in the long-term. [64][87] Several muscles can be used for tendon transfer surgery in patients with an MIRT. Good clinical results of transfers with the LD, lower trapezius, and teres major muscles have been reported [47] The teres major transfer has a similar line of pull as the torn infraspinatus. However, this technique has not gained widespread popularity, mainly because of the challenging fixation on the greater tuberosity with its limited tendon length.[47] As an alternative, the lower trapezius transfer has recently been reported with initial outcomes of the lower trapezius transfer being comparable to the LDT. [21] Similar to the teres major, the lower trapezius transfer recreates a more anatomic to the infraspinatus line of pull when compared to the LDT. However, the technique requires an additional graft to achieve fixation on the footprint and long-term results are still to be reported. [83]

Latissimus dorsi transfer for massive irreparable rotator cuff tears

The LDT was initially reported by Gerber for patients with an MIRT. [25] The rationale behind the transfer was to change the function of the LD muscle by transferring the tendon with its large vascularized muscle to the footprint of the supraspinatus. It was expected that after transfer, the muscle would no longer be active as a shoulder internal rotator and adductor and would now function as an external rotator and abductor.

The long-term, 10-year clinical outcome has been promising. [23, 64, 87] However, patients with an MIRT extending into the subscapularis or high-grade fatty infiltration of the teres minor have shown inferior results after an LDT transfer. [23, 64] Moreover, a shoulder with a pseudoparesis or pseudoparalysis is a relative contraindication and demonstrates inconsistent outcomes after an LDT in patients with an MIRT. [3, 10, 15, 26, 66] A reason for this inconsistency could be the different definition of a shoulder with a clinical pseudoparalysis or pseudoparesis amongst these authors. Therefore, it remains unknown whether or not to perform an LDT in patients with a shoulder that has a clinical pseudoparalysis.

The rationale behind the LDT has not been confirmed by muscle activation studies. It is still unclear whether the LD muscle changes its function actively after transfer or if its success can be attributed to the downward-directed pull after transfer, the so-called tenodesis effect. [22, 32, 33, 64]

After an LDT for an MIRT some restoration of the shoulder kinematics could be expected as it clinically restores active range of motion. However, a few studies have shown that shoulder kinematics do not restore, and resemble the kinematics of a massive torn cuff. [22, 49] There remains a paucity of literature on this topic.

It is not known how the LDT increases active shoulder elevation. It could be that the surrounding shoulder muscles change their muscle activation pattern after LDT, accommodating active shoulder elevation. The intensity of activation, timing of activation, or prolonged activation could be affected after transfer. Shoulder muscle activation patterns have been evaluated for several other shoulder conditions such as shoulder impingement, rotator cuff tears, muscle fatigue, and instability. [30, 61] Studies that report on muscle activation after LDT predominantly focus on the activity of the LD muscle after transfer and not on the surrounding periscapular muscles. [32, 33]

Failure after an LDT is not uncommon and can be diagnosed clinically by increased pain, loss of strength, decreased range of motion, and a shoulder with a clinical pseudoparesis or paralysis. However, the mode of failure is not clearly understood. Failure to heal on the greater tuberosity, rupture at the musculotendinous junction, cuff tear progression, and degeneration or GH osteoarthritis are several possible modes of failure. In the current literature, no postoperative MRI studies have been reported after LDT to assess the integrity of LDT transfer. The altered anatomy in the shoulder after LDT may influence adequate grading of pathology according to the current rotator cuff classifications.

General introduction

The introduction and aim of the thesis are stated in **Chapter 1**. Shoulder kinematics and muscle activation patterns are explained in the setting of a rotator cuff tear (RCT). Classification systems are presented to grade rotator cuff tendon tears, degeneration, and access reparability of the rotator cuff tendon. If not reparable, the LDT is a viable surgical treatment option, although the mode of function is not understood.

Part 1: The repairable and irreparable rotator cuff tear

After conservative treatment of the RCT has failed, surgical treatment should be considered. Primary rotator cuff repair is more likely to heal in tears without much tendon degeneration. Options for primary rotator cuff repair and concomitant procedures are reviewed and summarized in **Chapter 2**. The clinical outcomes after primary rotator cuff repair are reported in a meta-analysis in **Chapter 3**. The high failure-to-healing rate makes a chronic massive posterosuperior rotator cuff tear (MIRT) not suitable for primary cuff repair. In **Chapter 4,** the conservative and surgical options for an MIRT are presented in a systematic review and meta-analysis.

Part 2: The latissimus dorsi transfer for a massive posterosuperior rotator cuff tear

3-dimensional shoulder kinematics and muscle activation after an LDT for an MIRT are presented in **Chapter 5** and compared to the asymptomatic contralateral shoulder (ACS). The change in shoulder kinematics after an LDT is achieved by reprogramming activation in the muscles responsible for active shoulder elevation. The shoulder muscle activation pattern in active elevation after LDT is reported and compared with the ACS in **Chapter 6**. Although long-term good results after an LDT are reported, failure is not uncommon. To determine the mode of failure after LDT the intra and inter-observer agreement after LDT was assessed with MRI in **Chapter 7**.

The thesis concludes with a general discussion in **Chapter 8**.

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Part I

The repairable and irreparable rotator cuff tear

2

Efficacy of different rotator cuff repair techniques

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ABSTRACT

Overview article

The purpose of this review article was to describe the currently used techniques for rotator cuff repair and post-operative rehabilitation.

The literature was searched for the different surgical techniques for rotator cuff repair and concomitant procedures: [i] full arthroscopic and arthroscopic-assisted rotator cuff repair, [ii] acromioplasty as an additional treatment to rotator cuff repair[iii] the use of plasma rich platelets (PRP) after rotator cuff repair, [iv] the single and double row fixation techniques, [v] long head of the biceps brachii tenotomy or tenodesis with rotator cuff repair, [vi] scaffolds in rotator cuff surgery, and [vii] early motion or immobilization after cuff repair. The rationale, the results, and the scientific evidence were reported and summarised for the eligible procedures.

Keywords

Rotator cuff tear, acromioplasty, plasma rich platelets, tendon healing, rotator cuff repair

INTRODUCTION

Rotator cuff surgery has been evolving rapidly in the last decennia. The first rotator cuff fixation was conducted in the late eighteenth century. The rotator cuff was reattached to the humerus after humeral head resection was performed for a chronic dislocation. [35] At the beginning of the nineteenth century Perthes (1906)[33] described the use of suture anchors and later on, Codman (1911)[10] described the surgical technique for a rotator cuff repair. To date, this is still considered as one of the landmarks for rotator cuff surgery. In the following period, several techniques were described for open cuff repair, where the transosseous repair was considered to be the gold standard. [11, 13, 14]

In 1990, Levy et al[23] reported the first arthroscopic assisted repair, soon to be followed by the first report of full arthroscopic rotator cuff repair. [35] Since the advent of arthroscopy, with smaller scars, less postoperative pain, fewer complications, and shorter hospital admittance, this minimal invasive technique gained more and more popularity. Since the arthroscopic techniques produce similar functional outcomes this is considered the standard procedure in most centers.

The goal of our study was to report the different rotator cuff repair techniques and results in today's literature and clinical practice: [i] arthroscopic versus arthroscopic assisted rotator cuff repair, [ii] acromioplasty as an additional treatment to rotator cuff repair, [iii] the use of plasma rich platelets (PRP) after rotator cuff repair, [iv] the single and double row fixation techniques, [v] additional treatment of the long head of the biceps brachii with rotator cuff repair, [vi] scaffolds in rotator cuff surgery, and [vii] early rehabilitation or immobilization after repair.

Arthroscopic assisted and all-arthroscopic rotator cuff repair

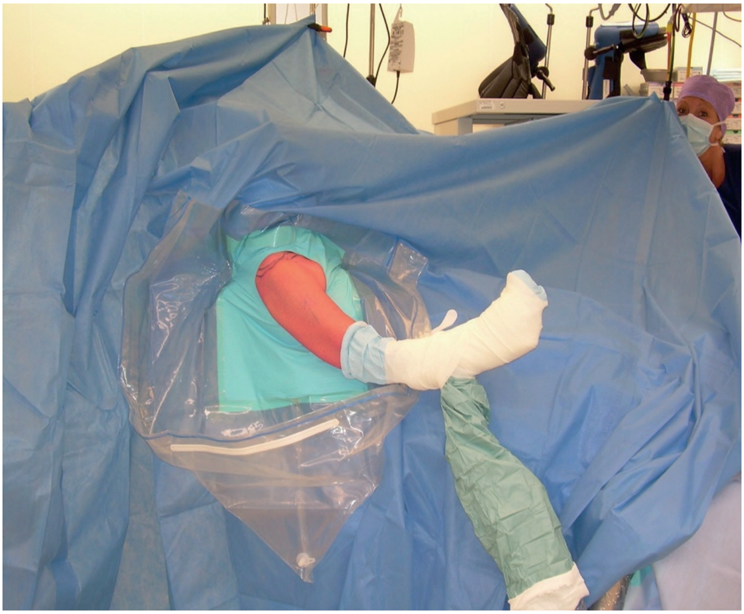
After the introduction of arthroscopy for shoulder surgery, surgeons started to use this technique in addition to the open approach for rotator cuff repair. [18] In order to perform a mini-open repair, a diagnostic arthroscopy and preparation of the rotator cuff and footprint is performed first. After this, the anterosuperior portal is extended by 1-2 cm, and the fibers of the deltoid are split, without detaching the muscle from the acromion. Via this approach, the greater tuberosity can be accessed for the tendon to bone fixation.

Mini-open repair has been regarded the gold standard for rotator cuff repair for decades and it is able to achieve good to excellent results in 90 % of the patients. [4, 30, 31] The all-arthroscopic rotator cuff repair technique was reported shortly after the assisted technique. [30] Decreased post-operative pain in the short term, faster recovery, and better cosmetic results urged many surgeons to prefer an all-arthroscopic approach. [9, 32, 40] Several studies comparing mini-open with arthroscopic repair have been reported and show comparable functional results. [9, 19, 41, 42] Cho et al[9] compared the early clinical outcomes in 60 patients with mini-open rotator cuff repair and all-arthroscopic rotator cuff repair. The only significant finding was less pain in the first days after the all-arthroscopic procedure. It did not support the hypothesis that less pain in the all-arthroscopic treatment allows for earlier recovery of shoulder range of motion.

Another study comparing the early postoperative outcomes between arthroscopic rotator cuff repair and the mini-open technique did not find any clinical differences or differences in the structural integrity of the repair at 1-year follow-up between the two groups. [42] They did report better shoulder-specific outcomes and lesser pain 6 weeks postoperative in the arthroscopy group, therefore patients attaining benefits earlier after the all-arthroscopic procedure. Ji et al recently reported a meta-analysis comparing clinical outcome, surgery time, and range of motion in the early postoperative period between mini-open and arthroscopic rotator cuff repair. The authors included 5 level-1 randomized controlled trials with a total of 166 patients. The analysis revealed no differences in all outcome measures between the two techniques.[18]

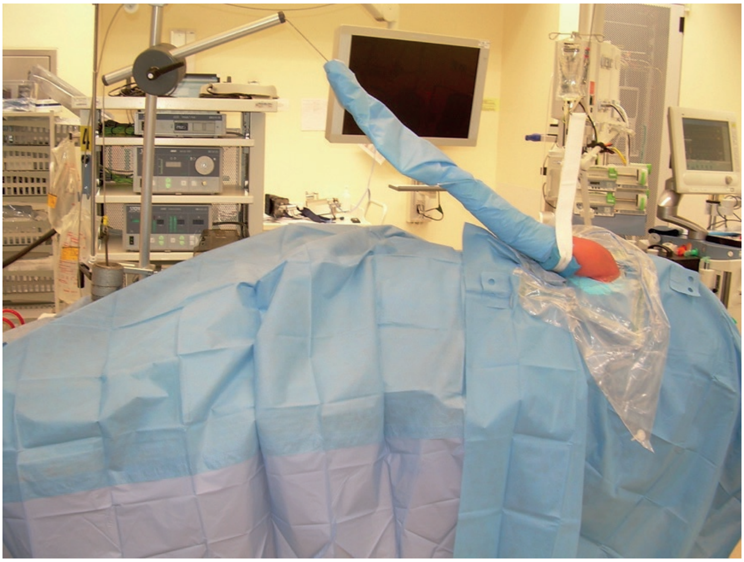
Depending on the preference of the surgeon, rotator cuff repair can be performed in lateral decubitus position or beach chair position. The patient should be placed as close to the edge as possible for the beach chair position (Figure 1). This is performed to gain an unobstructed view of the medial border of the scapular spine. The ulnar and common peroneal nerve are the most commonly injured, therefore these regions should be well-padded and remain free from pressure. The hips are flexed 45 – 60°, with the knee flexed in 30° to relax the sciatic nerve. The non-surgical arm is placed in an arm holder or tucked at the side. With the beach chair position, a mechanical arm is often utilized to fix or change the position of the surgical arm. In the lateral decubitus position, the patient lies on the side with a ridged post system or a beanbag requiring suction (Figure 2). The surgical extremity is placed in a sling and traction is applied longitudinally with weights. An optional abduction traction band can be applied especially useful for the stabilizing procedures. The amount of traction is crucial to allow adequate visualization, however, too much traction should be avoided to minimize brachial plexus nerve injury. An axillary roll is placed under the contralateral axilla to relieve pressure on the plexus. The knee is slightly bent and the fibular head of the lower leg is padded to prevent pressure injuries to the common peroneal nerve. It has been argued that beach chair position provides a better view of the anterior shoulder structures when compared to the lateral decubitus position. Procedures such as arthroscopic shoulder stabilization can be performed more easily in the lateral decubitus position. Whereas capsular releases and rotator cuff repairs are easier performed in the beach chair position.[25] Although rare, patients in the beach chair position might experience cerebral hypoperfusion and complications ranging from cranial nerve injury to infarction.

Figure 1



Beach chair position

Figure 2



Lateral decubitus position

Acromioplasty in addition to rotator cuff repair

Several studies have implicated the anterior acromion in the pathogenesis of what Neer initially described as chronic impingement syndrome. [28] It was hypothesized that excrescence of the acromion could cause rotator cuff impingement leading to injury and tearing of the rotator cuff. [1] Ellman reported the technique for arthroscopic anterior acromioplasty, which clears the anterior acromion spur.[12] Although the theory of performing an additional acromioplasty to a rotator cuff repair promises favorable results, recent randomized controlled studies show no significant benefit of this added procedure.

In a randomized controlled trial by Abrams including 114 patients, no clinical benefit of performing an acromioplasty to a rotator cuff repair was demonstrated 2 years after follow-up. [1] A recent study by Kukkonen reported the clinical outcomes of rotator cuff tears treated with [i] physiotherapy, [ii] physiotherapy and acromioplasty, or [iii] rotator cuff repair, acromioplasty, and physiotherapy. They included 180 shoulders, with 55 shoulders in group 1, 57 in group 2, and 55 in group 3. They did not find significant differences between all the groups at one-year follow-up. [22] A systematic review and meta-analysis by Chahal et al. reported the shoulder-specific outcome measures and re-operation rate with or without additional acromioplasty in arthroscopic rotator cuff repair. [8] They included four level-1 randomized controlled trials with 373 patients and found no significant differences between both groups.

Platelet-rich plasma (PRP) in rotator cuff surgery

Arthroscopic rotator cuff repair is commonly fixed with a single row of anchors. Although good clinical outcomes have been reported with this technique, re-tears are reported. Platelets are thought to contain growth factors and play a role in tissue repair and wound healing. Platelet concentrates have been introduced in rotator cuff surgery to increase tendon-to-bone healing after a repair. [39] Although several studies with favorable results have been reported in chronic foot ulcers, the use of platelet-rich plasma (PRP) in rotator cuff surgery remains uncertain. [39]

A randomized controlled study by Randelli et al with 53 patients reporting clinical outcome and re-tear rate after PRP in arthroscopic rotator cuff repair, only concluded early postoperative benefit. [34] They report less pain in the PRP group when compared to the control group in the early postoperative (30 days) period. At 3 months the clinical outcome measures revealed higher scores in the PRP group, however, no difference was observed at the 6, 12, and 24 months follow-up between both groups. The re-tear rate at 12 months observed with MRI did not show any differences between the PRP group and the control group. In a double-blind randomized controlled trial, Ruiz Monteo et al included 69 patients and performed rotator cuff repairs with and without PRP application. Clinical outcome and re-tear rate, one year after rotator cuff repair were not significantly different between both groups. The authors postulated that PRP is of no benefit in rotator cuff surgery. [37] A recent meta-analysis included 7 randomized controlled trials with 417 shoulders after rotator cuff repair, found no differences in clinical outcome and re-tear rates between the PRP and control group with a minimum follow-up of 12 months. They also concluded no additional benefit of PRP in rotator cuff repair. [24]

Single, double, and triple-row rotator cuff repair

To repair the rotator cuff, a single row anchors or a double row of anchors can be used from medial to lateral. In a single-row repair, the anchors are placed onto the footprint adjacent to the cartilage of the proximal humerus (Figure 3). The sutures are passed through the torn rotator cuff tendon and reattached to the footprint. The single-row technique repair has been the standard since the introduction of arthroscopic rotator cuff repair; even though several studies have reported high re-tear rates and incomplete tendon healing after this type of repair. [5, 24] This led to the double and later the triple row fixation technique. In the double-row technique, two rows of anchors are implanted for tendon repair. The medial row anchors are placed just adjacent to the articular surface of the humeral head and the lateral row anchors, lateral to the footprint of the tendon. The sutures of the medial row are first passed through the torn rotator cuff tendon, thereafter placed as a mattress, and docked in the lateral row, also known as the Suture Bridge technique (Figure 4). This technique aims to enlarge the surface area of contact between the repaired tendon and the greater tuberosity. It is hypothesized that this promotes better ingrowth of the tendon, increased fixation strength, and decreased re-tear rates.

A randomized controlled study conducted in Taiwan comparing single and double-row cuff repair did not show a difference in clinical outcome after two years. [26] Strength was reported to be better in tear sizes >3 cm when repaired with the double row repair. Re-tear rates were similar at 6 months and 2 years after surgery. Another randomized controlled trial by Koh et al compared the clinical outcome and re-tear rate in 71 shoulders between single and double row cuff repair and reported no significant differences at 24 months follow-up.[20]

In contrast to the previous study, Carbonel et al reported a randomized controlled trial with 160 patients and found significantly better clinical outcomes in the double-row rotator cuff repair group when compared to the single-row repair group, at 2 years follow-up. These differences were even more evident in the larger than 30mm tears. Again, the authors found no differences in re-tear rate at the 2-year follow-up with MRI. [7] In 2014, Millett et al presented a meta-analysis including 7 level-I randomized controlled trials reporting re-tear rates and clinical outcomes in single and double row rotator cuff repair. The analysis was performed with 285 patients in the single row group and 282 in the double-row group. The integrity of the cuff was evaluated with MRI or ultrasound. The authors reported a significantly higher rate of tendon healing in patients with double-row fixation. However, this was not associated with superior clinical outcome. [27]

When comparing the results of the single and double row techniques with either the mattress, modified Mason-Allen, or suture bridge technique, a systematic review and meta-analysis by Brown et al reported no differences in the re-tear rate. This study included level 1 to level 4 studies, therefore, their conclusions should be interpreted with caution. [6] A novel study has reported the triple row fixation technique to achieve increased tendon-to-bone contact and subsequently tendon healing. Although this technique might increase tendon healing and decrease re-tear, there are no randomized studies comparing the outcomes of this technique. [29]

Figure 3

Single-row rotator cuff repair

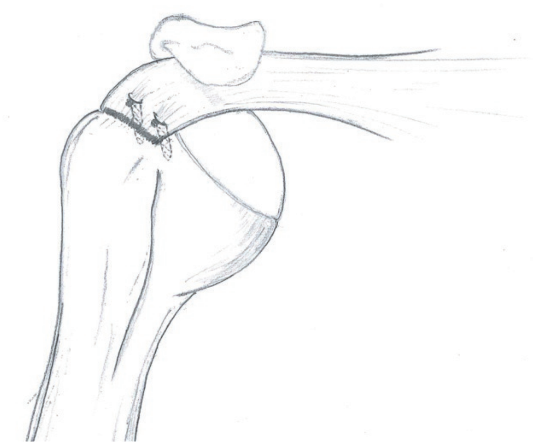


Figure 4

Double-row rotator cuff repair

Additional treatment of the long head of the biceps brachii

Rotator cuff pathology can be associated with tendinopathy of the tendon of the long head of the biceps brachii (LHB). Operative treatment consists of tenotomy or tenodesis of the LHB. Arthroscopic LHB tenotomy is considered a technically low-demanding surgical procedure. This procedure is associated with the occurrence of a post-operative Popeye deformity in the upper arm with temporary muscle cramps in the retracted muscle. LHB tenodesis is a technically more challenging procedure requiring a different rehabilitation period. Arthroscopically, a suture anchor is inserted into the intertubercular groove with the LHB tendon tied down to the anchor. [41] The LHB can also be fixed using the suture anchors implanted for the rotator cuff repair. Many different arthroscopic tenodesis techniques are available for LHB pathology. LHB tendinopathy can also be managed with open subpectoral tenodesis. A 3-4 cm incision is made in the axilla after performing a tenotomy of the LHB at the labrum. The diseased portion is excised, and the remaining tendon is whip-stitched just proximal to the myotendinous junction and docked proximal to the lower border of the pectoralis major.

A recent cohort study with 46 patients and isolated LHB pathology did not find any differences in clinical outcome, popeye deformity, or cramping pain between the arthroscopic suprapectoral and open subpectoral LHB tenodesis. However, they reported that the open procedure might carry a higher complication rate secondary to the more invasive technique. [15] Gurnani et al. conducted a meta-analysis and reported the clinical outcome and popeye deformity after LHB tenotomy and tenodesis with concomitant procedures. They included 9 studies with 650 patients and did not find any significant difference in clinical outcome but did report a significant higher occurrence of a popeye deformity after LHB tenotomy. [16] A recent level 1 randomized controlled trial by Zhang et al reported clinical outcome in 151 patients, undergoing arthroscopic rotator cuff repair with LHB tenotomy or tenodesis. They reported no significant differences in clinical outcome, strength, popeye deformity, cramping pain and satisfaction level at 24 months follow up between the two groups. In favor of the biceps tenotomy group, the authors also reported a shorter surgery time and faster pain relief. [41]

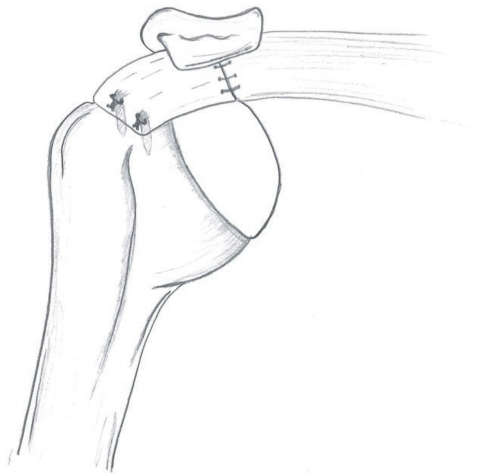
Scaffolds in rotator cuff repair

Another option for rotator cuff repair is the use of scaffold augmentation. [2, 17, 36] Tissue engineering strategies that include the use of scaffolds and growth factors or a combination of both have been designed to improve tendon healing. The rationale for using a scaffold in rotator cuff repair surgery is to increase tendon healing by mechanically off-loading the repair. In addition to this, it has been postulated that biological augmentation leads to an increased healing rate.[2] The scaffolds are surgically attached on top of the repair as an augmentation. However, in the situation of an irreparable rotator cuff tear, the graft or scaffold can be used to bridge the defect between tendon and greater tuberosity (Figure 5).

Currently, 3 types of scaffold devices exist: (1) extracellular matrix (ECM) based scaffolds, (2) synthetic patches, and (3) hybrid scaffolds. ECM scaffolds are obtained either from human, porcine, or bovine dermis, porcine small intestinal submucosa, or equine pericardium. [17] This type of scaffold could assist in the biological repair of the tendon by providing a temporary, collagen-based matrix as a substrate for expected healing of the repaired tendon to bone. The biological properties of the scaffolds could create an unwanted immune response in the host. [3] To provide a scaffold with optimal tensile characteristics, synthetic scaffolds have been manufactured using poly-L-lactic acid and polycarbonate substrates. [3] Although these products are made from non-bio-degradable polymers, in-vivo degradation has been observed. [17] In turn, these scaffolds could be associated with a chronic or foreign body immune response. These newly manufactured scaffolds are being developed to improve host response to the implant and increase mechanical properties, the main concern remains the lack of well-documented human studies, and only a few describing complications and adverse events.[3]

Figure 5

Scaffold for bridging large rotator cuff tears



Immobilization versus early motion

Rotator cuff healing after repair could be affected by the postoperative rehabilitation plan. On one hand, we want the tendon to heal to bone, therefore immobilizing the shoulder. On the other hand, we want the patient to regain a full range of shoulder motion without too much stiffness, therefore, starting shoulder exercises earlier.

A level 1 randomized controlled study investigated the rehabilitation protocol in 124 patients after rotator cuff repair. One group was immobilized for 6 weeks with delayed range of motion exercises, the other group received traditional rehabilitation with early range of motion exercises after rotator cuff repair. They reported a significant better range of motion in the traditional group at 3 months follow up. At final follow-up (24 months) no differences were seen in range of motion, clinical outcome, and re-tear rates.[21] A systematic review and meta-analysis by Shen et al included 3 randomized controlled trials comparing early mobilization with immobilization after rotator cuff repair. A total of 132 shoulders in the early motion and 123 in the immobilization group were included. The early motion group started with passive range of motion on the first day postoperative and the immobilization group was immobilized for 4-6 weeks after surgery. They reported no differences in tendon healing, range of motion, and functional outcome measures between the two regimes. [38] However, the early mobilization group might recover full range of shoulder motion earlier.

CONCLUSION

In the last decades, rotator cuff surgery has developed from open surgery to an all-arthroscopic procedure. Different additional treatments such as acromioplasty, tenotomy or tenodesis of the long head of the biceps, and augmentation with PRP have been described. Clinical outcome, however, does not seem to increase with the different concomitant procedures with rotator cuff repair. Early passive range of motion or immobilization after cuff repair does not seem to affect clinical outcome or failure rate of the repair. Scaffolds still exhibit a problematic immune response and have not been reported sufficiently in human trials. Advanced suture fixation techniques have been designed to decrease re-tear rates. Thus far, they might have superior clinical outcomes and better healing rates.

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3

Shoulder-specific outcomes 1 year after nontraumatic full-thickness rotator cuff repair: a systematic literature review and meta-analysis

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ABSTRACT

Background
Non-traumatic full thickness rotator cuff tears are commonly initially treated conservatively. If conservative treatment fails, rotator cuff repair is a viable subsequent option. The objective of the present meta-analysis is to evaluate the shoulder specific outcomes one year after arthroscopic or mini-open rotator cuff repair of non-traumatic rotator cuff tears.

Methods
A literature search was conducted in PubMed and EMBASE in the period January 2000 to January 2017. All studies measuring the clinical outcome at 12 months after non-traumatic rotator cuff repair of full thickness RCTs were listed.

Results
We included 16 randomized controlled trials that met our inclusion criteria with a total of 1.221 shoulders. At 12 months after rotator cuff repair the mean Constant score had increased 29.5 points; the mean American Shoulder and Elbow Score increased by 38.6 points; mean Simple Shoulder Test score increased by 5.6 points; mean University of California Los Angeles score improved by 13.0 points and finally, mean Visual Analogue Scale score decreased by 4.1 points.

Conclusion
Based on this meta-analysis, significant improvements in the shoulder specific indices are observed 12 months after non-traumatic arthroscopic or mini-open rotator cuff repair.

Keywords
Rotator cuff repair, rotator cuff tear, quality of life, shoulder specific outcome

MATERIALS AND METHODS

Data sources and searches

A literature search was performed using PubMed and EMBASE databases from January 2000 to January 2017. This period was chosen to include the most recent operative techniques. 1238 unique articles were found using the search terms listed in the appendix. This search was developed and performed with the assistance of medical research librarians. To be as inclusive as possible, a large number of terms were included in the search string, including Medical Subject Headings (MeSH), outcomes of interest, and study design. In addition, review articles and book chapters related to rotator cuff repair were identified within the search results, and all references from these sources were manually evaluated for potential inclusion. All references of articles meeting the inclusion criteria were similarly examined.

Study selection

To evaluate the highest quality of the available literature only randomized controlled trials were included. Only trials studying interventions according to today's consensus that do not influence the clinical results were included. This was to prevent inclusion of those patients treated with an inferior cuff repair. We included one study, that compared arthroscopic with mini-open full thickness rotator cuff repair.[32] Some authors have compared rotator cuff repair with additional treatments in the shoulder region, such as acromioplasty or augmentation with platelet rich plasma.[1, 7, 10, 12–14, 17, 21, 22, 24, 26] Others have compared single row to the double row fixation method for RCTs.[5,19] Finally, postoperative rehabilitation programs are compared.[15] This was conducted to increase the focus on the common treatment of rotator cuff repair.

Inclusion criteria for articles identified by the search were: (i) inclusion of patients who underwent non-traumatic full-thickness primary rotator cuff repair performed arthroscopically or with a mini-open procedure. Because of the increasing tendency of performing arthroscopic or mini-open cuff repair, we did not include studies reporting outcomes after open rotator cuff repair; (ii) surgical indication specified with a pre-operative full-thickness rotator cuff tear without glenohumeral arthritis; (iii) comparative studies were included (with or without acromioplasty, with or without augmentation with platelet rich plasma, single row or double row fixation technique and arthroscopic or mini-open procedure); (iv) reported at least one of the following shoulder specific outcome indices pre- and postoperatively; Constant score[8], American shoulder and Elbow score (ASES)[25], Simple Shoulder Test (SST)[20], Visual Analogue Scale (VAS) [30] or University of California Los Angeles score (UCLA) score,[3] (v) studies reporting their outcomes at 12 months follow-up with mean and standard deviation. No studies were excluded on the basis of patient characteristics, including age, sex, race/ethnicity, socio-economic status, tear size if repairable, or comorbidity. Studies were excluded if (i) there were 10 or fewer patients; (ii) it contained irreparable or partial thickness rotator cuff tears; (iii) traumatic cuff tears; (iv) 12 month follow up outcome indices not reported; (v) data presented were duplicative with those of previous publication; or the report was not in the English language. All inclusion and exclusion criteria were reviewed by two orthopedic surgeons specialized in shoulders. All articles identified with the search strategy were evaluated for inclusion by the lead author.

Data extraction and evidence assessment

Information of each study, including publication year, study location, and method of patient selection was assessed. Number of patients, attrition, preoperative and postoperative shoulder specific outcome indices with mean and standard deviation, preoperative diagnosis of a full thickness rotator cuff repair, average follow-up, patient demographics and funding source were abstracted. The significance of any study findings was reported, as were any references of surgical techniques used. Sources of potential bias with patient selection were recorded. In many cases, the authors of the studies did not detail complications according to the specific patient group, so it was not possible to accurately characterize complications beyond their effect on aggregate shoulder specific outcome indices as reported for each patient group.

Data synthesis and analysis

All analyses were performed with use of meta-analysis software (Review Manager 5.1, Cochrane Collaboration, London, UK). The number of included shoulders was used as the group size (n) for each study, as the number of patients was less frequently reported for the specific treatment groups. All shoulder specific indices were treated with continuous variables, and Cohen's d was used to estimate effect size from individual studies. For each index, the chi square test statistic for heterogeneity was calculated. Random effects models were used for this meta-analysis because of the observed heterogeneity in the collected data. Forest plots were generated for each outcome index, displaying individual mean differences (MD) and corresponding 95% confidence intervals (CIs), individual study weights, and overall summary effect size. P values were required to be ≤ 0.05 to indicate significance.

RESULTS

Data source and selection

Of the initial 1238 selected studies, 16 studies met the inclusion criteria with 1221 shoulders (Table 1) were included (Figure 1). Although the period of our search started in 2000, the first published study that met our inclusion criteria is dated 2009. In 7 studies comprising 476 shoulders; shoulder specific indices were reported after rotator cuff repair with or without augmentation with platelet rich plasma (PRP).[7, 12–14, 21, 24, 26] Four studies with 351 shoulders comparing rotator cuff repair with or without acromioplasty.[1, 10, 22, 28] One study with 55 shoulders comparing physiotherapy alone, acromioplasty and physiotherapy, or rotator cuff repair with acromioplasty and physiotherapy;[17] two with 130 shoulders comparing the single row and double row fixation techniques;[5, 19] one with 95 shoulders comparing the mini-open with arthroscopic cuff repair; [32] and one with 114 shoulders comparing the early with delayed rehabilitation procedure.[15] Baseline characteristics (age, gender, shoulder-specific indexes) did not differ between the two or three comparative groups in each included study. All the authors of the included studies found no clinically significant difference at final follow-up between the compared rotator cuff repair groups. We extracted the shoulder specific indices reported at 12 months after rotator cuff repair. We also included 1 article with a mean follow up of 16 months. [7]

Shoulder-specific indices (Table 2)

In 13 studies on a total of 912 shoulders, the outcome was reported using the Constant score (Figure 2). A significant increase of 29.5 points ($p < 0.001$, 95% CI= 25.7 – 33.3) at 12 months after rotator cuff repair was observed. Nine studies with a total of 734 shoulders reported outcomes using the ASES score (Figure 3). Significant improvements were observed after rotator cuff repair with a mean increase of 38.6 points ($p < 0.001$, 95% CI= 36.4-40.9). In six articles the SST score was reported for 474 shoulders (Figure 4), which also showed a significant increase of 5.6 points ($p < 0.001$, 95% CI 5.1-6.2). Six studies reported outcome using the UCLA score for 436 shoulders (Figure 5), revealing a significant mean increase of 13.0 points ($p < 0.001$, 95% CI 10.3-15.6). Finally, the VAS score was reported in 6 studies on 386 shoulders. A significant mean decrease of 4.1 points (SMD= $p < 0.001$, 95% CI -4.6, -3.5) was seen after repair (Figure 6).

Figure 1 Summary of the systematic review process

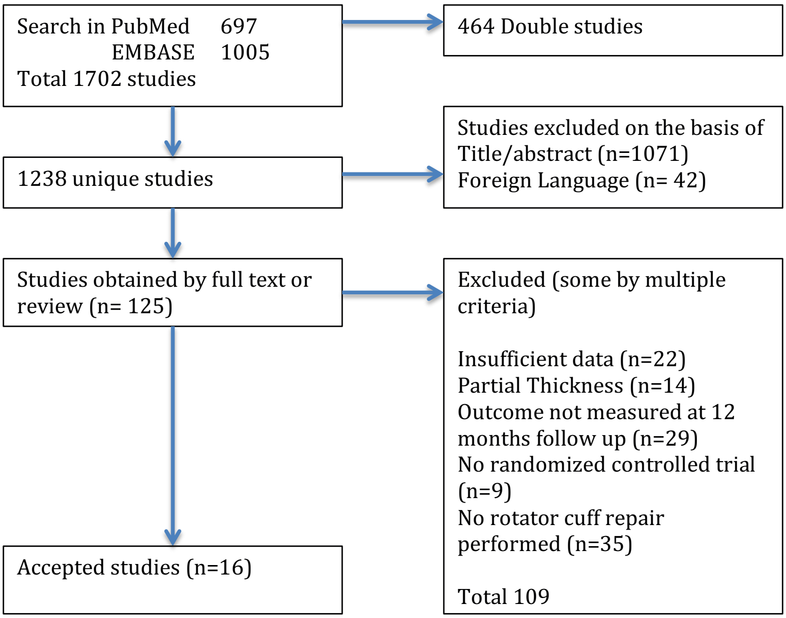


Table 1 Study Characteristics

Author(year)	Study	Number of patients	Follow-up	Outcome
Jo (2015)	Arthroscopic cuff repair, full thickness, PRP versus no PRP	37 PRP 37 No PRP	12 Months	Constant Score, SST, ASES, UCLA,VAS
Malavolta (3014)	Arthroscopic cuff repair, full thickness, PRP versus no PRP	27 PRP 27 No PRP	12 Months	Constant Score, UCLA, VAS
Abrams (2014)	Arthroscopic cuff repair, full thickness with or without acromioplasty	43 Nonacromioplasty 52 Acromioplasty	12 Months	Constant Score, SST, ASES, UCLA
Kukkonen (2014)	Physiotherapy versus acromioplasty versus cuff repair for full thickness rotator cuff tears	55 Cuff repair	12 Months	Constant Score
Keener (2014)	Arthroscopic cuff repair, full thickness, early mobilization versus delayed	61 Early 53 Delayed	12 Months	SST, ASES, VAS
Jo (2013)	Arthroscopic cuff repair, full thickness, PRP versus no PRP	24 PRP 24 No PRP	12 Months	Constant Score, SST, ASES, UCLA
Van der Zwaal (2013)	Arthroscopic versus mini open rotator cuff repair, full thickness	47 Arthroscopic repair 48 Mini open	12 Months	Constant Score, VAS

Table 1 Continued

Author(year)	Study	Number of patients	Follow-up	Outcome
Lapner (2012)	Arthroscopic cuff repair, Full thickness, single row versus double row	48 Single row 42 Double row	12 Months	Constant Score, ASES
Shin (2012)	Arthroscopic cuff repair, Full thickness, with or without acromioplasty	60 Nonacromioplasty 60 Acromioplasty	12 Months	Constant Score, ASES, UCLA, VAS
Gumina (2012)	Arthroscopic cuff repair, full thickness, with or without leukocyte platelet membrane	40 PRP membrane 40 No PRP membrane	12 Months	Constant Score, SST
Rodeo (2012)	Arthroscopic cuff repair, Full Thickness, with or without PRP	40 PRP 39 No PRP	12 Months	ASES
Castricini (2011)	Arthroscopic cuff repair, full thickness with or without platelet rich plasma	43 PRP 45 No PRP	16 Months	Constant Score
Dezaly (2011)	Arthroscopic cuff repair versus acromioplasty, full thickness tears	68 Cuff repair	12 Months	Constant Score
MacDonald (2011)	Arthroscopic cuff repair, Full thickness, with or without acromioplasty	36 Nonacromioplasty 32 Acromioplasty	12 Months	ASES
Randelli (2011)	Arthroscopic cuff repair, Full Thickness, PRP versus not PRP	26 PRP 27 No PRP	12 Months	Constant Score, SST, UCLA
Burks (2009)	Arthroscopic cuff repair, full thickness, single row versus double row	20 Single row 20 Double row	12 Months	Constant Score, ASES, UCLA

PRP, Platelet Rich Plasma; ASES, American Shoulder and Elbow score; SST, Simple Shoulder Test; UCLA, University of California of Los Angeles; VAS, Visual Analogue Score

Table 2 Results

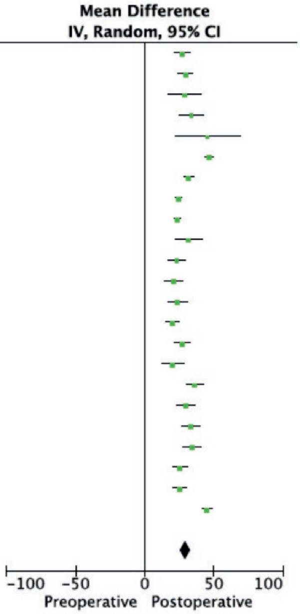
Shoulder specific outcome	Included studies	Shoulders	Mean difference	P value	95 % CI
Constant score	13	912	29.5	<0.001	25.7 - 33.3
ASES	9	734	38.6	<0.001	36.4 - 40.9
SST	6	474	5.6	<0.001	5.1 – 6.2
UCLA score	6	436	13.0	<0.001	10.3 -15.6
VAS	6	386	- 4.1	<0.001	-4.6,- 3.5

ASES American Shoulder and Elbow score
SST Simple Shoulder Test
UCLA University of California of Los Angeles
VAS Visual Analogue Score
SMD Standardized Mean Difference
CI Confidence Interval

Figure 2 Meta-analysis Constant score

Study or Subgroup	Postoperative Mean	SD	Total	Preoperative Mean	SD	Total	Weight	Mean Difference IV, Random, 95% CI
Abrams (2014) (1)	79	12.5	52	51.9	17.2	52	4.5%	27.10 [21.32, 32.88]
Abrams (2014) (2)	77.8	6.2	43	48.3	17.1	43	4.6%	29.50 [24.06, 34.94]
Burks (2009) (3)	74.4	18.4	20	45.6	20.3	20	3.4%	28.80 [16.79, 40.81]
Burks (2009) (4)	77.8	9	20	44.1	18.8	20	3.9%	33.70 [24.57, 42.83]
Castricini (2011) (5)	88.4	79	43	42.9	7.9	43	1.7%	45.50 [21.77, 69.23]
Castricini (2011) (6)	88.4	7.6	45	42	6.7	45	4.9%	46.40 [43.44, 49.36]
Dezaly (2011)	75.8	10	68	44	12.1	68	4.8%	31.80 [28.07, 35.53]
Gumina (2012) (7)	74.2	6.1	40	50.1	3.7	40	5.0%	24.10 [21.89, 26.31]
Gumina (2012) (8)	77.9	5.7	40	54.3	4.1	40	5.0%	23.60 [21.42, 25.78]
Jo (2013) (9)	74.8	14.3	24	43	18.8	24	3.9%	31.80 [22.35, 41.25]
Jo (2013) (10)	69.8	16.3	24	46.7	2.2	24	4.4%	23.10 [16.52, 29.68]
Jo (2015) (11)	74.7	9.2	37	53.8	17.9	37	4.4%	20.90 [14.42, 27.38]
Jo (2015) (12)	70.9	9.8	37	47.2	20.3	37	4.3%	23.70 [16.44, 30.96]
Kukkonen (2014)	77.9	12.2	55	58.1	13.2	55	4.7%	19.80 [15.05, 24.55]
Lapner (2012) (13)	81.9	13.5	48	55.1	15	48	4.6%	26.80 [21.09, 32.51]
Lapner (2012) (14)	78.5	18.6	42	58.2	19.2	42	4.1%	20.30 [12.22, 28.38]
Malavolta (2014) (15)	83.3	11.1	27	47	11.9	27	4.5%	36.30 [30.16, 42.44]
Malavolta (2014) (16)	76.9	13.2	27	47.4	12	27	4.4%	29.50 [22.77, 36.23]
Randelli (2011) (17)	75.7	9.5	27	42.2	15.2	27	4.4%	33.50 [26.74, 40.26]
Randelli (2011) (18)	78.3	6.4	26	44	16.5	26	4.4%	34.30 [27.50, 41.10]
Shin (2012) (19)	82.3	12.2	60	56.8	17.6	60	4.6%	25.50 [20.08, 30.92]
Shin (2012) (20)	83.9	11.3	60	58.3	15.8	60	4.7%	25.60 [20.68, 30.52]
Van der Zwaal (2013)	87	1.8	47	42	12	47	4.9%	45.00 [41.53, 48.47]
Total (95% CI)			**912**			**912**	**100.0%**	**29.48 [25.68, 33.29]**

Heterogeneity: $Tau^2 = 74.28$; $Chi^2 = 305.15$, df = 22 ($P < 0.00001$); $I^2 = 93\%$
Test for overall effect: Z = 15.19 ($P < 0.00001$)

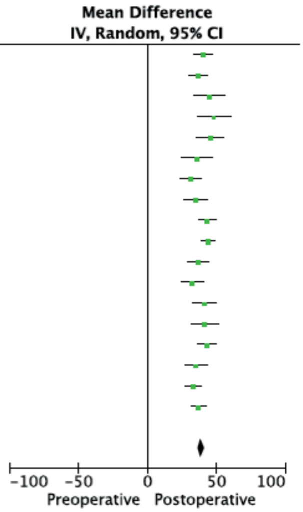


(1) Acromioplasty
(2) Nonacromioplasty
(3) Double row
(4) Single row
(5) PRP
(6) Non PRP
(7) Non PRP
(8) PRP
(9) PRP
(10) Non PRP
(11) PRP
(12) Non PRP
(13) Single row
(14) Double row
(15) PRP
(16) Non PRP
(17) Non PRP
(18) PRP
(19) Nonacromioplasty
(20) Acromioplasty

Figure 3 Meta-analysis ASES score

Study or Subgroup	Postoperative Mean	Postoperative SD	Postoperative Total	Preoperative Mean	Preoperative SD	Preoperative Total	Weight	Mean Difference IV, Random, 95% CI
Abrams (2014) (1)	89	16.4	52	48.8	18.2	52	6.7%	40.20 [33.54, 46.86]
Abrams (2014) (2)	91.5	13.3	43	55.1	19.1	43	6.3%	36.40 [29.44, 43.36]
Burks (2009) (3)	85.9	14	20	41	21.5	20	3.1%	44.90 [33.66, 56.14]
Burks (2009) (4)	85.5	20	20	37.6	19.3	20	2.8%	47.90 [35.72, 60.08]
Jo (2013) (5)	88.9	13.6	24	43.5	20.6	24	3.9%	45.40 [35.52, 55.28]
Jo (2013) (6)	85.6	17.3	24	50.1	22.6	24	3.1%	35.50 [24.11, 46.89]
Jo (2015) (7)	88	13.1	37	56.8	18.8	37	5.8%	31.20 [23.82, 38.58]
Jo (2015) (8)	83.7	14.6	37	48.9	21.9	37	4.8%	34.80 [26.32, 43.28]
Keener (2014) (9)	89.1	14.1	59	45.9	20.3	59	7.1%	43.20 [36.89, 49.51]
Keener (2014) (10)	88.1	15.8	65	44.2	14.5	65	8.7%	43.90 [38.69, 49.11]
Lapner (2012) (11)	84.4	18.7	48	47.8	17.6	48	6.0%	36.60 [29.34, 43.86]
Lapner (2012) (12)	86.5	17.1	42	54	19	42	5.5%	32.50 [24.77, 40.23]
MacDonald (2011) (13)	85	18.1	27	44	18	40	4.6%	41.00 [32.18, 49.82]
MacDonald (2011) (14)	86.6	19.1	26	45.2	21.4	37	3.8%	41.40 [31.33, 51.47]
Rodeo (2012) (15)	96.4	5.6	22	53.7	18.4	34	6.7%	42.70 [36.09, 49.31]
Rodeo (2012) (16)	91.3	9.53	19	56.2	18.9	32	5.4%	35.10 [27.27, 42.93]
Shin (2012) (17)	84.6	16.4	60	51.5	16.9	60	7.6%	33.10 [27.14, 39.06]
Shin (2012) (18)	89.3	11.2	60	52.6	18.5	60	8.3%	36.70 [31.23, 42.17]
Total (95% CI)			**685**			**734**	**100.0%**	**38.63 [36.42, 40.85]**

Heterogeneity: $Tau^2 = 7.67$; $Chi^2 = 26.05$, df = 17 ($P = 0.07$); $I^2 = 35\%$
Test for overall effect: $Z = 34.17$ ($P < 0.00001$)

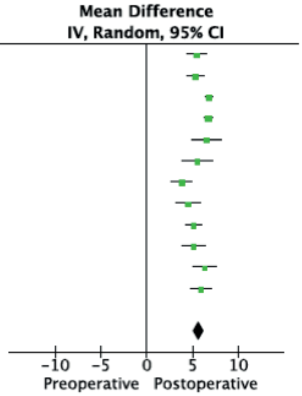


(1) Acromioplasty
(2) Nonacromioplasty
(3) Single Row
(4) Double Row
(5) PRP
(6) Non PRP
(7) PRP
(8) Non PRP
(9) Immobilization
(10) Traditional Rehabilitation
(11) Singe row
(12) Double row
(13) Nonacriomioplasty
(14) Acromioplasty
(15) Non PRP
(16) PRP
(17) Nonacromioplasty
(18) Acromioplasty

Figure 4 Meta-analysis SST score

Study or Subgroup	Postoperative Mean	Postoperative SD	Postoperative Total	Preoperative Mean	Preoperative SD	Preoperative Total	Weight	Mean Difference IV, Random, 95% CI
Abrams (2014) (1)	10.5	2.1	43	5.1	3	43	8.3%	5.40 [4.31, 6.49]
Abrams (2014) (2)	10.5	2.3	52	5.2	2.6	52	9.0%	5.30 [4.36, 6.24]
Gumina (2012) (3)	10.5	0.8	40	3.7	1	40	11.3%	6.80 [6.40, 7.20]
Gumina (2012) (4)	10.1	1	40	3.4	1	40	11.2%	6.70 [6.26, 7.14]
Jo (2013) (5)	10.3	2.3	24	3.8	3.3	24	6.2%	6.50 [4.89, 8.11]
Jo (2013) (6)	9.9	2.8	24	4.4	3	24	6.0%	5.50 [3.86, 7.14]
Jo (2015) (7)	10.2	2.1	37	6.4	2.9	37	8.1%	3.80 [2.65, 4.95]
Jo (2015) (8)	9.8	2.3	37	5.3	3.6	37	7.1%	4.50 [3.12, 5.88]
Keener (2014) (9)	10.3	2.3	65	5.2	2.5	65	9.6%	5.10 [4.27, 5.93]
Keener (2014) (10)	10	3.1	59	4.9	3.6	59	7.8%	5.10 [3.89, 6.31]
Randelli (2011) (11)	11.1	0.9	26	4.8	3.1	26	7.7%	6.30 [5.06, 7.54]
Randelli (2011) (12)	10.6	1.5	27	4.7	2.8	27	7.9%	5.90 [4.70, 7.10]
Total (95% CI)			**474**			**474**	**100.0%**	**5.63 [5.06, 6.21]**

Heterogeneity: $Tau^2 = 0.72$; $Chi^2 = 52.81$, df = 11 ($P < 0.00001$); $I^2 = 79\%$
Test for overall effect: $Z = 19.23$ ($P < 0.00001$)

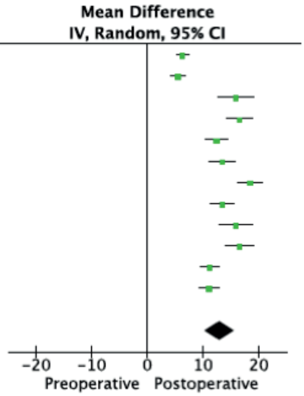


(1) Nonacromioplasty
(2) Acromioplasty
(3) PRP
(4) Non PRP
(5) PRP
(6) Non PRP
(7) PRP
(8) PRP
(9) Traditional Rehabilitation
(10) Immobilization
(11) PRP
(12) Non PRP

Figure 5 Meta-analysis UCLA score

Study or Subgroup	Postoperative Mean	Postoperative SD	Postoperative Total	Preoperative Mean	Preoperative SD	Preoperative Total	Weight	Mean Difference IV, Random, 95% CI
Abrams (2014) (1)	18.1	2.5	43	11.8	2.8	43	8.7%	6.30 [5.18, 7.42]
Abrams (2014) (2)	16.2	3.5	52	10.7	2.9	52	8.7%	5.50 [4.26, 6.74]
Burks (2009) (3)	29.5	5.6	20	13.6	4.6	20	7.8%	15.90 [12.72, 19.08]
Burks (2009) (4)	28.6	3.6	20	12.1	3.9	20	8.3%	16.50 [14.17, 18.83]
Jo (2015) (5)	30.7	4.2	37	18.3	5	37	8.4%	12.40 [10.30, 14.50]
Jo (2015) (6)	29.5	4.9	37	16.1	5.2	37	8.3%	13.40 [11.10, 15.70]
Malavolta (2014) (7)	32.3	3.5	27	13.9	4.6	27	8.3%	18.40 [16.22, 20.58]
Malavolta (2014) (8)	30	4.5	27	16.6	3.6	27	8.3%	13.40 [11.23, 15.57]
Randelli (2011) (9)	31.2	5.2	26	15.3	5.9	26	7.9%	15.90 [12.88, 18.92]
Randelli (2011) (10)	31	4.1	27	14.5	5.6	27	8.1%	16.50 [13.88, 19.12]
Shin (2012) (11)	30.1	4.5	60	18.9	4.5	60	8.6%	11.20 [9.59, 12.81]
Shin (2012) (12)	30.8	4.1	60	19.7	5.8	60	8.5%	11.10 [9.30, 12.90]
Total (95% CI)			**436**			**436**	**100.0%**	**12.95 [10.31, 15.59]**

Heterogeneity: $Tau^2 = 20.50$; $Chi^2 = 253.47$, df = 11 ($P < 0.00001$); $I^2 = 96\%$
Test for overall effect: $Z = 9.61$ ($P < 0.00001$)

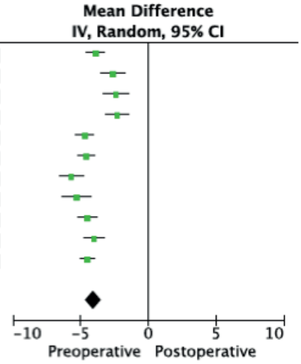


(1) Nonacromioplasty
(2) Nonacromioplasty
(3) Double row
(4) Single row
(5) PRP
(6) Non PRP
(7) PRP
(8) Non PRP
(9) PRP
(10) Non PRP
(11) Acromioplasty
(12) Nonacromioplasty

Figure 6 Meta-analysis VAS score

Study or Subgroup	Postoperative Mean	Postoperative SD	Postoperative Total	Preoperative Mean	Preoperative SD	Preoperative Total	Weight	Mean Difference IV, Random, 95% CI
Abrams (2014) (1)	0.5	0.9	52	4.4	2.3	52	9.5%	−3.90 [−4.57, −3.23]
Abrams (2014) (2)	1.2	1.6	43	3.8	2.5	43	8.7%	−2.60 [−3.49, −1.71]
Jo (2015) (3)	0.8	1.2	37	3.2	2.7	37	8.4%	−2.40 [−3.35, −1.45]
Jo (2015) (4)	0.9	1.6	37	3.2	2.1	37	8.8%	−2.30 [−3.15, −1.45]
Keener (2014) (5)	0.9	1.2	59	5.6	2.3	59	9.6%	−4.70 [−5.36, −4.04]
Keener (2014) (6)	1.1	1.7	65	5.7	1.8	65	9.8%	−4.60 [−5.20, −4.00]
Malavolta (2014) (7)	1	1.8	27	6.7	1.6	27	8.6%	−5.70 [−6.61, −4.79]
Malavolta (2014) (8)	1.7	2.1	27	7	1.9	27	8.0%	−5.30 [−6.37, −4.23]
Shin (2012) (9)	1	1.3	60	5.5	2.4	60	9.4%	−4.50 [−5.19, −3.81]
Shin (2012) (10)	1.5	1.9	60	5.5	2.4	60	9.1%	−4.00 [−4.77, −3.23]
Van der Zwaal (2013)	2.4	0.2	47	6.9	1.8	47	10.0%	−4.50 [−5.02, −3.98]
Total (95% CI)			**514**			**514**	**100.0%**	**−4.06 [−4.64, −3.48]**

Heterogeneity: $Tau^2 = 0.80$; $Chi^2 = 66.72$, df = 10 ($P < 0.00001$); $I^2 = 85\%$
Test for overall effect: Z = 13.70 ($P < 0.00001$)



(1) Acromioplasty
(2) Nonacromioplasty
(3) Non PRP
(4) PRP
(5) Immobilization
(6) Tradional Rehabilitation
(7) PRP
(8) Non PRP
(9) Acromioplasty
(10) Nonacromioplasty

DISCUSSION

The objective of this meta-analysis was to evaluate the improvement of the shoulder-specific quality of life after one year following non-traumatic arthroscopic or mini-open repair of a full-thickness rotator tear. Based on this study, a repair of a non-traumatic full thickness RCT demonstrated to be a highly effective intervention in all the shoulder specific indices.

The strong points of this study according to the Preferred Reporting Items for Systematic Reviews and Meta-Analysis (PRISMA) guidelines are the inclusion of only randomized studies based on a strictly defined systematic search of the literature in the commonly used databases. This thorough search was developed and performed with the assistance of medical research librarians.

Limitations of the current meta-analysis are that several randomized controlled trials did not report a standard deviation but only confidence intervals, so these trials could not be included in the current meta-analysis. Assessment was performed focusing on the indices 12 months after repair. Some studies also or only reported the indices at 6 months or at 2-year follow-up. Only data reported at 12 months were extracted and used in this study. Because shoulder outcome can still increase 6 months after rotator cuff repair and mostly stabilizes after 12 months, we did not include studies if not reporting the indices at 12 months in the current analysis. Due to the heterogeneity of the included trials, the conclusions of this meta-analysis are not generalizable to the whole population. A potential limitation in generalizing these results to all mini-open and arthroscopic cuff repair procedures, is that hospital volume, surgeon volume, and experience have an effect on outcome. Although the results of this analysis show good results of rotator cuff repair after one year, it remains unclear if the positive effect carries through on the long-term (>1 year). According to the title this meta-analysis focuses on the shoulder specific indices, pooling of more general outcome measures such as SF12, SF 36, and EuroQoL was not possible because of poor reporting.

The ASES score has been reported to be reliable, valid and responsive, with a minimal clinically important difference of 6.4 points.[27] The mean improvement in the ASES score found in this meta-analysis was 38.6 points, which is a major improvement. The SST has been shown to have discriminant construct validity, to be reproducible, and to be responsive to changes in shoulder function after intervention. [11, 27] In non-operative treatment of rotator cuff disease a minimal clinically important difference was seen of 2 points, [30] whereas we found a mean increase of 5.6. Although we did not find any specific validation and reliability of the UCLA score for rotator cuff disease, it is widely used in studies to determine shoulder outcome. More than 50 percent of the scale is based on pain relief, passive motion and patient satisfaction and designed for shoulder arthroplasty.[3] Although a fair correlation between the UCLA score and Constant score is observed in rotator cuff repair.

Despite the Constant score being one of the widest used scoring systems for shoulder pathology there still exists concern about its validity. Current evidence indicates an excellent responsiveness for different shoulder pathologies except for shoulder instability. [30] Standardization of the range of motion and strength of the Constant score might increase reliability. [4, 29] The minimal clinically important difference for the Constant score is 10 points [18], whereas an increase of 29.5 was observed in the current analysis. One included study reported the relative Constant score, which is a Constant score standardized for age and sex, these data were excluded because the other studies only reported an absolute score. Finally, the VAS score is also used widely in rotator cuff diseases and has a minimal clinically important difference of 1.4 in non-operated shoulders. [30] Other outcome indices were not analyzed due to the insufficient amount of studied shoulders that met our inclusion criteria.

Although with ranging postoperative follow up, repair of full thickness rotator cuff tears have been reported to show failure rates between 25 and 90 percent. [31] Interestingly, several authors have reported shoulder specific outcomes in re-tears after rotator cuff repair showing no difference in clinical outcome. [23, 31] Full thickness rotator cuff tears can also be managed non-operatively with physiotherapy, resulting in good clinical outcomes. [2] This is supported by the results of a multicenter prospective cohort study including 452 shoulders, reporting improvement in the outcomes studied with physiotherapy alone. [16] However, 25 percent was eventually indicated to undergo surgery after a 2-year follow-up. Another randomized controlled trial (n=167) comparing the outcomes after (i) physiotherapy, (ii) acromioplasty and physiotherapy or (iii) cuff repair, acromioplasty and physiotherapy reported no significant differences in Constant score at final follow-up. [17] The risk of treating a rotator cuff tear non-operatively is the possible enlargement of the tear and the development of cuff tear arthropathy (CTA) in the long term. Although the treatment of choice for full thickness rotator cuff tears remains controversial, our results show that operative management results in significant improvement of shoulder-specific outcomes.

A recent large multicenter randomized controlled trial in the United Kingdom compared the effectiveness of arthroscopic with open repair of the rotator cuff. [6] The study included 273 patients (136 arthroscopic and 137 open) treating degenerative tears of the rotator cuff. The Oxford Shoulder Score (OSS) was analyzed with a 2- years follow-up and the integrity of the cuff repair was assessed. The OSS is poorly reported in the current literature for rotator cuff tears, but its uptake is increasing in a number of countries.[9] The OSS did not differ between both groups, neither did the re-tear rate. However, they did report a significant improvement in the OSS, Shoulder Pain and Disability Index (SPADI), EuroQol, Mental Health Inventory (MHI-5) if the rotator cuff was repaired. Although the outcome measures in our meta-analysis are different, our findings of increased shoulder function and decreased pain are similar with that study.

CONCLUSION

The findings of this meta-analysis show a significant increase of all the analyzed shoulder specific indices at 12 months after non-traumatic full thickness rotator cuff repair. Patients with a rotator cuff tear have high pain scores and might have a reduced quality of life with an increased dependency on their caregivers. Rotator cuff repair appears to be an effective intervention in patients with tears. Based on this study we recommend repair in non-traumatic rotator cuff repair if conservative treatment has failed. The relative value of surgical treatment in relation to non-operative treatment with for example physiotherapy cannot be determined based on this study. This comparison is still open for debate for several subgroups and larger multicenter randomized controlled trials, with quality of life and patient reported outcome measures.

APPENDIX

Search terms

Aspect	MeSH	Text	Total
Rotator cuff tears (full)	"Rotator Cuff"[Mesh] OR "Shoulder Joint"[Mesh] OR "Shoulder Impingement Syndrome"[Mesh] "Tendons"[Mesh] OR "Tendon Injuries"[Mesh]	"Rotator Cuff"[All fields] OR "Rotator Cuffs"[All fields] OR "Shoulder Joint"[All fields] OR "Shoulder Joints"[All fields] OR OR "Shoulder Impingement Syndrome"[All fields] "Tendons"[All fields] OR "Tendon"[All fields] RC tear" [tiab] OR "RC tears"[tiab]) RCT[tiab] or RCTs[tiab] or RCT's[tiab]	(("Rotator Cuff"[Mesh] OR "Shoulder Joint"[Mesh] OR "Shoulder Impingement Syndrome"[Mesh] OR "Shoulder Impingement Syndrome"[tiab] OR "Rotator Cuff"[tiab] OR "Rotator Cuffs"[tiab] OR "Shoulder Joint"[tiab] OR "Shoulder Joints"[tiab] OR "RC tear"[tiab] OR "RC tears"[tiab]) OR (("Tendons"[Mesh] OR "Tendon Injuries"[Mesh] OR "Tendons"[tiab] OR "Tendon"[tiab] OR RCT[tiab] or RCTs[tiab] OR rct's[tiab]) AND ("Shoulder Joint"[Mesh] OR "shoulder"[MeSH Terms] OR shoulder[tiab] OR shoulders[tiab])))
Repair	"Wound Healing"[Mesh] OR "Arthroscopy"[Mesh] OR Surgical Procedures, Minimally Invasive"[Mesh]	Repair[all fields] OR Arthroscopic[all fields] OR Arthroscopy[all fields] OR surgery[all fields] OR surgical*[all fields] OR operati*[all fields]	"Wound Healing"[Mesh] OR "Arthroscopy"[Mesh] OR "Surgical Procedures, Minimally Invasive"[Mesh] OR repair[TiAb] OR arthroscopic[TiAb] OR arthroscopy[TiAb] OR surgery[TiAb] OR surgical*[TiAb] OR operation[TiAb] OR operative[TiAb]

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4

Low level of evidence for all treatment modalities for irreparable posterosuperior rotator cuff tears

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ABSTRACT

Purpose

This systematic review assesses evidence for improvements in outcome for all reported types of treatment modalities (physical therapy, tenotomy or tenodesis of the long head of the biceps, debridement, partial repair, subacromial spacer, deltoid flap, muscle transfer, rotator cuff advancement, graft interposition, superior capsular reconstruction (SCR), and reverse shoulder arthroplasty (RSA)) used for irreparable posterosuperior rotator cuff tears without glenohumeral osteoarthritis. The primary aim was to be able to inform patients about expectations of the amount of clinical improvement after these treatments.

Methods

A systematic search was conducted in MEDLINE, EMBASE, CINAHL and Cochrane databases for studies on irreparable posterosuperior rotator cuff lesions without glenohumeral osteoarthritis, published from January 2007 until January 2019, with minimum 2-year follow-up. Studies with preoperative and/or intraoperative determination of cuff tear irreparability were included. We defined the non-adjusted Constant Score as the primary outcome.

Results

Sixty studies (2000 patients) were included with a fair mean quality score, according to the Modified Coleman Methodology Score. The employed definitions of 'irreparable' were mainly based on MRI criteria and were highly variable among studies. The smallest weighted mean pre- to postoperative improvements in Constant Score were reported for biceps tenotomy/tenodesis (10.7 points) and physical therapy (13.0). These were followed by debridement (21.8), and muscle transfer (27.8), whereas the largest increases were reported for partial repair (32.0), subacromial spacer (32.5), rotator cuff advancement (33.2), RSA (34.4), graft reconstruction (35.0), deltoid flap (39.8), and SCR (47.4). Treatment using deltoid flap showed highest mean weighted improvement in Constant Score among studies with available medium-term (4-5 years') follow-up. Treatments deltoid flap, muscle transfer and debridement were the only treatments with available long-term (8-10 years') follow-up and showed similar improvements in Constant Score at this time point.

Conclusion

The variability in patient characteristics, co-interventions, outcome reporting and length of follow-up in studies on irreparable rotator cuff tears without osteoarthritis complicates sound comparison of treatments. Clinically important treatment effects were seen for all 11 different treatment modalities.

Level of Evidence
Level 4

Keywords
Irreparable rotator cuff tear, reverse shoulder arthroplasty, balloon spacer, graft, muscle transfer, superior capsular reconstruction, biceps, partial repair, tuberoplasty, deltoid flap

INTRODUCTION

Chronic massive posterosuperior rotator cuff tears (comprising the supraspinatus and/or infraspinatus tendons, sizing at least 5 cm) are common, represent up to 40% of all rotator cuff tears [88], and often cause major morbidity and disability [37, 57]. Due to progressive fatty infiltration, hypotrophy, adhesions and retraction of the associated muscles over time, conventional rotator cuff repair to the footprint is often not possible. The latter occurs in around 20%-30% of all massive rotator cuff tears [37,44,86].

Intra-operative determination of irreparability is relatively subjective. Yet, pre-operative magnetic resonance imaging (MRI)-based prediction of reparability can even be more difficult [44]. Parameters that are often associated with irreparability include superior humeral migration, grade 3 or 4 fatty infiltration [44] and intra-operative inability to suture the rotator cuff back to the footprint in ≤60 degrees of abduction despite adequate releases [28]. Leaving rotator cuff tears untreated can result in cuff tear arthropathy [20], for which reverse shoulder arthroplasty (RSA) is a widely performed surgical treatment.

Treatment of irreparable posterosuperior rotator cuff tears without glenohumeral osteoarthritis represents a therapeutic challenge and remains a subject of debate [81]. Current treatment options are versatile and include physical therapy, debridement, subacromial spacer, biceps tenotomy or tenodesis, partial repair, graft interposition, superior capsular reconstruction (SCR), deltoid flap, tendon transfer, and RSA. Various case series and reviews of single treatment modalities have been published [21,49,66,71,85]. However, to our knowledge, no systematic review has evaluated all therapeutic options.

This paper aims to systematically review outcomes for all above reported types of treatment modalities used for irreparable posterosuperior rotator cuff tears without glenohumeral osteoarthritis. The primary clinical aim was to be able to inform patients about expectations of the amount of clinical improvement after these treatments. It was hypothesized that physical therapy, tenotomy or tenodesis of the long head of the biceps and debridement showed least gain in functional outcome parameters. The rationale behind this hypothesis was that the basis of the treatments is not to restore the vertical and/or horizontal muscular imbalance caused by the massive cuff tear. Therefore, relatively smaller and shorter-lasting treatment effects were expected compared to other treatments.

MATERIALS AND METHODS

The study protocol was a priori registered at the International Prospective Register of Systematic Reviews (PROSPERO) (http://www.crd.york.ac.uk/), number CRD42017071760. The study was conducted according to the PRISMA guidelines [58].

Study selection

Studies eligible for this systematic review examined non-surgical and surgical treatment of patients with irreparable posterosuperior rotator cuff tears, with or without subscapularis tendon tears. Inclusion criteria were (1) a minimum of 2 years of follow-up for all patients in the study, (2) a minimum of 10 included patients, (3) reported pre-and postoperative patient-reported outcomes, and (4) publication from January 2007 until January 2019. A 12-year time frame was chosen to allow for results of contemporary treatments. The study publication had to explicitly state that the rotator cuff tears were irreparable, as determined pre-operatively and/or intra-operatively. Studies entailing shoulders with Hamada stage 4 or 5 cuff arthropathy [33] were excluded, as the presence of glenohumeral osteoarthritis is an exclusion criterion for this study. No language limits were applied.

Search strategy

A systematic literature search was performed with the help of a medical librarian in MEDLINE, EMBASE, CINAHL and Cochrane databases, using the search terms mentioned in Appendix 1, on January 18th, 2019. The obtained titles and abstracts were independently screened by two reviewers (BK and AW). The full-text papers were examined by one author (B.W.K.) and consensus was reached by discussion with the co-authors. Additionally, the bibliographies of all potentially eligible full-text articles, including those of review papers, were hand-searched.

Study quality assessment

The risk of bias was evaluated using the Modified Coleman Methodology Score (MCMS) [11], which is a 15-item questionnaire scored 0 to 100. Scores of 85 to 100 are considered excellent, 70 to 84 good, 55 to 69 fair, and less than 55 poor. It was designed for quality assessment of surgical studies.

Data collection

Data concerning study design, authors' definition of irreparability, baseline patient details and outcomes were collected in a pre-defined database. The database is enclosed in Appendix 2. In case of missing data, the authors were contacted. When studies also reported data on patients with reparable rotator cuff tears or with Hamada stage 4 or 5 arthropathy, authors were requested to provide data for patients with Hamada stage 1 to 3 only. If these subgroup data could not be presented, the study was excluded.

We categorized investigated treatments into physical therapy (defined as any pre-defined shoulder muscle strengthening regimen), tenotomy or tenodesis of the long head of the biceps, debridement (including tuberoplasty, bursectomy, and/or acromioplasty), partial rotator cuff repair, subacromial spacer, deltoid flap, muscle transfer (including latissimus dorsi transfer, teres major transfer and/or trapezius transfer, excluding pectoralis major transfer), rotator cuff muscular advancement (muscle origins are released in order to repair the insertions), graft interposition (autograft, allograft, or synthetic patches), SCR, and RSA. The potential for conflicts of interest was noted from the conflict of interest statement in each paper.

Outcome measures

All outcome measures reported in the studies were examined. For conciseness of this review paper, it was chosen to report summary measures reported in 10 or more of the included studies. These include the non-adjusted Constant score (scored 0-100 with higher scores indicating better function; minimal clinically important difference (MCID) for rotator cuff lesions: 10.4)[46], the sex- and age-adjusted Constant score, the American Shoulder and Elbow Surgeons (ASES) score (scored 0-100 with higher scores indicating better function; MCID: 12.0)[82], the University of California Los Angeles (UCLA) score (scored 0-35 with higher scores indicating better function; the MCID is unknown)[1], Visual Analogue Scale (VAS) for pain (scored 0-10 with lower scores indicating less pain; MCID: 1.4) [82], Pain sub score from the Constant score (scored 0-15 with higher scores indicating less pain), anterior elevation, abduction, external rotation in adduction, and the percentage of patients rating their result as ‘good’ or ‘excellent’. Additionally, we noted complications, re-operations and radiological outcomes. The non-adjusted Constant score was defined as the primary outcome of interest, as this is a well-validated and widely used outcome measure combining subjective and objective observations.

Statistical analysis

As there was substantial heterogeneity in inclusion criteria for the different interventions studied, a formal meta-analysis was not performed. Rather, the outcomes per treatment were merely summarized. Summary outcomes per treatment are reported as weighted means, that is, the mean improvement of each study weighted by its sample size. For ease of interpretation, we also analyzed outcomes according to reported mean length of follow-up; that is, into short-term follow-up (2 to 3 years), mid-term follow-up (4 to 5 years) and long-term follow-up (8 to 10 years). Agreement between investigators for study selection was reported using Cohen's kappa (κ)[10]. For descriptive statistics of continuous data, we used means and standard deviations (SD).

RESULTS

Study selection and characteristics

Sixty original studies (Figure 1) were included, concerning 11 different treatment categories in a total of 2185 patients with a minimum 2-year follow-up and with a mean age of 63 years (Table 1). The agreement for study selection between investigators was high (κ=0.96).

Risk of bias

One study was level 2, 4 studies were level 3, and 55 studies were level 4. The mean modified Coleman Methodology Score was 56.7 (SD 8.0), corresponding to fair methodological quality (Table 1).

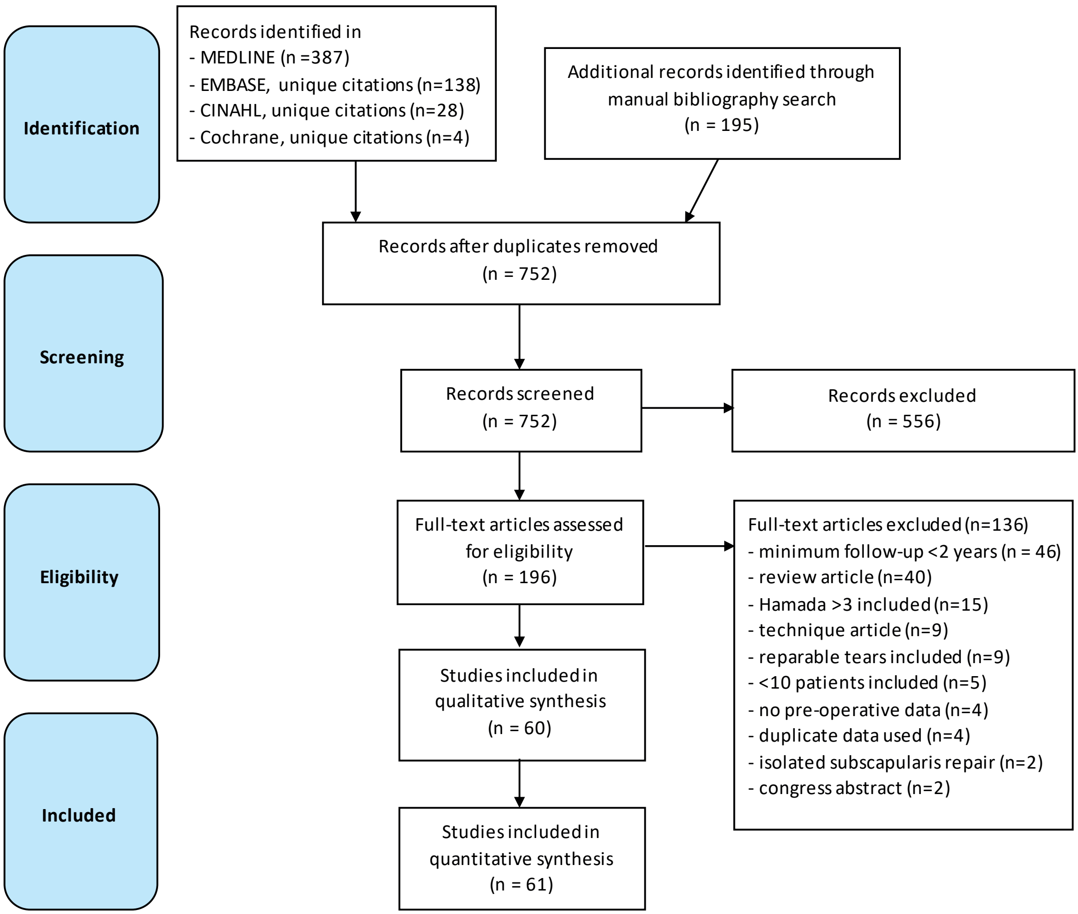
Definitions of rotator cuff irreparability

Table 2 shows the variability of definitions employed in the included studies. Forty-three studies reported an intra-operative confirmation of irreparability as an inclusion criterion and 14 studies used intra-operative confirmation as the only inclusion criterion. The most frequently used pre-operative definition was stage 3 or 4 fatty degeneration on MRI (16 studies).

Indications for surgery

The minimal duration of non-operative treatment prior to surgery varied from 0 months (1 study), to 3 months (7 studies), to 6 months (24 studies). Twenty-eight studies did not report on prior non-operative treatment. Three studies excluded Hamada grade ≥2 arthropathies, 21 studies excluded Hamada grade ≥3 arthropathies, 23 studies excluded Hamada grade ≥4 arthropathies, and 12 studies stated only that osteoarthritis was excluded. Twenty-one studies excluded subscapularis tears (Table 1). Pseudoparalysis was an exclusion criterion in 9 studies and an inclusion criterion in 7 studies. Twelve studies excluded patients who had undergone previous shoulder surgery.

Figure 1. PRISMA chart of study selection process [57]



Outcomes

Appendix 3 shows the reported ranges of pre- to post-operative change in outcome parameters that were most frequently reported (that is, in more than 10 studies) for all treatments. The most frequently reported outcome was the non-adjusted Constant Score (43 studies). The pre- to post-operative changes in mean Constant Score and ASES score are depicted in Figures 2 and 3, respectively.

The smallest weighted mean increases in Constant Score from pre-operative until last follow-up were reported by studies on biceps tenotomy/tenodesis (10.7 points, Table 3) and physical therapy (13.0). These were followed by debridement (21.8), and muscle transfer (27.8), whereas the largest increases were reported for partial repair (32.0), subacromial spacer (32.5), rotator cuff advancement (33.2), RSA (34.4), graft reconstruction (35.0), deltoid flap (39.8), and SCR (47.4). The largest weighted mean improvement in ASES score was reported for SCR (61.6 points).

For treatments with available medium-term (4-5 years') follow-up, mean weighted improvement in Constant Score was highest for deltoid flap (Table 3). For treatments with available long-term (8-10 years') follow-up, this was also highest for deltoid flap.

The most frequently reported radiological outcome was the pre- to postoperative change in the acromiohumeral distance on plain radiographs (21 studies). This change was highly variable among studies and among treatment categories (Table 4).

Table 1. Characteristics of the included studies, per treatment assessed

	Studies (n)	References	Patients with follow -up (n)	Range of mean reported follow-up (months)	Range of mean reported age (years)	Studies excluding subsca- pularis tears (n)	Studies excluding pseudo- paralysis (n)	Mean MCMS (0-100)
Physical therapy	2	[12,90]	58	24	67-74	0	0	54
Biceps	1	[5]	33	35	70	0	0	58
Debridement	4	[38,48,51,69]	156	40-98	62-71	0	3	50
Partial repair	12	[9,14,28-30,59,68, 73,74,78,86 90	467	24-83	58-67	4	3	57
Subacromial spacer	4	[3,76,77,78]	59	24-60	64-71	0	0	57
Deltoid flap	4	[24,32,52,75]	115	41-166	52-62	2	0	58
Muscle transfer	18	[7,13,15,18,19,29,31, 33,36,39,40,41,45, 50,54,62,63,67]	673	26-146	53-67	12	2	57
Rotator cuff advancement	1	[61]	34	33	65	0	0	60
Graft reconstruction	9	[2,26,27,59,60, 65,68,73,84,89]	242	29-54	58-67	3	1	58
SCR	3	[16,55,56]	131	24-60	65-66	0	0	55
RSA	5	[6,22,36,64,87]	232	34-61	59-73	0	0	57
Total	63 a		2200	24-166	52-74	21	9	57

[a] There were 60 studies, of which 3 (comparative) studies comprised 2 cohorts, thus resulting in 63 study cohorts.
Means represent weighted means.
SCR: superior capsular reconstruction; RSA: reverse shoulder arthroplasty; MCMS: modified Coleman methodology score.

Table 2. Definitions of irreparability of posterosuperior cuff tears in the included studies

	MRI criteria				Number of studies
Criteria	**Fatty degeneration (Goutallier/Fuchs)[23]**	**Retraction (Patte)[70]**	**Hypotrophy (Thomazeau)[83]**	**Size**	
MRI	>2	-	-	-	16
	-	3	-	-	6
	>2	3	-	-	4
	>2	3	3	-	3
	4	3	-	-	2
	4	-	-	-	2
	>2	-	3	-	2
	>1	-	-	-	1
	-	-	-	>3 cm	1
	-	-	-	>5 cm	1
Intra-operative only	-	-	-	- - -	14
Not specified	-	-	-	-	8

MRI: magnetic resonance imaging; cm: centimeter.

Figure 2 Longitudinal weighted mean non-adjusted Constant Scores for all treatments

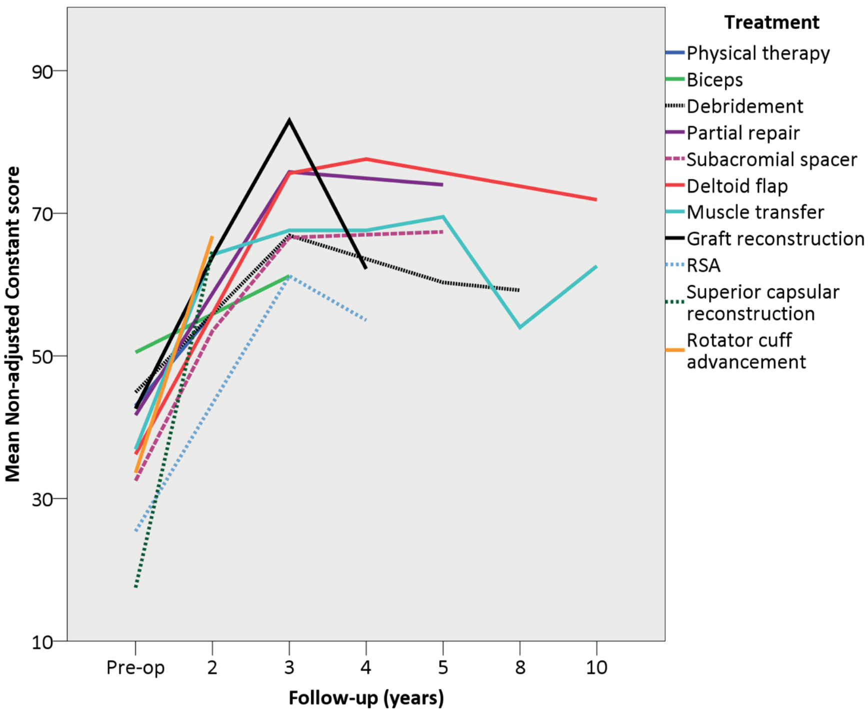


Figure 3 Longitudinal weighted mean ASES scores for all treatments

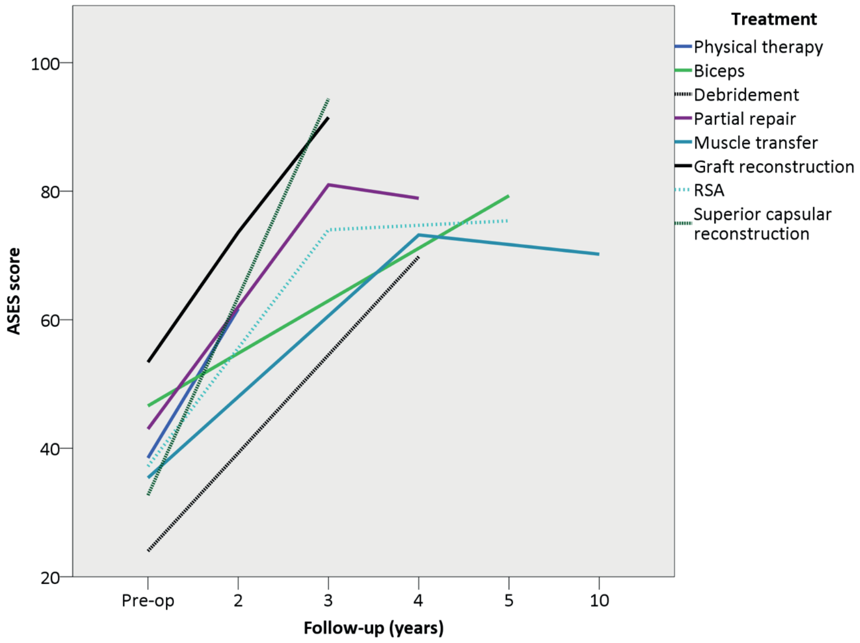


Table 3. Weighted mean pre- to post-operative improvements in Constant Score for all treatments in short-term (2-3 years postoperatively), mid-term (4-5 years postoperatively) and long-term follow-up (8-10 years postoperatively)

	Weighted mean pre- to post-operative improvements in Constant Score			
	2-3 year follow-up	**4-5 year follow-up**	**8-10 year follow-up**	**All follow-ups**
Physical therapy	13.0	NR	NR	13.0
Biceps	10.7	NR	NR	10.7
Debridement	22.0	20.7	19.6	21.8
Partial repair	32.5	31.8	NR	32.0
Subacromial spacer	32.2	33.2	NR	32.5
Deltoid flap	42.4	44.1	22.8	39.8
Muscle transfer	27.8	29.0	18.5	27.8
Rotator cuff advancement	33.2	NR	NR	33.2
Graft reconstruction	36.8	20.7	NR	35.0
SCR	47.4	NR	NR	47.4
RSA	36.2	28.4	NR	34.4

NR: not reported; SCR: superior capsular reconstruction; RSA: reverse shoulder arthroplasty

Table 4. Change in acromiohumeral distance on plain radiographs from preoperative to final follow-up in the 21 studies reporting on this.

		Acromiohumeral distance (millimeters)	
Reference	**Treatment category**	**Preoperative**	**Final follow-up**
[5]	Biceps tenotomy/tenodesis	5.6 (1.7)	4.5 (2.0)
[69]	Debridement	5.0 (2.0)	4.0 (2.0)
[48]	Debridement	5.1 (2.1)	5.3 (2.0)
[51]	Debridement	8.3 (1.7)	7.0 (2.3)
[79]	Partial repair	6.9 (1.9)	6.1 (2.1)
[43]	Partial repair	6.5 (1.5)	5.9 (1.8)
[73]	Partial repair	6.1 (1.6)	9.1 (2.2)
[42]	Partial repair	8.3 (0.7)	8.0 (1.0)
[9]	Partial repair	8.3 (2.7)	8.8 (2.5)
[52]	Deltoid flap	7.0 (2.5)	3.0 (1.9)
[32]	Deltoid flap	5.1 (1.4)	9.1 (1.5)
[40]	Muscle transfer	3.1 (1.4)	5.7 (1.7)
[18]	Muscle transfer	5.9 (2.4)	4.9 (2.3)
[31]	Muscle transfer	4.0 (1.0)	4.4 (1.3)
[27]	Muscle transfer	7.4 (1.9)	4.9 (2.0)
[67]	Muscle transfer	5.7 (2.3)	5.5 (2.3)
[13]	Muscle transfer	6.3 (0.9)	5.5 (1.3)
[62]	Muscle transfer	6.9 (2.8)	5.9 (2.7)
[41]	Muscle transfer	6.7 (2.7)	2.0 (0.9)
[56]	SCR	4.6 (2.2)	8.7 (2.6)
[16]	SCR	6.4 (3.3)	7.1 (2.5)

SD, standard deviation: not reported; SCR: superior capsular reconstruction; RSA: reverse shoulder arthroplasty

DISCUSSION

In this comprehensive systematic review of short- to long-term results of all treatments of irreparable posterosuperior rotator cuff tears, we found that the indications for treatment, the definitions of an irreparable cuff tear, and the improvements after treatment are quite variable among the different treatment modalities studied. As hypothesized, physical therapy, tenotomy or tenodesis of the long head of the biceps, and debridement showed least gain in functional outcome parameters, although these gains were still clinically meaningful.

The robustness of our findings is mainly limited by the low methodological quality of the reviewed studies. Moreover, there is a lack of agreement among studies regarding preoperative criteria for rotator cuff reparability, degree of osteoarthritis, and inclusion of concomitant subscapularis tears and pseudoparalysis, leading to substantial heterogeneity between studied patient groups. This makes comparison of results among the different treatments not meaningful, and it would, for example, be incorrect to recommend SCR or deltoid flap for all patients with irreparable posterosuperior cuff tears. Therefore, we refrained from any statistical testing of differences in outcomes among the different treatment modalities. Most importantly, the heterogeneity of included patients underlines the necessity of prospective randomized studies that employ uniform inclusion criteria and long-term follow-up in order to identify the optimal treatment for irreparable posterosuperior cuff tears.

In addition, the use of outcome measures was variable among the studies, making comparisons between studies difficult [53]. The lack of a gold standard outcome in this patient group further complicates intervention comparisons. For the most commonly used parameter, the Constant score, the MCID has only been studied in reparable cuff tears [46] and not in irreparable tears. Notwithstanding these challenges, this review is the first to assess the outcome of all treatment types for irreparable posterosuperior rotator cuff tears alongside one another. By including studies with both pre- and postoperative outcome measurements and sufficient follow-up, our findings can serve to inform patients about the expected gains from the different treatments. An outstanding challenge to the field is that the literature seems to strongly disagree as to which tears are irreparable based on preoperative imaging. A recent MRI validation study on massive rotator cuff tears showed that grade 3 or 4 fatty infiltration of the infraspinatus muscle combined with grade 3 retraction was the best predictor of irreparability [44]. Using these cut-off points to define irreparability, 21 of 60 studies reviewed here used suboptimal definitions of cuff irreparability. MRI assessment of fatty infiltration has only moderate inter-rater agreement and increased the imprecision of preoperatively defining cuff irreparability [47,80]. Apart from radiological definitions, there is high clinical heterogeneity among patients with irreparable rotator cuff tears and the exact indications are not similar for all available treatment options. In choosing the optimal treatment strategy in daily practice [4], other aspects are taken into account as well, such the presence of pseudoparalysis, the number of tendons torn, biological age, patient expectations, and general health issues [84]. For example, young, active patients with pseudoparalysis in external rotation with insufficient effect of non-operative treatment may be offered a latissimus dorsi and/or teres major transfer, whereas low-demand patients where pain is the predominant problem may be offered partial repair and/or biceps tenotomy. It is this clinical heterogeneity that complicates decision making and is probably one of the reasons that many different treatment modalities exist nowadays.

Yet, only short-term follow-up is currently available for many of these treatment types. Although SCR showed the highest improvements in Constant and ASES scores, this was only after 2 to 3 years of follow-up and it is unknown if the improvement is diminished at even medium-term (4 to 5 years') follow-up, as is true for graft reconstruction and RSA. Notably, partial repair, muscle transfer and subacromial spacer studies did show persistent substantial improvement in Constant Score in this longer timeframe. Given the low reported complication rate, primarily aiming for a partial repair in case of a posterosuperior tear which is deemed irreparable preoperatively, may thus be worthwhile.

Comparative studies on irreparable rotator cuff tears are scarce. In a recent study on 218 patients [8], Constant Score improvement one year postoperatively was highest for RSA (44-point increase), followed by partial repair (21 points), latissimus dorsi transfer (18 points), tenotomy or tenodesis of the long head of the biceps (10 points) and non-operative treatment (17 points). Another recent study found a substantially higher increase in ASES scores 1 year following SCR compared to 3 years following muscle transfer (25 vs 12 points, respectively) [72]. Yet, follow-up was only 1 year for the SCR group and the muscle transfer group had substantially more Worker's Compensation cases (6% vs 65%, respectively).

Although the present review included studies with different patient populations, the findings may be helpful in counseling patients regarding expected improvement for treatment options for irreparable posterosuperior rotator cuff tears. Most importantly, partial rotator cuff repair at least yielded similar medium-term clinical improvement compared to more extensive (muscle transfer) or expensive (subacromial spacer) treatments. As such, performing a partial repair may be worthwhile when a posterosuperior cuff tear is determined to be irreparable intra-operatively. Yet, patients should also be informed about the low level of evidence on which these expectations are based.

Conclusion

The variability in patient characteristics, co-interventions, outcome reporting and length of follow-up in studies on irreparable rotator cuff tears without osteoarthritis complicates sound comparison of treatments. Clinically important treatment effects were seen for all 11 different treatment modalities.

Appendix 1. Search strategy

Databases: EMBASE, MEDLINE, CINAHL, Cochrane database of systematic reviews.
Date of search: January 18th, 2019.
Publication year: 2007-2019.
Language limits: none.
Search terms:
((“Rehabilitation”[Mesh] OR “Physical Therapy Specialty”[Mesh] OR “Physical Therapy Modalities”[Mesh] OR rehabilitati*[tiab] OR physiotherap*[tiab] OR (physical[tiab] AND (therapy[tiab] OR therapies[tiab])) OR nonsurgic*[tiab] OR non-surgic*[tiab] OR nonoperati*[tiab] OR non-operati*[tiab] OR conservative[tiab]) OR (“Tendon Transfer”[Mesh] OR tendon transfer*[tiab] OR muscle transfer[tiab] OR latissimus transfer[tiab]) OR (partial cuff[tiab]) OR (cuff debridement[tiab]) OR ((“Tenotomy”[Mesh] OR tenotom*[tiab] “Tenodesis”[Mesh] OR tenodes*[tiab]) AND biceps[tiab]) OR (augmented cuff repair[tiab] OR superior capsular reconstruction[tiab] OR autograft[tiab] OR allograft[tiab] OR fascia lata graft[tiab] OR patch graft[tiab]) OR (cuff spacer[tiab] OR cuff balloon[tiab] OR biodegradable spacer[tiab]) OR (“Arthroplasty, Replacement, Shoulder”[Mesh] OR (reverse AND ((shoulder[tiab] OR “Shoulder”[Mesh]) AND (prosthesis[tiab] OR arthroplasty[tiab])))) OR (manag*[tiab] OR treat*[tiab] OR therap*[tiab] OR surger*[tiab] OR surgical*[tiab] OR operative*[tiab] OR “Surgical Procedures, Operative”[Mesh] OR “Surgeons”[Mesh] OR operation*[tiab] OR surgeon*[tiab] OR intervent*[tiab] OR reconstruct*[tiab] OR improve*[tiab])) AND (“Rotator Cuff”[Mesh] OR rotator cuff[tiab] OR ((“Shoulder”[Mesh] OR shoulder[tiab]) and cuff[tiab])) AND (irreparable[tiab] OR irrepairable[tiab])

Appendix 2. Database to be found online with the article

Appendix 3. Change of outcome parameters from baseline to final follow-up for all 60 studies

Treatment (number of studies)	Range of mean reported changes from pre-operative to last follow-up									
	Non-adjusted Constant Score (43 studies)	**VAS pain (19 studies)**	**Pain score from Constant Score (20 studies)**	**ASES (16 studies)**	**UCLA (13 studies)**	**Anterior elevation (degrees) (36 studies)**	**Abduction (degrees) (27 studies)**	**External rotation (degrees) (32 stud-ies)**	**Percentage of satisfied patients (18 studies)**	**Percentage of complications (29 studies)**	**Percentage of re-operations (34 studies)**
Physical therapy (2)	13.0a	3.0a	NR	23.1a	NR	NR	NR	NR	NR	NR	NR
Biceps (1)	10.7a	NR	7.3a	NR	NR	3.5a	NR	- 11.9 a	78a	0%	NR
Debridement (4)	19.6-22.8	3.7-4.6	3.9a	45.8 a	11.3-16.9	22.0-26.8	7.0a	1.0-1.8	81a	0%	RSA: 1-12%
Partial repair (12)	24.3-37.2	2.0-5.8	7.0a	31.8-45.3	3.8-18.6	-14.0-51.7	34.0-47.6	9.0-19.0	87a	0%-3% - 0%-3% frozen shoulder	0%-10% - 0%-10% RSA - 0%-3% muscle transfer - 0%-3% arthroscopic release
Subacromial spacer (4)	18.5-49.6	NR	6.2-7.1	NR	NR	50.0a	30.0-35.2	15.0 a	NR	0%-10% synovitis	0-33% RSA
Deltoid flap (4)	22.8-46.6	5.5 a	8.5 a	NR	NR	4.6-75.0	5.0-50.0	1.0-25.0	80-89	0%-16% - 0%-6% hematoma, - 0%-5% flap necrosis - 0%-3% superficial wound infection - 0%-3% DVT	0%-10% - 0%-5% hematoma evacuation - 0%-5% flap revision - 0%-10% arthroscopic acromioplasty
Muscle transfer (18)	14.0-38.7	5.0-5.7	3.2-11.1	24.9-40.1	13.8-21.0	14.4-60.0	10.5-80.0	1.6-18.7	71-93	0%-20% - 0%-16s% hematoma - 0%-8% deep infection - 0%-2% neuropraxia - 0%-8% greater tuberosity fracture - 0%-7% re-rupture - 0%-5% DVT	0%-10% - 0-10% irrigation and debridement - 0%-4% RSA - 0%-4% arthrodesis - 0%-3% re-do muscle transfer

Appendix 3. Continued

Treatment (number of studies)	Range of mean reported changes from pre-operative to last follow-up										
	Non-adjusted Constant Score (43 studies)	VAS pain (19 studies)	Pain score from Constant Score (20 studies)	ASES (16 studies)	UCLA (13 studies)	Anterior elevation (degrees) (36 studies)	Abduction (degrees) (27 studies)	External rotation (degrees) (32 stud-ies)	Percentage of satisfied patients (18 studies)	Percentage of complications (29 studies)	Percentage of re-operations (34 studies)
Graft reconstruction (9)	20.7-43.7	4.3-6.7	7.2 a	22.1-53.3	9.1-18.3	38.5-55.0	31.4-60.0	3.4-18.9	96-100	0%-20% - 0%-20% graft failure - 0%-5% deep infection	0%-10% - 0%-5% irrigation and debridement - 0%-5% patch removal (infection)
RSA (5)	28.4-36.7	3.5-4.4	7.4-8.4	32.4-42.1	NR	36.0-81.0	49.0-76.0	-6.0-26.0	85 a	0%-17% - 0%-6% baseplate failure - 0%-6% periprosthetic fracture - 0%-9% capsulitis - 1%-4% deep infection - 0%-1% hematoma - 0%-1% dislocation - 0%1% broken center screw	0%-8% - 0%-6% revision - 0%-3% irrigation and debridement
SCR (3)	47.4 a	NR	NR	52.9-74.9	22.5 a	59.4-69.0	64.0-67.5	14.0-22.5	NR	5%-10% - 2-5% infection - 3% anchor pullout - 3% frozen shoulder - 1% gluteal discomfort	5%-6% arthroscopic debridement
Rotator cuff advancement (1)	33.2 a	NR	8.5 a	NR	18.2 a	54.0 a	61.0 a	NR	NR	9% a - 6% transient finger paresthesias	0% a

[a] No range reported as there was only one study in this category
NR: not reported; SCR: superior capsular reconstruction; RSA: reverse shoulder arthroplasty.

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Part II

The latissimus dorsi transfer for massive irreparable rotator cuff tears

5

Shoulder kinematics and muscle activity following latissimus dorsi transfer for massive irreparable posterosuperior rotator cuff tears in shoulders with pseudoparalysis

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ABSTRACT

Background

The aim of this study was to evaluate the thoracohumeral (TH) and glenohumeral (GH) motion with muscle activity after latissimus dorsi transfer (LDT) in a shoulder with a massive irreparable posterosuperior rotator cuff tear (MIRT) and pseudoparalysis compared with the asymptomatic contralateral shoulder (ACS).

Methods

We recruited and evaluated 13 patients after LDT in a shoulder with preoperative clinical pseudoparalysis and an MIRT on magnetic resonance imaging, with a minimum follow-up period of 1 year, and with a Hamada stage of 3 or less. Three-dimensional electromagnetic tracking was used to assess shoulder active range of motion in both the LDT shoulder and the ACS. The maximal active elevation of the shoulder (MAES) was assessed and consisted of forward flexion, scapular abduction, and abduction in the coronal plane. Maximal active internal rotation and external rotation were assessed separately. Surface electromyography (EMG) was performed to track activation of the latissimus dorsi (LD) and deltoid muscles during shoulder motion. EMG was scaled to its maximal isometric voluntary contraction recorded in specified strength tests.

Results

In MAES, TH motion of the LDT shoulder was not significantly different from that of the ACS ($F_{1,12}$ = 1.174, P = .300) but the GH contribution was significantly lower in the LDT shoulder for all motions ($F_{1,12}$ = 11.230, P= .006). External rotation was significantly greater in the ACS (26° ± 10° in LDT shoulder vs. 42° ± 11° in ACS, $P < .001$). The LD percentage EMG maximum showed no significant difference between the LDT shoulder and ACS during MAES ($F_{1,11}$ = 0.005, P= .946). During maximal active external rotation of the shoulder, the LDT shoulder showed a higher percentage EMG maximum than the ACS (3.0% ± 2.9% for LDT shoulder vs. 1.2% ± 2.0% for ACS, P = .006).

Conclusions

TH motion improved after LDT in an MIRT with pseudoparalysis and was not different from the ACS except for external rotation. However, GH motion was significantly lower after LDT than in the ACS in active-elevation range of motion. The LD was active after LDT but not more than in the ACS except for active external rotation, which we did not consider relevant as the activity did not rise above 3% EMG maximum. The favorable clinical results of LDT do not seem to be related to a change in LD activation and might be explained by its effect in preventing proximal migration of the humeral head in active elevation.

Level of evidence

Level 4, Retrospective cohort study

Key words

Latissimus dorsi, muscle transfer, massive rotator cuff tear, shoulder kinematics, electromyography, shoulder surgery

INTRODUCTION

A massive irreparable posterosuperior rotator cuff tear (MIRT), in a patient aged < 65 years can be challenging to manage adequately. A massive tear [4, 7, 11, 13, 17, 22, 54, 61] does not necessarily mean an irreparable tear, [13] but excessive retraction, loss of elasticity, muscle atrophy, and the inability to achieve fixation in 60° of abduction despite adequate releases make repair impossible. [3, 4, 22, 23, 25, 27, 28, 32, 45, 65] The prevalence of massive tears ranges from 10% to 40% in all rotator cuff tears and retear rate of MIRT is 90% after primary repair. [1, 16]

An MIRT is clinically observed by pain in the shoulder with an impairment of active forward flexion, abduction, and external rotation.[1, 4, 53] The symptoms may vary from mild pain and maintained active shoulder motion to severe pain with pseudoparalysis and loss of strength.[3, 4, 15, 19, 22, 40, 44, 52] Pseudoparalysis is generally defined as a limitation of active forward flexion to 90° with no restriction in passive range of motion (ROM). [15, 66] Clinical pseudoparalysis does not develop in all patients with MIRTs: It could be that the coupled coronal and transverse forces are still balanced around the glenohumeral (GH) joint during active shoulder motion, and this balance is lost in an MIRT with pseudoparalysis during active ROM. [6, 15, 67]

Different treatment modalities have been reported for MIRTs: physical therapy, tenotomy or tenodesis of the long head of the biceps, debridement, partial repair of the tear, muscle transfer, rotator cuff advancement, graft interposition, superior capsular reconstruction, and reverse shoulder arthroplasty.[1, 29, 31, 47] Latissimus dorsi transfer (LDT) has been well described as a treatment option for an MIRT with good functional outcomes reported, but this procedure is controversial for the treatment of a shoulder with pseudoparalysis. [4, 24, 40, 64] Several authors have reported inferior outcomes after an LDT with a preoperative pseudoparalysis, [10, 14, 22, 23, 40] and although recent literature has demonstrated good outcomes, it may be still considered controversial to perform an LDT in a patient with a pseudoparalysis. [8, 55, 57, 62]

Regarding transfers, the often implicit assumption is that the transferred muscles are capable to adapt to their new mechanical role. [20, 37, 42, 53] For the LDT shoulder, the latissimus dorsi (LD) is assumed to adapt to its change in function, but the muscle might also work more as a tenodesis without (the need for) active functional adaptation.[39, 41] However, literature on the active contribution of the LD after transfer is scarce and several questions are still unanswered, including whether the LD contributes actively or not (ie, works as a tenodesis or shows active force contribution) or whether the activity of the muscle adapts its new mechanical reality. [20, 38, 39, 41, 42]

The aim of this study, therefore, was to analyze whether LDT can restore shoulder function in patients with an MIRT and clinical pseudoparalysis. LDT can affect active shoulder elevation motions as well as rotation motions in the shoulder. Therefore, maximal active elevation in 3 planes (forward flexion, scapular abduction, and abduction in the coronal plane) and maximal rotation (internal rotation and external rotation) in the shoulder were assessed in the LDT shoulder and asymptomatic contralateral shoulder (ACS). The maximal muscle activity of the LD and deltoid muscle during each active shoulder movement was reported. The hypothesis was that restoration of function in the LDT shoulder would be accompanied by active contraction of the LD muscle that is linked to its new mechanical role.

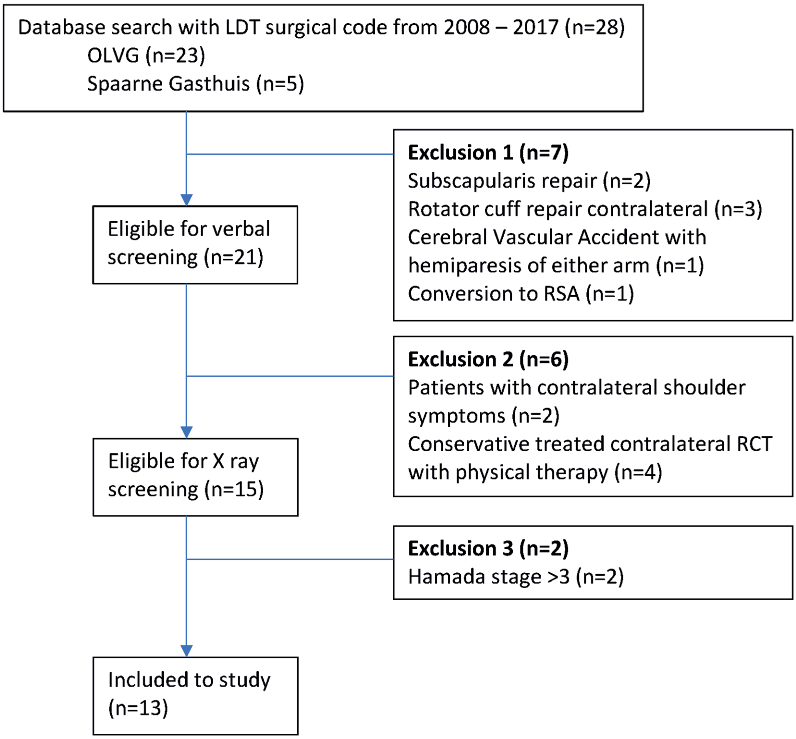
MATERIALS AND METHODS

Study design and participants

This was a retrospective cohort study. We recruited patients in June 2018 by searching for the surgical code of LDT in the participating clinics - Onze Lieve Vrouwe Gasthuis (OLVG, Amsterdam, The Netherlands) and Spaarne Gasthuis (Hoofddorp, The Netherlands)- and included patients treated by 3 shoulder surgeons. The inclusion criteria were as follows: (1) patients with a chronic (>6 months) MIRT (tear size > 5 cm in diameter with >2 tendons completely torn and retracted) treated with LDT, (2) clinical preoperative pseudoparalysis of the affected shoulder, (3) grade 3 or higher fatty infiltration of the rotator cuff tear, (4) no concomitant repair of the subscapularis muscle, (5) intact teres minor muscle, (6) no GH arthritis, (7) no adhesive capsulitis, (8) follow-up period of at least 1 year, (9) contralateral shoulder with no previous surgery or symptoms, and (10) no neurologic or vascular deficiencies in either arm. We included patients who underwent primary LDT or LDT after previous attempts at rotator cuff repair. The LDT surgical procedure was performed in all patients as described by Gerber et al[24] with protocolized postoperative care (Appendix).

A total of 28 patient files were reviewed, and 21 patients eligible for verbal screening were contacted by phone to provide information and were invited to participate in the study (Figure 1). After verbal screening, 2 patients with symptoms and 4 patients with a conservatively treated rotator cuff tear in the contralateral shoulder were excluded. Fifteen patients were eligible for radiographic screening and signed informed consent forms. Prior to final inclusion, a radiograph was obtained at either clinic to assess the Hamada stage. [34] Two patients showed progressive cuff arthropathy to Hamada stage 4 and were excluded, resulting in a total of 13 patients in this study. Included patients followed the study procedures summarized in Table 1. All included patients underwent preoperative magnetic resonance imaging (MRI) and underwent postoperative radiography and an MRI scan of the LDT shoulder, which were analyzed by 2 independent musculoskeletal radiologists; the findings were documented in separate lists to preserve blinding of the assessors.

Figure 1 Flowchart Inclusion- and exclusion criteria



LDT, latissimus dorsi transfer; OLVG, Onze Lieve Vrouwe Gasthuis, Amsterdam, The Netherlands; RSA, reverse shoulder arthroplasty; RCT, rotator cuff tear.

Table 1 Study procedure

Phone contact	Verbal screening and provide study information
Written information	Information folders containing: Study rationale and goals, study procedure, minimal health risks of participation, important contact details in case of questions about the study.
Two weeks pause	Time to consider participation
Second phone contact	Radiography was planned, and questions regarding participation were answered.
Informed consent and radiography	Informed consent was acquired, and radiography of the affected shoulder was performed.
Third phone contact	Patients with Hamada stage > 3 were excluded. Patients were informed about their shoulder radiographs and final inclusion. PROM questionnaires (ADLER) were sent to patients' address of residence. The included patients' general practitioners received study information and contact details of the study coordinator in case of questions.
Visit to OLVG	An MRI scan of the affected shoulder was performed.
Visit to Duyvensz-Nagels research facility (Reade Rehabilitation and Rheumatology Center, Amsterdam, The Netherlands)	The ADLER score was received and checked with patients in case of any ambiguity; the Constant-Murley score was obtained; and 3D kinematic range-of-motion, muscle activation (EMG), and strength assessments were performed.

PROM, patient-reported outcome measure; ADLER, activities of daily living requiring active external rotation; OLVG, Onze Lieve Vrouwe Gasthuis, Amsterdam, The Netherlands; MRI, magnetic resonance imaging; 3D, 3-dimensional; EMG, electromyography

Three-dimensional kinematics and active ROM

Measurements were performed at the Reade Rehabilitation and Rheumatology Center, Amsterdam, the Netherlands. By use of the Flock-of Birds system (Ascension Technologies, Burlington, VT, USA) and accompanying software (Motion Monitor Biomech I; Innovative Sports Training, Chicago, IL, USA), 3-dimensional kinematics were measured. By use of Fixomull self-adhesive tape (Beiersdorf, Hamburg, Germany), 4 sensors were attached to the patient: (1) sternum, (2) humerus, (3) forearm, and (4) acromion (Figure 2). A pointer was used to locate the bony landmarks and construct anatomic local coordinate systems. The thoracohumeral (TH) motion and GH motion were assessed from bony landmarks and expressed as angles according to the International Society of Biomechanics standardization proposal of the International Shoulder Group [34] (Table 2).

Figure 2 Patient setup

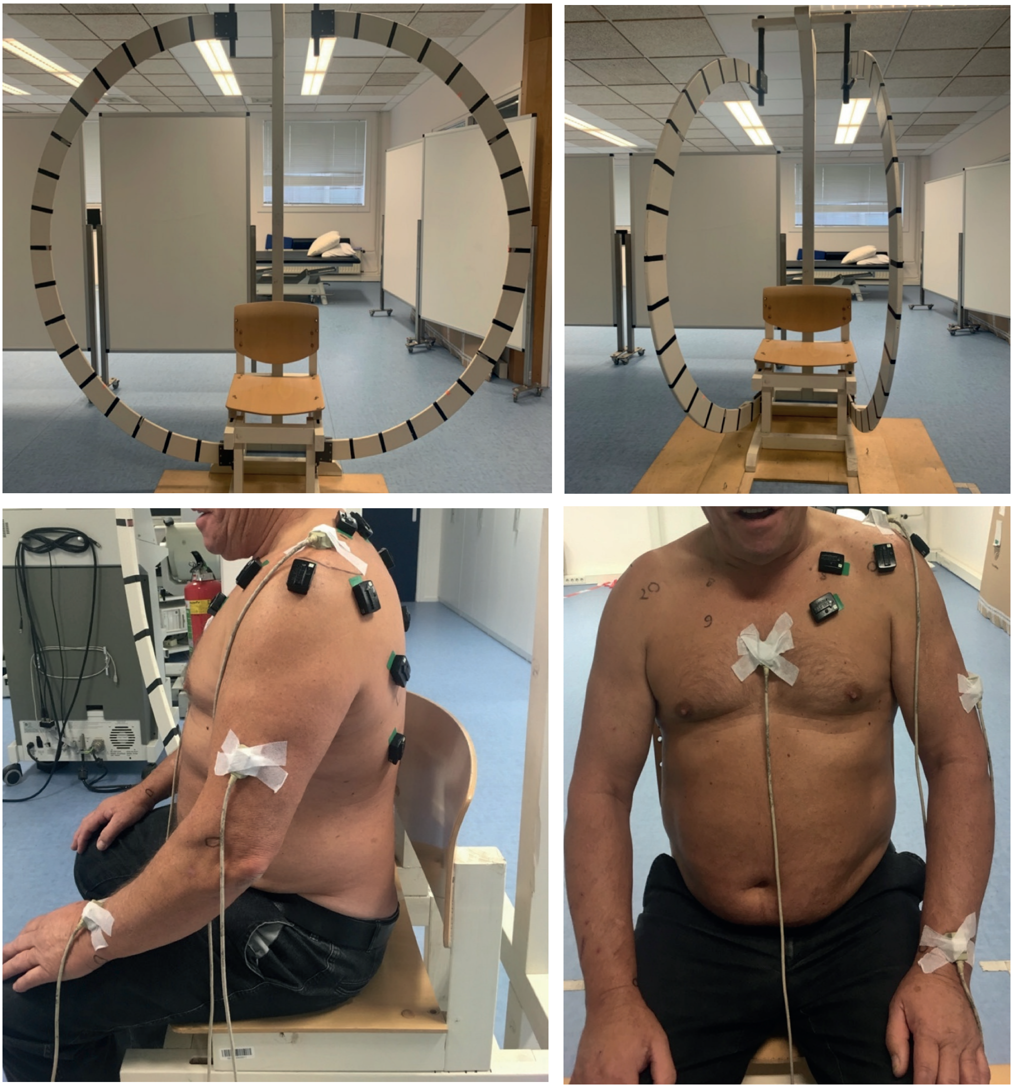


Table 2 Bony landmarks for 3-dimensional kinematic analysis

Thorax and Spine	Scapula	Humerus	Forearm
Jugular notch	Angulus acromialis	Medial epicondyle	Radial styloid
Xiphoid process	Trigonum scapulae	Lateral epicondyle	Ulnar styloid
Seventh cervical vertebrae	Angulus inferior		
Eighth thoracic vertebrae			

Three-dimensional kinematics of 5 different active movements were analyzed: forward flexion, abduction in the scapular plane (scapular abduction), abduction in the coronal plane, internal rotation, and external rotation, performed with the arm stabilized in 90° of abduction and 90° of elbow flexion by one of the investigators. Two semicircular arches with a scale of 10°, ranging from 0° to 180°, functioned as a goniometer for the executed motions and were used to guide active movements (Figure 2). Patients were instructed to maximally move the investigated arm in the respective plane starting with the arm in the anatomic position adjacent to the body. The shoulders were analyzed separately and not concurrently; all measurements were performed 3 times and at each participant's own pace. The outcome measures for each active maximal shoulder movement were (1) TH motion and (2) GH motion, reported in degrees. Three-dimensional kinematic data were processed with the use of MATLAB (The MathWorks, Natick, MA, USA). The highest value of the TH elevation angle was selected as the maximal TH angle for that movement. The same procedure was used for GH angles.

Muscle activity

Muscle activity of the deltoid and LD muscles was measured simultaneously during each active shoulder movement with wireless electromyography (EMG) sensors (Trigno Wireless; Delsys, Boston, MA, USA). Furthermore, muscle activity was recorded during 3 activities of daily living (ADL) tasks: (1) scratching the lower back, (2) grasping a cup at chest level and moving it to the mouth, and (3) combing the hair from the front to the back of the head. All tasks started from the neutral position, with the arm adjacent to the body.

The LD sensor was placed approximately 6 cm under the angulus inferior of the scapula. For the anterior and middle deltoid muscles, the sensors were placed on the respective muscle bellies. To scale the EMG signal of the performed tasks to the maximal performance of the muscle in question, maximal isometric voluntary contractions (MIVCs) of both shoulders of each patient were performed during 6 different movements in a fixed order, separated by 1-minute rest periods: forward flexion at 45°, flexion in the scapular plane at 45°, internal rotation and external rotation at 90° of shoulder abduction, retroflexion, and horizontal adduction at 90° of shoulder forward flexion. One of the researchers held a handheld dynamometer (Lafayette Instrument, Lafayette, IN, USA), and the patient was asked to push against it as forcefully as he or she could for that specific movement. This was performed 3 times, and the muscle activity during the best performance for each task was selected for further analysis.

Raw EMG data were corrected for offset before rectification and low-pass filtering (2-Hz recursive Butterworth) to obtain a linear envelope. The maximal EMG value measured during the MIVCs was used to scale the EMG signal of the performed tasks to the maximal performance of the muscle in question (100% EMG max). The highest value during each movement was selected as the maximal value of the muscle in question and was reported as a percentage of the EMG max for the different movements.

Shoulder function

The Constant-Murley score [12] and the activities of daily living requiring active external rotation (ADLER) score [5] were collected during the visit at READE and reported separately in the Appendix.

Statistical analysis

The maximal active elevation of the shoulder (MAES), which consisted of forward flexion, scapular abduction, and abduction in the coronal plane, was analyzed collectively for the LDT shoulder and ACS in a 2-way repeated-measures analysis of variance with post hoc tests and Bonferroni correction. The MAES was reported in TH motion and GH motion. TH motion and GH motion were also analyzed separately for each maximal active shoulder movement (forward flexion, scapular abduction, abduction in the coronal plane, internal rotation, and external rotation) with paired t-tests.

The percentage EMG max values of the LD and deltoid muscles were analyzed collectively during MAES for the LDT shoulder and ACS in a 2-way repeated analysis of variance with post hoc tests and Bonferroni correction. The percentage EMG max was also analyzed separately during each maximal active shoulder movement (forward flexion, scapular abduction, abduction in the coronal plane, internal rotation, and external rotation) and ADL task (grasping cup, combing hair, and scratching back) with paired t-tests. The significance level was set at .05.

RESULTS

Baseline characteristics

Patients were assessed after a mean follow-up period of 66.9 ± 36.7 months (range, 12-112 months). The average age was 60.7 years, and the male-to-female ratio was 10:3. Primary LDT was performed in 6 patients, whereas LDT was performed after previous cuff repair in 10. All patients had an intact LDT on MRI. Constant-Murley scores can be found in the appendix.

LDT versus ACS

Active shoulder ROM

In MAES, TH motion of the LDT shoulder was not significantly different from that of the ACS ($F_{1,12}$ = 1.174, P = .300) but GH motion was significantly lower in the LDT shoulder ($F_{1,12}$ = 11.230, P = .006) (Table 3, Figure 3). When we looked at the individual elevation movements (forward flexion, scapular abduction, and abduction in the coronal plane), during all movements, GH motion contributed less to TH motion in the LDT shoulder than was observed in the ACS (Table 3). Significantly lower shoulder maximal external rotation was seen for the LDT shoulder (26° ± 10° for LDT shoulder vs. 43° ± 11° for ACS, P < .001).

Table 3 LDT versus ACS

Active movement	N	LDT	ACS	P
ROM TH (°)				
Forward flexion	13	103 ± 26	112 ± 18	.325
Scapular abduction	13	108 ± 25	115 ± 18	.416
Abduction	13	108 ± 27	119 ± 17	.218
Internal rotation	13	48 ± 15	54 ± 12	.077
External rotation	13	26 ± 10	43 ± 11	<.001
ROM GH (°)				
Forward flexion	13	57 ± 19	82 ± 14	.004
Scapular abduction	13	60 ± 17	84 ± 19	.012
Abduction	13	57 ± 19	84 ± 20	.006
Latissimus dorsi (% EMG max)				
Forward Flexion	12	11.5 ± 7.6	10.9 ± 6.9	.747
Scapular abduction	13	14.2 ± 11.1	13.3 ± 9.0	.795
Abduction	13	11.5 ± 10.4	10.4 ± 8.4	.605
Internal rotation	13	11.8 ± 11.7	10.8 ± 7.9	.776
External rotation	13	3.0 ± 2.9	1.2 ± 2.0	.006
Scratching back	12	28.6 ± 23.2	33.5 ± 25.2	0.511
Grasping cup	13	N.A.	N.A.	N.A.
Combing hair	13	9.3 ± 10.6	5.2 ± 10.6	0.182
Deltoid (% EMG max)				
Forward Flexion	13	73.5 ± 26.2	62.3 ± 23.9	0.249
Scapular abduction	13	87.6 ± 19.4	64.0 ± 15.2	<0.001
Abduction	13	88.0 ± 16.3	66.1 ± 24.9	0.005

LDT, latissimus dorsi transfer; ACS, asymptomatic contralateral shoulder; TH, thoracohumeral; ROM, range of motion; GH, glenohumeral; ADL, activity required for daily living; ADLER, activities of daily living requiring active external rotation; EMG max, largest electromyographic value for specific muscle; NA, not applicable.

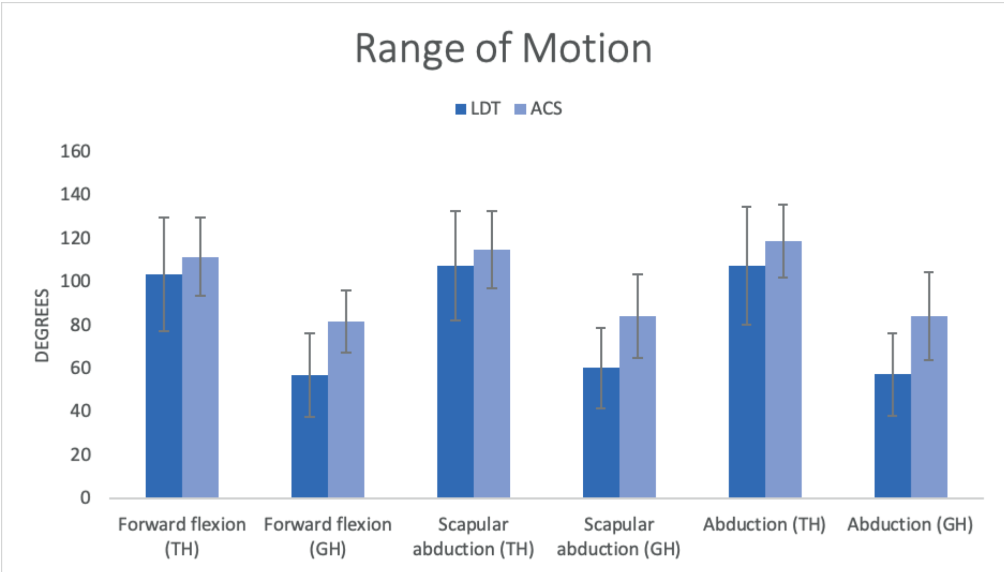
LD activity

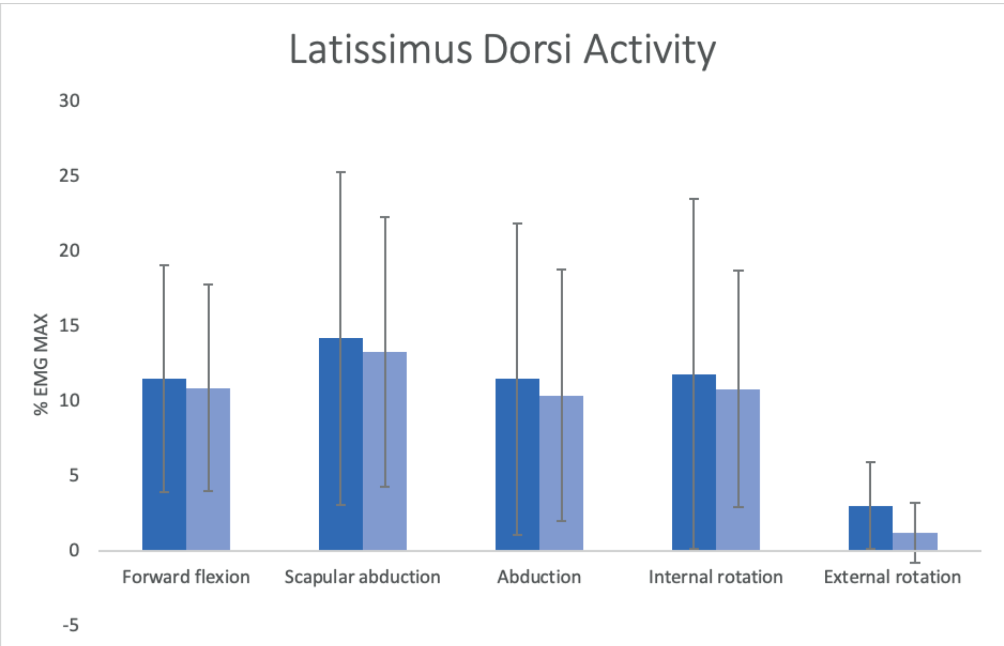
The LD percentage EMG max during MAES did not show any difference between the LDT shoulder and ACS ($F_{1,11} = 0.005$, $P = .946$) (Table 3, Figure 3). An examp of this finding is shown in Figure 4. During maximal external rotation, a higher LD percentage EMG max was seen in the LDT shoulder (3.0% ± 2.9% EMG max) than in the ACS (1.2% ± 2.0% EMG max, $P = .006$). No significant differences in LD percentage EMG max values in the LDT shoulder and ACS were observed for all the ADL exercises. The ADL task of grasping a cup did not show any LD activity.

Deltoid activity

The LDT shoulder showed a higher percentage EMG max of the deltoid muscle in MAES compared with the ACS ($F_{1,12} = 17.241$, $P = .001$). When we looked at the individual movements, the LDT shoulder did not show a higher deltoid percentage EMG max than the ACS only in maximal active forward flexion (73.5% ± 26.2% EMG max for LDT shoulder vs. 62.3% ± 23.9% EMG max for ACS, $P = .249$). An example of these findings is shown in Figure 4.

Figure 3 LDT and asymptomatic contralateral shoulder (ACS)

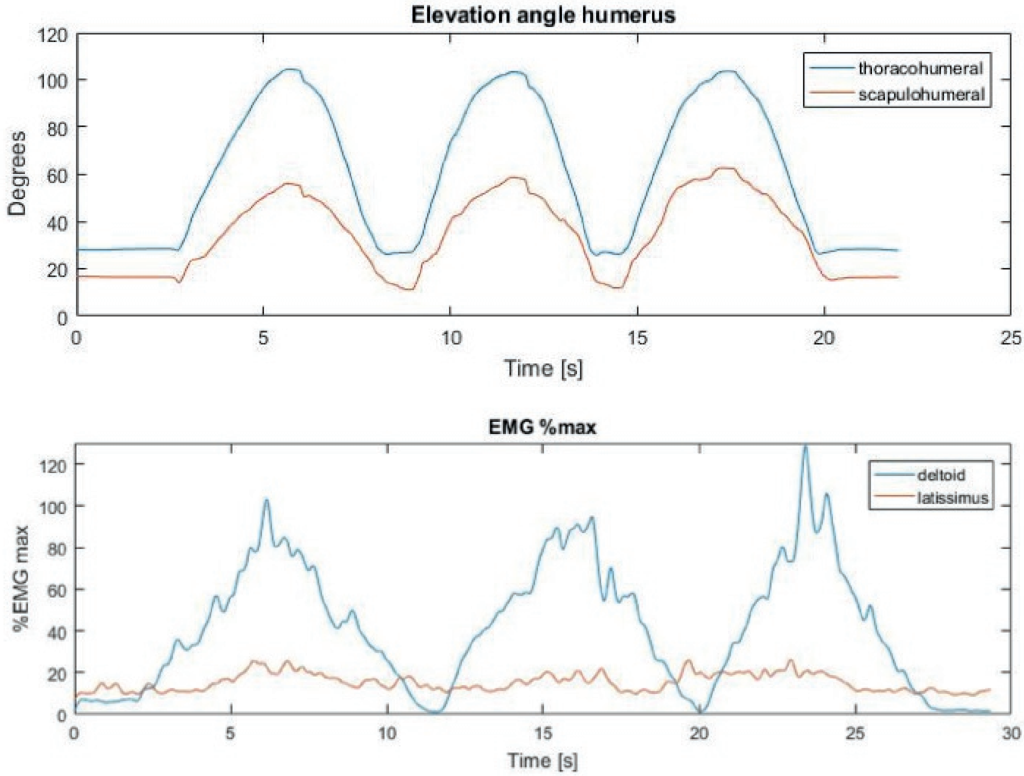




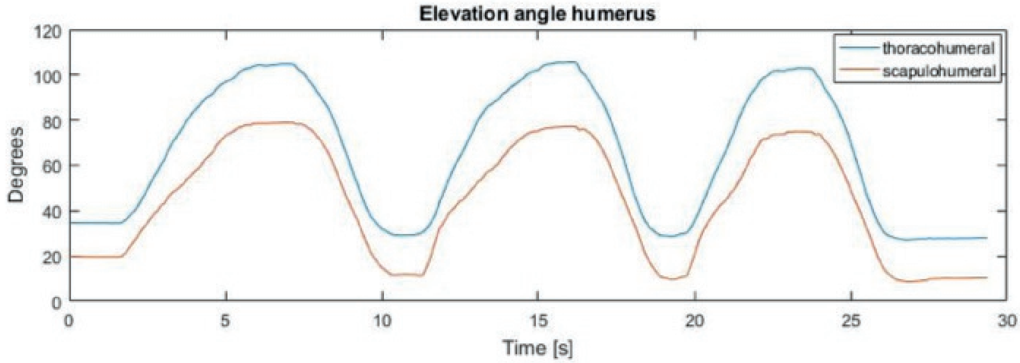
TH, thoracohumeral motion; GH, glenohumeral motion; EMG, electromyography; MAX, maximum.

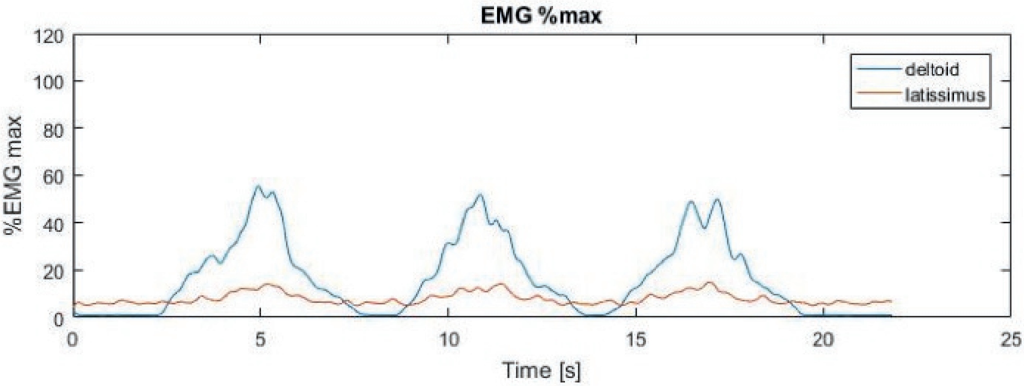
Figure 4. Example curves of elevation (3-dimensional) and surface electromyography (EMG) of latissimus dorsi transfer (LDT) shoulder and asymptomatic contralateral shoulder (ACS)

Example LDT shoulder



Example ACS





Scapulohumeral elevation indicates glenohumeral elevation; max, maximum.

DISCUSSION

The aim of this study was to evaluate whether LDT can restore shoulder function in patients with an MIRT and whether this is done actively in it is new mechanical role. The LDT shoulder showed similar TH motion in MAES to the ACS, although not for maximal active external rotation. Moreover, it became apparent that the functional result was reached with less movement in the GH plane. Despite the near-normal maximum elevation, however, it could not be concluded that this result was associated with a change in the LD's native activity after transfer.

Previous studies compared 3-dimensional motion of the LDT shoulder with the ACS as well.[20, 39] Galasso et al [20] reported forward flexion and abduction values after LDT that were approximately 40° higher than those observed in our patients, but this difference was also found in the contralateral shoulder. In line with our findings Galasso et al described an increase in thoraco-scapular motion in active elevation for the LDT shoulder when compared the ACS. Higher thoraco-scapular motion is also seen in active elevation in patients with cuff tears but is restored to normal after repair. [46, 49, 67] This restorative effect on joint kinematics is not observed after LDT in this study, which is in accordance with Galasso et al [20] and Henseler et al.[37]

LD activity

In this study, no modified LD activation (percentage EMG max) in active shoulder ROM was found between the LDT shoulder and ACS, except for minimal differences in external rotation. If the LD muscle had gained a new active role in external rotation after a mean follow-up period of 66.9 months, more activity would have been expected. Apparently, the LD muscle remains active in its native function, either because it does not need to change its function or because it does not have the necessary adaptive capacity. LD muscle activity after transfer has been the subject of several studies. However, varying results have been reported. [2, 9, 21, 26, 33, 38–41, 43, 58]

The method of analysing LD muscle activity varies among studies, which likely adds to the inconsistency. Habermeyer, [33] Iannotti et al, [40] Ippolito et al, [39] and Henseler et al [38] measured MIVCs to compare preoperative and postoperative LD activity and observed increased LD muscle activity, concluding active muscle contraction it its new function. However, MIVCs do not mimic isokinetic active ROM in the shoulder, and the LD muscle activity could be the result of increased co-contraction after transfer.[56, 60] In addition, De Casas et al. [8] and Irlenbusch et al[43] reported that active muscle contraction was responsible for the observed favorable outcome after LDT. However, these authors used the contralateral LD muscle as a reference, set to 100% EMG max, and reported peak EMG values of LDT. As the LDs on both sides cannot be assumed to be as strong and they are mechanically different owing to the transfer, activity scaled to only 1 side is risky: The same activity for both muscles thus does not refer to the same force level or even mechanical action. In our opinion, it is more accurate to scale muscle activation to the MIVC of that same muscle. Clavert et al [9] reported an active role of the LD after transfer but reported minimal information on their assessment in the description of their methods. Recent studies by Galasso et al [20] and Hetto et al [39] comparing the LDT shoulder with the ACS with isokinetic movements reported similar results to our study, that is, no difference in LD muscle activation after LDT compared to the ACS.

GH joint stability after LDT

The rationale behind restoration of shoulder function after LDT is to restore a stable GH joint by providing a sufficiently balanced shoulder and glenoid-directed joint compression force. [6, 15, 36] An MIRT is characterized by a deficient supraspinatus and infraspinatus muscle and occasionally a deficient teres minor muscle. [55] In the absence of a properly balanced force couple around the glenoid in an MIRT, the humeral head is unstable in posterosuperior direction during active shoulder movements. [59] LDT is assumed to restore stability in the GH joint because of its (posterior) caudally directed pull, either actively by contraction or passively by the tenodesis effect. Because it was not quantified in this study, whether GH stability was restored by performing LDT remains unknown. LDT yielded improved TH motion, but did not provide a similar GH contribution comparable to the ACS. However, we can only assume that the transfer increased TH elevation in shoulders with pseudoparalysis; no local preoperative pain inhibitor was administered, and it remains unclear whether pain was the limiting factor. [18]

In active elevation in an MIRT, the deltoid muscle will produce joint-destabilizing shear forces, causing cranial migration of the humeral head. To (partially) counteract the cranial migration, the shoulder adductor muscles (LD and teres major) are activated during active shoulder elevation (coactivation).[30, 36, 56] This counteracting effect is not sufficient to restore shoulder function in patients with a pseudoparalysis. [15, 36, 48] It could be that LDT, with its new proximal insertion site, exerts a stronger caudally directed pull, counteracts the cranially directed forces, and stabilizes the GH joint by providing a stable fulcrum for the deltoid.[35, 36, 50] This is supported by the findings of increased deltoid activity in scapular abduction and abduction after LDT.[35] The smaller GH motion found after an MIRT or LDT could be explained by the change in function of remnant GH muscles from mobilizing the GH joint to increasing the joint reaction force to prevent the cranial directed force of the deltoid during active elevation. [35] Other authors have suggested that the smaller GH motion is because of the relatively increased scapular rotation that improves deltoid tension compensating for loss of the torn rotator cuff muscles. [20, 51] In future studies, it would be useful to also focus on the function of the thoraco-scapular muscles after LDT. [50, 63]

Limitations

It remains unknown at which time point after surgery the LDT shoulder has adapted its new course of action. The follow-up period in this study ranged widely from 12 to 112 months postoperatively. As we only included patients ≥12 months after LDT, it could be that some patients, with time, displayed increased active ROM and clinical outcomes owing to training and muscle adaptation. Although other patients with a much longer follow-up period may have shown deterioration over time, we could not prove this because we did not have the interim data of the patients with longer follow-up periods. Moreover, because of the limited number of patients included in our study, conclusions need to be made with care.

For future studies, it is essential to compare 3 groups regarding shoulder kinematics (TH, thoraco-scapular, and GH) and surface EMG muscle activity of the LD muscle and other shoulder muscles: the preoperative group with MIRTs (1), the postoperative LDT group

(2), and the ACS group or age-matched controls (3). By comparing the activity of the LDT shoulder with the preoperative MIRT state and the ACS, it could be possible to track different muscle activity after LDT. This could lead to a better understanding of what the LDT shoulder does after transfer.

Conclusion

Although TH elevation returns to near normal after LDT, this does not seem to be due to a restoration of normal GH motion. Because no clear difference in the muscle activity of the LD muscle in the LDT shoulder and the ACS was observed in active ROM, we cannot conclude that the LD changed its activity after transfer. We can only assume that the positive outcome could be related to a tenodesis effect or the positive effects of the original activation in its new position on the proximal humerus - or a combination thereof.

Acknowledgements

We express our sincere gratitude to A. van Noort (Orthopaedic surgeon, Spaarne Gasthuis, Hoofddorp, The Netherlands) for assisting in patient inclusion and H.J. van der Woude, V.P.M. van der Hulst, and M. Schavenmaker (musculoskeletal radiologists at Onze Lieve Vrouwe Gasthuis [OLVG], Amsterdam, The Netherlands) for radiologic assessment.

APPENDIX

1. Surgical procedure

The LDT was performed as described by Gerber with an interscalene brachial block and general anesthesia. The patient was placed in the lateral decubitus position (on the contralateral side with the affected arm on an arm rest). A 5 - 7cm S-shaped incision was made at the posterior axillary fold to harvest the LD tendon. The distal LD muscle is released from the chest wall with care of mobilizing the thoracodorsal neurovascular pedicle. The tendon is armed with two non-absorbable Ultrabraid sutures (Smith & Nephew, Andover, MA, USA). An anterolateral incision of 5 cm was made to expose the interval between the anterior and middle deltoid muscles. The footprint of the supra- and infraspinatus muscle was debrided. Blunt dissection was performed to create the interval between the long head of the triceps and dorsal deltoid muscle. Two to four double loaded footprint anchors (Smith & Nephew, Andover, MA, USA) were used to fix the tendon flat covering the infraspinatus footprint and as far as possible on the supraspinatus footprint.

5

2. Postoperative care

All patients were immobilized with a shoulder immobilizer for 6 weeks continuously postoperatively. Active exercises of the elbow, wrist and hand were encouraged immediately after surgery, leaving the shoulder immobilized. Thereafter, passive physical therapy was started under guidance of a physical therapist. Active assisted range of motion exercises were allowed from 12 weeks postoperatively and included, arm elevation, table side and wall climb. Patients were instructed to perform exercises only within their comfort zone of tolerance and the intensity with isometric training (elevation, abduction, internal and external rotation) was increased until 6 months.

3. Pre- and postoperative clinical outcome LDT shoulder

Clinical outcome	Preoperative	Postoperative	P value
Constant Murley Score	31.1 ± 8.9 (25 – 45)	65.5 ± 10.9 (59 – 79)	.001
Pain	4.2 ± 1.0 (0 – 10)	11.7 ± 3.1 (5 – 15)	.006
ADL	2.8 ± 2.1 (0 – 6)	12.4 ± 3.2 (10 – 16)	.005
Range of Motion	13.7 ± 3.2 (8 - 16)	34.9 ± 6.4 (28 – 40)	.003
Strength	5.8 ± 3.7 (4 – 9)	6.4 ± 2.3 (3 – 12)	.774
ADLER score	6.7 ± 1.6 (3 – 8)	19.4 ± 2.7 (14 – 23)	<.001

4. Postoperative clinical outcome for LDT and ACS

Clinical outcome	LDT	ACS	P value
Constant Murley Score	65.5 ± 10.9	81.1 ± 13.1	<.001
Pain	11.7 ± 3.1	14.0 ± 2.1	.004
ADL	12.4 ± 3.2	15.1 ± 2.7	<.001
Range of Motion	34.9 ± 6.4	37.8 ± 4.6	.056
Strength	6.4 ± 2.3	14.2 ± 6.5	<.001
ADLER score	19.4 ± 2.7	27.6 ± 1.8	<.001

LDT, Latissimus Dorsi Transfer; ACS, Asymptomatic contralateral shoulder

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Shoulder muscle activity after latissimus dorsi transfer in an active elevation

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ABSTRACT

Background

After latissimus dorsi transfer (LDT), an increase in scapulothoracic (ST) contribution in thoracohumeral (TH) elevation is observed when compared to the asymptomatic shoulder. It is not known which shoulder muscles contribute to this change in shoulder kinematics, and whether the timing of muscle recruitment has altered after LDT. The aim of the study was to identify which shoulder muscles and what timing of muscle recruitment are responsible for the increased ST contribution and shoulder elevation after LDT for a massive irreparable posterosuperior rotator cuff tear (MIRT).

Methods

Thirteen patients with a preoperative pseudoparalysis and MIRT were recruited after LDT with a minimum follow-up of 1 year. Three-dimensional electromagnetic tracking was used to assess maximum active elevation of the shoulder (MAES) in both the LDT and the asymptomatic contralateral shoulder (ACS). Surface electromyography (EMG) tracked activation (% EMG max) and activation timing of the latissimus dorsi (LD), deltoid, teres major, trapezius (upper, middle and lower) and serratus anterior muscles. MAES was studied in forward flexion, scapular abduction and abduction in the coronal plane.

Results

In MAES, no difference in thoracohumeral motion was observed between the LDT and ACS, $P = .300$. However, the glenohumeral motion for MAES was significantly lower in LDT shoulders $F(1,12) = 11.230$, $P = .006$. The LD % EMG max did not differ between the LDT and ACS in MAES. A higher % EMG max was found for the deltoid $F(1,12) = 17.241$, $P = .001$, and upper trapezius $F(1,10) = 13.612$, $P = .004$ in the LDT shoulder during MAES. The middle trapezius only showed a higher significant difference in % EMG max for scapular abduction, $P = .020$ (LDT, 52.3 ± 19.4; ACS, 38.1 ± 19.7). The % EMG max of the lower trapezius, serratus anterior and teres major did not show any difference in all movement types between the LDT and ACS and no difference in timing of recruitment of all the shoulder muscles was observed.

Conclusions

After LDT in patients with a MIRT and preoperative pseudoparalysis, the LD muscle did not alter its % EMG max during MAES when compared to the ACS. The cranial transfer of the LD tendon with its native %EMG max, together with the increased %EMG max of the deltoid, middle and upper trapezius muscles could be responsible for the increased ST contribution. The increased glenohumeral joint reaction force could in turn increase active elevation after LDT in a previous pseudoparalytic shoulder.

Level of evidence
Level 4, Retrospective cohort study

Key words
Tendon transfer, massive rotator cuff tear, electromyography, latissimus dorsi, shoulder surgery

INTRODUCTION

Shoulder kinematics change after a rotator cuff tear. [49, 56, 57] In a normal shoulder, after 30 degrees of elevation the glenohumeral (GH): scapulothoracic (ST) ratio is 2.3-2.7:1 until maximum. [4, 7] The contribution of the scapulothoracic part of the maintained thoracohumeral (TH) motion increases in patients with a cuff tear, the contribution can be restored after repair. [56] Some posterosuperior rotator cuff tears are massive and irreparable (MIRT), [38, 53] which can be managed by muscle transfer surgery. [3, 13, 20, 38, 45] The latissimus dorsi transfer (LDT) is a viable option described by Gerber in 1988, [17] as it increases active range of motion in the shoulder and reduces pain. [1, 8, 21, 23, 32, 43, 53] The shoulder elevation after LDT has an increased ST contribution, which is similar to a cuff tear and does not restore kinematics to a healthy shoulder. [22] The mode of function of the LDT is not fully understood yet. It has been postulated that the latissimus dorsi (LD) muscle changes its active function to its new mechanical role after transfer to elevate and externally rotate the arm.[8, 15, 16, 23, 29, 32, 34] Others did not find any change of LD muscle activity in active shoulder ROM and therefore attribute the function to the tenodesis effect.[30, 33] The tenodesis effect is the downward directed passive pull of the LD on the proximal humerus, opposing the upward directed force of the deltoid in active elevation of the shoulder. This tenodesis effect might be able to create a more balanced force, acting on the GH joint, making elevation in the shoulder possible.

While the LDT can restore shoulder elevation, it does not reestablish shoulder kinematics to that of a healthy shoulder. Even after LDT, the ST contribution to TH motion in the shoulder continues to be increased. [15, 28] Scapulothoracic muscles and recruitment timings have been analysed in (massive) rotator cuff tears,[27, 50, 55, 56] subacromial impingement, [9, 10, 48, 51, 55] glenohumeral instability,[51] shoulder muscle fatigue,[41, 52] suprascapular nerve block [39] and after LDT. [29, 30] The studies reporting on muscle activity after LDT have solely focused on LD activity in its new mechanical role, whether it has changed its function from an internal rotator and adductor to an external rotator and abductor of the shoulder. It is not known which other shoulder muscles or changes in shoulder muscle recruitment time are responsible for the increased ST contribution in maximum active elevation of the shoulder (MAES) after LDT.

The aim of this study was to evaluate shoulder muscle activity and timing of recruitment after LDT compared to their asymptomatic contralateral shoulder (ACS) in active elevation of the shoulder. Several muscles around the shoulder could be responsible for the increased ST contribution in MAES. Therefore, together with the muscle activity of the LD muscle, muscle activities of the scapulohumeral muscles (deltoid, teres major) and scapulothoracic muscles (trapezius and serratus anterior) were analysed.

Our hypothesis is that the transferred LD and other scapular muscles increase their muscle activity with a difference in timing of recruitment to facilitate the increase in ST motion in MAES compared to the ACS.

METHODS

Study design and participants

This retrospective cohort study was approved by the local medical ethical committee, OLVG (Amsterdam, the Netherlands, WO – 15.116). The patient group and mode of assessment in the present study has been reported in a prior study.[22]

Patients were recruited from two orthopaedic clinics: OLVG (Amsterdam, NL) and Spaarne Gasthuis (Hoofddorp, NL). Participants were identified in June 2018 by searching for cases by surgical code in the orthopaedic database. Inclusion criteria were (1) LDT for a massive cuff tear (tear size >5cm diameter with at least 2 tendons completely torn, (2) retracted and grade 3 or higher fatty infiltration on magnetic resonance imaging [18, 36], (3) patients with a chronic (>6 months) rotator cuff tear, failed rotator cuff repair and a clinical pseudoparalysis (<90 degrees of active elevation), [12, 54] (4) no concomitant treatment of the remaining rotator cuff, (5) intact subscapularis without glenohumeral arthritis, (6) no adhesive capsulitis, (7) no previous surgery or symptoms of the contralateral shoulder, (8) no vascular or neurologic deficiencies in either arm (9) and a follow up of at least 1 year after LDT with an intact LD transfer on magnetic resonance imaging.

The surgical procedure was performed as described by Gerber [17] followed by protocolized postoperative care which can be found in the appendix.

3-dimensional kinematics and MAES

The Flock-of Birds system (Ascension Technologies, Inc., Burlington, VT, USA) and accompanying software (Motion Monitor Biomech I, Innovative Sports Training, Chicago, USA) were utilized for 3-dimensional kinematics. The Center for Rehabilitation and Rheumatology, Amsterdam, the Netherlands was utilized for the measurements. According to the International Society of Biomechanics standardization, proposal of the International Shoulder Group (ISG), the TH and GH motion were assessed. [24] The highest value of the elevation angle was selected as the maximal angle for that movement and the data was processed with Matlab (MathWorks, Natick, MA, USA).

MAES was analysed by including three different active elevation movements: forward flexion, abduction in the scapular plane (scapular abduction) and abduction in the coronal plane. Patients were instructed to maximally move the measured arm in the respective plane starting with the arm in neutral rotation beside the body. The measurements were repeated three times and completed at the patient's own pace. Each shoulder was analysed separately.

Muscle activation

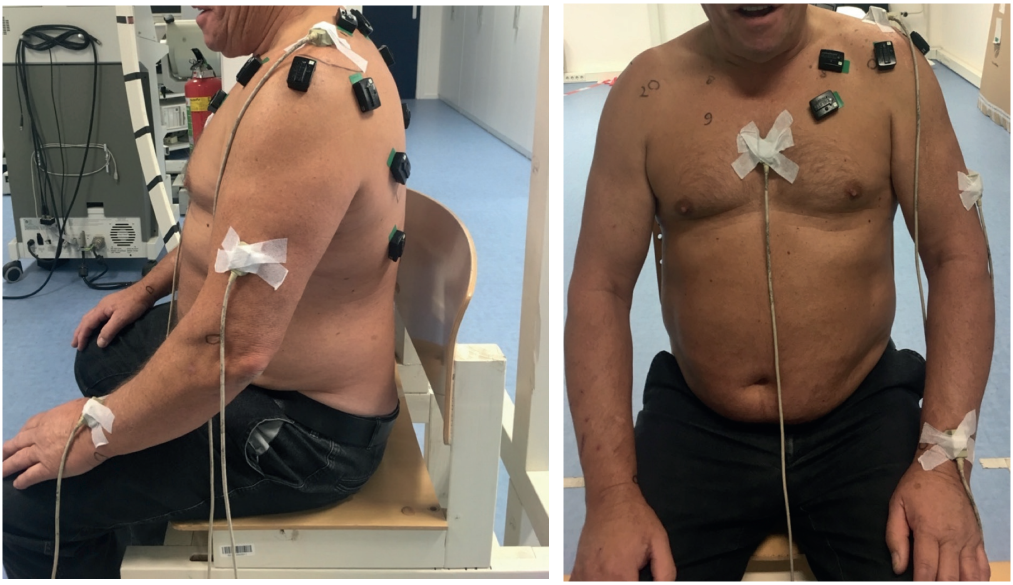
Muscle activation and activation time of the LD, deltoid, teres major, serratus anterior and trapezius (upper, middle and lower) were measured with wireless EMG (Delsys Trigno Wireless, Boston, USA). Location of the sensors can be viewed in Table 1 and patient setup in Figure 1. EMG was used to measure activity of the muscles during active maximum shoulder elevation movements for the LDT and ACS: forward elevation, scapular abduction and abduction in coronal plane.

To scale EMG max for all muscles in the LDT and ACS, maximal isometric voluntary contractions (MIVC) were performed in 6 different movements in a standardized order: forward flexion at 45°, flexion in the scapular plane at 45°, internal and external rotation at 90°of shoulder abduction, retroflexion, horizontal adduction at 90° of shoulder forward flexion. Each resisted task was performed three times and patients had a 1-minute rest period, the largest value was used for MIVC further analysis. The researcher held and resisted the arm at the level of the wrist while the patient was asked to elevate or rotate the arm as forcefully as possible for that specific movement. Muscle activity during the MIVC was measured in millivolts (mV). A linear envelope was achieved by correcting the raw EMG data for offset before rectification and low-pass filtering (2Hz recursive Butterworth). The maximal EMG value measured during the MIVCs for each muscle was used to scale the EMG signal to the maximal performance and this maximal value was set as 100% EMG max. For further analysis, the highest EMG value during each elevation movement was selected and reported as a percentage of the EMG max of that muscle. The timing of recruitment was reported by observing the start of the kinematic elevation curve and measuring the time to recruitment of each shoulder muscle.

Table 1 Sensor placement electromyography

Muscle	Sensor placement
Anterior deltoid	One finger breadth distal to the anterior acromion
Medial deltoid	Most lateral position on muscle
Posterior deltoid	Two finger breadths medial the angle of the acromion
Latissimus dorsi	6 cm below the angulus inferior of the scapula
Serratus anterior	Level of the xiphoid process, lateral body contour and 45° rising to dorsal
Trapezius descendens	1/2 on the line from acromion to the spine on vertebra C7
Trapezius transversus	1/2 between the medial border of the scapula and vertebra T3
Trapezius ascendens	2/3 on the line from the trigonum spinae to the vertebra T8
Teres major	Middle on the muscle belly

Figure 1 Patient setup



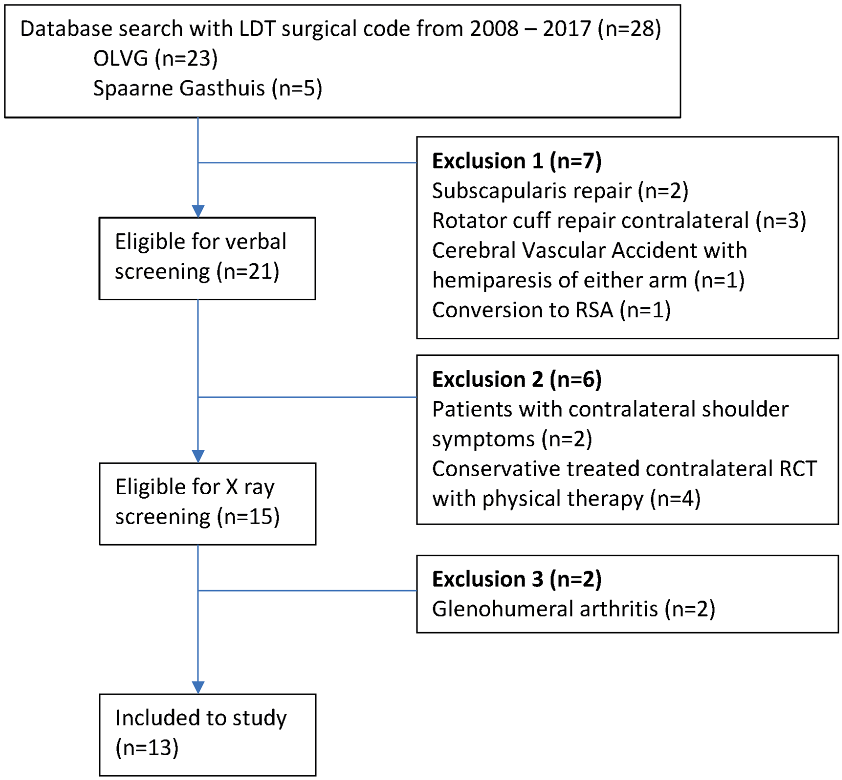
Statistical analysis

The muscle activity in % EMG max of the shoulder muscles (LD, deltoid, trapezius, serratus anterior and teres major muscles) during MAES (forward flexion, scapular abduction, abduction in the coronal plane) for the LDT shoulder and the ACS were analysed in a two-way repeated ANOVA with post hoc tests and Bonferroni correction. The muscle activity was also reported separately for each muscle and active shoulder elevation motion in paired T-tests. The significance level was set at 0.05.

RESULTS

Of the 28 eligible patients identified, 13 patients met the inclusion criteria (Figure 2) and were included. Patient characteristics are listed in Table 2. The mean follow-up was 66.9 ± 36.7 (12 – 112) months. In MAES, the TH motion showed no significant difference between the LDT and ACS shoulder ($F(1,12) = 1.174$, $p=0.300$). However, the GH motion was significantly lower in the LDT shoulder ($F(1,12) =11.230$, $p=0.006$). The results of the shoulder kinematics for each elevation type are reported separately and can be found in the appendix.

Figure 2 Flowchart Inclusion- and exclusion criteria



OLVG: Onze Lieve Vrouwe Gasthuis, Amsterdam, the Netherlands
RSA: Reverse shoulder arthroplasty

Table 2 Patient characteristics

Characteristics (N=13)		**%**
Age at surgery	60.7 years ± 3.2 (57 – 69)	
Gender	Male 10 Female 3	77 23
Smoking perioperative	Yes 2 No 11	15 85
Diabetes mellitus	Yes 1 No 12	8 92
Dominant shoulder LDT	Yes 8 No 5	62 38
Body Mass Index (BMI)	27 ± 3.2 (24.2 – 33.6)	
Radiology		
Hamada	Stage I: 3 Stage II: 9 Stage III: 1	23 69 8
Posterosuperior cuff tear size	Massive (> 5cm): 13 Compete tear of SSP and ISP	100
Cuff tear atrophy (Goutallier)	Grade 3: 10 Grade 4: 3	76 24
Retraction cuff tear (Patte)	Grade 3: 13	100
Subscapularis fatty infiltration	Grade 0: 7 Grade 1: 6	54 46
Teres minor fatty infiltration	Grade 0: 8 Grade 1: 3 Grade 2: 1 Grade 3: 1	61 23 8 8

LDT: Latissimus dorsi transfer
SSP: Supraspinatus muscle
ISP: Infraspinatus muscle

Muscle activity (%EMG Max, Table 3).

Latissimus dorsi

In MAES, the % EMG max did not differ between the LDT and ACS shoulder, $F(1,11) = 0.005$, $p= 0.946$.

Deltoid

The deltoid muscle had significantly higher % EMG max in MAES for the LDT shoulder, $F(1,12)=17.241$, $P=0.001$. When analysing the elevation motions separately, the significant difference was seen during abduction ($P=0.005$, LDT 88.0 ± 16.3, ACS 66.1 ± 24.9) and scapular abduction ($P=<0.001$, LDT 87.6 ± 19.4, ACS 64.0 ± 15.2).

Upper trapezius

The upper trapezius showed a higher % EMG max during MEAS for the LDT shoulder, $F(1,10)=13.612$, $P=0.004$. In the separate elevation motions, only scapular abduction had a significant higher % EMG max for the LDT shoulder, P=<0.001 (LDT 58.9 ± 22.0, ACS 33.7 ± 15.6).

Middle trapezius

In MAES the middle trapezius did not show any significant difference between both shoulders, $F(1,12)= 3.515$, $P=0.085$. However, when accessing the elevation motions separately, scapular abduction showed a higher % EMG max in the LDT shoulder, P =0.020 (LDT 52.3 ± 19.4, ACS 38.1 ± 19.7).

Lower trapezius, serratus and teres major

No differences were found in % EMG max during MEAS between both groups.

Table 3 Muscle activity LDT versus ACS

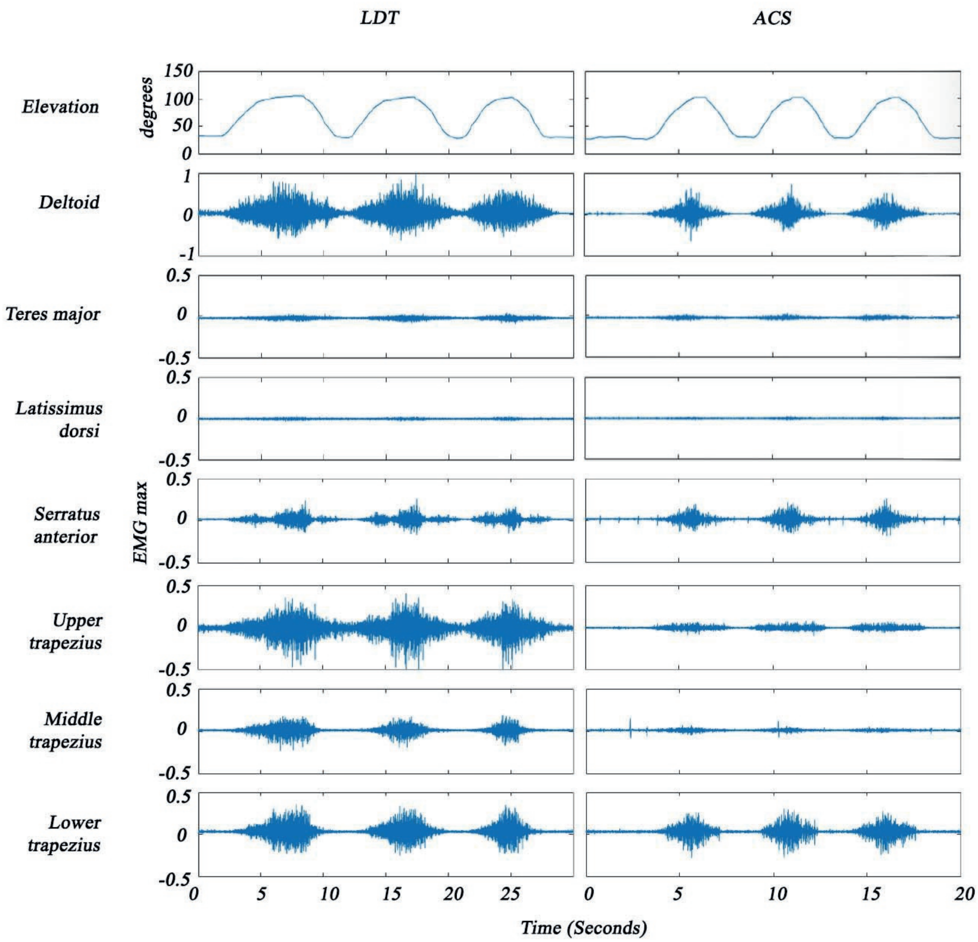
Muscle activation (% EMG max)	N	LDT	Contralateral	P
Latissimus dorsi				
Forward Flexion	12	11.5 ± 7.6	10.9 ± 6.9	0.747
Scapular abduction	13	14.2 ± 11.1	13.3 ± 9.0	0.795
Abduction	13	11.5 ± 10.4	10.4 ± 8.4	0.605
Deltoid				
Forward flexion	13	73.5 ± 26.2	62.3 ± 23.9	0.249
Scapular abduction	13	87.6 ± 19.4	64.0 ± 15.2	<0.001
Abduction	13	88.0 ± 16.3	66.1 ± 24.9	0.005
Trapezius descendens				
Forward flexion	12	45.1 ± 8.20	36.4 ± 28.6	0.286
Scapular abduction	12	58.9 ± 22.0	33.7 ± 15.6	<0.001
Abduction	12	60.1 ± 22.5	45.8 ± 21.0	0.089
Trapezius transversus				
Forward flexion	13	39.5 ± 29.9	38.8 ± 19.9	0.942
Scapular abduction	13	52.3 ± 19.4	38.1 ± 19.7	0.020
Abduction	13	59.4 ± 18.9	43.9 ± 22.0	0.057
Trapezius ascendens				
Forward flexion	13	46.0 ± 25.5	46.8 ± 20.2	0.928
Scapular abduction	13	49.6 ± 23.4	40.0 ± 12.6	0.120
Abduction	13	51.7 ± 24.2	44.9 ± 23.8	0.393
Serratus				
Forward flexion	11	27.7 ± 19.4	36.9 ± 12.6	0.071
Scapular abduction	12	36.6 ± 27.5	31.4 ± 17.1	0.348
Abduction	13	34.5 ± 27.8	34.0 ± 17.7	0.939

Teres major				
Forward flexion	12	21.0 ± 25.2	12.4 ± 5.2	0.249
Scapular abduction	13	18.6 ± 23.4	11.5 ± 8.3	0.337
Abduction	13	19.0 ± 24.7	9.2 ± 7.4	0.200

EMG max, largest electromyographic value for a specific muscle; LDT, Latissimus dorsi transfer

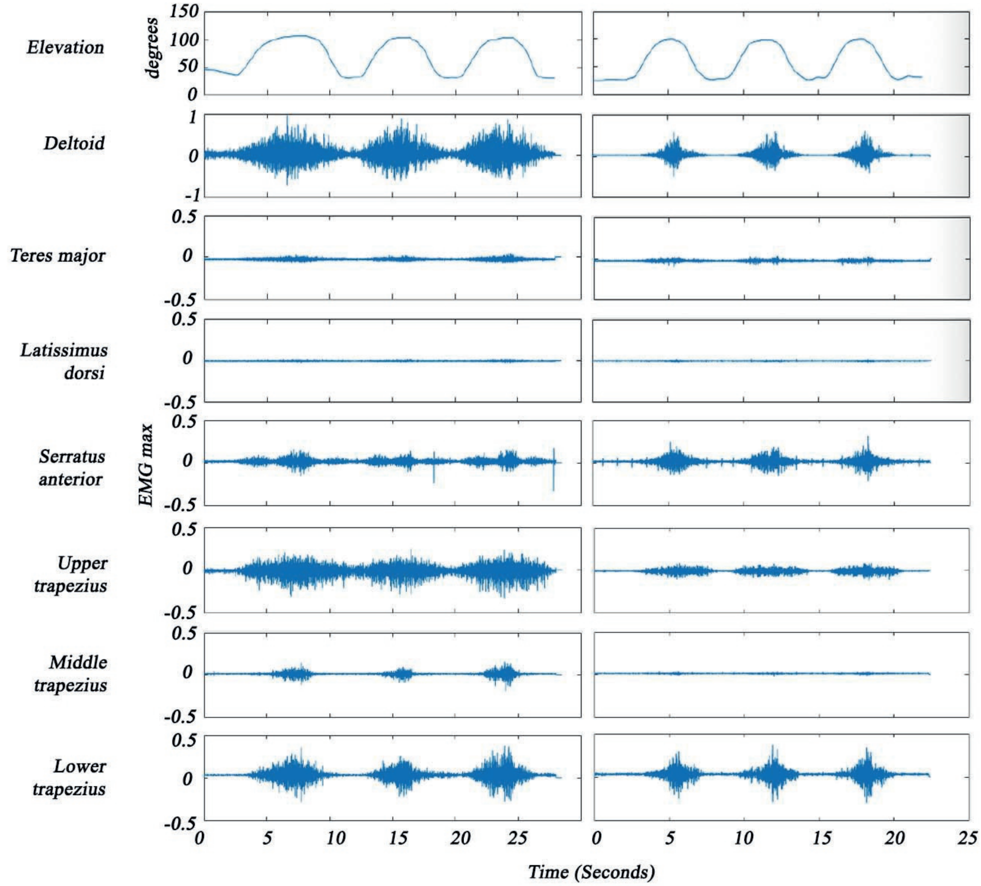
An example of the curves for forward flexion and scapular abduction can be viewed in Figures 3 and 4, respectively. Correct placement of the EMG on the LD muscle was confirmed with resisted retroflexion (Figure 5).

Figure 3 Forward flexion, muscle activity (% EMG max)



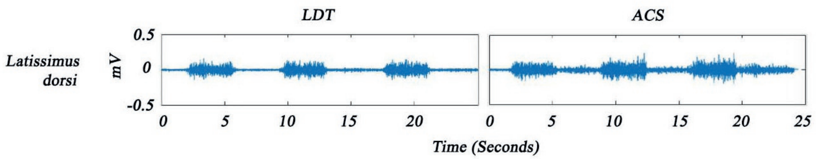
LDT, Latissimus dorsi transfer; ACS, asymptomatic contralateral shoulder

Figure 4 Scapular abduction, muscle activity (% EMG max)



LDT, Latissimus dorsi transfer; ACS, asymptomatic contralateral shoulder

Figure 5 Resisted retroflexion, latissimus dorsi muscle activity (Mv)



LDT, Latissimus dorsi transfer; ACS, asymptomatic contralateral shoulder

Timing of recruitment

No difference in the recruitment time of the shoulder muscles were seen in de LDT shoulder and ACS during MEAS.

DISCUSSION

In our study, patients with an MIRT and preoperative pseudoparalysis had similar shoulder elevation after LDT when compared to the ACS. However, LD muscle activity was not different from its activity in the ACS, which was the case for both magnitude and timing. The difference in muscle activity was seen in the deltoid, upper and middle trapezius muscles. The timing of recruitment of muscles, did not differ between the LDT shoulder and ACS.

As the LD muscle did not show any difference in maximal activity after transfer compared to its ACS during MAES, our findings do not support the theory of an altered LD activity after transfer to its new mechanical role.[22] Even more so, this study suggests that the LD muscle remains active, similar to its native role. Literature has not reached a consensus with regard to the activity of the LD after transfer. [2, 8, 16, 19, 23, 29, 30, 32, 33, 35, 47] One of the reasons of this inconsistency might be the method of assessment and analysing muscle activity results. Several authors measured the MIVC of the LD to compare preoperative and postoperative muscle activity and found an increased postoperative LD muscle activity. They attributed this finding to an active LD contraction after transfer in its new function. [23, 30, 31] However, MIVC is different to isokinetic movement of the shoulder and the LD muscle increased activity could be the result of increased co-contraction after transfer seen in patients with a cuff tear.[46, 49] Others, used the contralateral LD muscle as a reference, set it to 100 % EMG max and reported EMG max values of LD in the surgical shoulder. [6, 35] However, there is a difference in muscle strength between both sides and no account for the changed EMG max after transfer is taken into consideration. In the present study we scaled the muscle activation to the MIVC of that same muscle. Similar to our study, [22] recent studies with analysing isokinetic movements report no difference in LD muscle activation after LDT compared to the ACS. [15, 30]

In this study, the increased activity of the deltoid muscle is seen in scapular abduction and in abduction in the coronal plane after LDT, which is also reported in rotator cuff pathology, subacromial impingement, pain and fatigue of the shoulder.[39, 41, 48, 52] The increase in deltoid activation after LDT in active elevation found in this study is consistent with Hetto [30]and Henseler [29], which has been suggested to be necessary to compensate abduction torque from the MIRT and the additional counteracting forces of the shoulder adductors. [27]

In patients with a rotator cuff tear the shoulder adductors, i.e. latissimus dorsi, teres major and pectoralis major muscle, are more active during active elevation.[27] These muscles counteract the deltoid upward directed shear force during active elevation of the shoulder (co-activation), creating a stable GH fulcrum for the deltoid. [55] After transfer, the new insertion of the LD is located more cranially and dorsally on the humeral head, contributing to better co-activation and making the downward directed pull more effective in its original muscle activation. This phenomenon might be responsible for the better-balanced forces around the GH joint in active elevation and better functional outcomes after LDT. However, we are not certain whether this is achieved actively or passively, the tenodesis effect.[30]

The strong pull of the deltoid muscle without counteracting forces could cause imbalance around the GH joint making active shoulder elevation impossible in patients with an MIRT and pseudoparalysis. It is plausible that the balance of forces around the GH joint has to be partially restored to facilitate active elevation to overcome a pseudoparalysis of the shoulder.[49] A possible explanation for this may be found in that the remaining rotator cuff muscles, are transformed into stabilizers, increasing the GH joint reaction force and partly counteract the forces of the deltoid.[25] This theory of change in rotator cuff function is enforced by the decreased GH motion seen after LDT. [37, 40, 44] When the deltoid elevates the arm, it elevates the arm with a relatively 'fixed' GH joint, explaining the increase in ST contribution.

The increased ST contribution in active elevation is observed after LDT could support the latissimus dorsi and teres major to be biomechanically more effective in exerting additional GH joint reaction force to counteract the force of deltoid. A more laterally and upward rotated scapula increases the force of shoulder adductors directed to the GH joint. [5]

In this study a higher activity of the upper and middle trapezius in active scapular abduction was observed. This increase could partly be responsible for the increased ST contribution seen after LDT, a phenomenon not earlier described in literature reporting on LDT. However, studies have reported increased trapezius and serratus activity in a massive cuff tear or with suprascapular block simulated cuff tear.[27, 39]

Shoulder muscles are recruited to create a physiological scapulothoracic rhythm in active elevation of the arm. [7, 9–11, 26, 27, 42, 51] The change in timing of activation of each shoulder muscle could also be responsible for the increased functional outcome after LDT.[51] However, we did not find any difference in activation timing between the LDT shoulder and ACS.

Limitations

This study has some limitations. We only were able to include 13 patients in this study; if the study is performed on a larger scale some muscle activities and different muscle activity levels could be significantly different between LDT and ACS. The included patients did not receive any local pain inhibitor preoperative to determine whether pain was the limiting factor of shoulder elevation. We can only assume that the LDT increased shoulder elevation.[14] The ACS was considered to be healthy without any pathology. However, some shoulder pathologies can be asymptomatic yet reveal different muscle activation in EMG evaluation.

In this study, the MIVC for each muscle was measured in several positions for scaling the EMG max. In this assessment, it was assumed that the patients truly maximally contracted their muscle. This, however, might not always truly be happening as patients after LDT might have unconsciously held back to avoid pain. Therefore, overestimation of the activation of the muscle during the active movements may have occurred. Although the use of EMG bears the advantage of a noninvasive method of assessing muscle activity, the surface electrode attached on the skin may unintendedly have recorded muscle activity of a different muscle. Nevertheless, the EMG data of each muscle in our study had a consistent pattern between patients. Preoperative EMG data of the LDT shoulder was not available, making it difficult to attribute changes of % EMG max to the LDT, as it could result from an MIRT as well.

Another limitation is the large difference in follow-up time among the patients. Some patients were operated nine years before the measurements, while for others the transfer surgery was only one year postoperative. The muscles of some shoulders may therefore have had more time to adapt to the new situation than other muscles, possibly affecting the results of muscle activity assessment. Future studies should investigate which muscle activation patterns of the shoulder are needed to confirm the increased downward directed force with its native activity of the LD due to the new proximal insertion site on the proximal humerus.

Conclusion

After LDT, in MAES, the LD muscle remains active in its native form. The deltoid, upper, and, middle trapezius increase their activity after transfer. The combination of a more cranial insertion of the LD tendon after transfer, its native activity and the increased activity of the deltoid, middle and lower trapezius could be responsible for an increased GH joint reaction force increasing active elevation in the shoulder in patients with an MIRT.

APPENDIX

The supplementary data can be found in Chapter 5.

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7

Agreement of integrity after latissimus dorsi transfer, an MRI study

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ABSTRACT

Purpose

The aim of this study was to evaluate the intra and inter-observer agreement of tendon integrity and muscle degeneration after a latissimus dorsi transfer with magnetic resonance imaging (MRI).

Methods

Fifteen patients were recruited, after treatment with LDT for a massive irreparable posterosuperior rotator cuff tear (MIRT). Protocolized shoulder MRIs were conducted at least one year after surgery and were scored by two shoulder surgeons and 2 musculoskeletal radiologists. The integrity of the LDT and remaining rotator cuff tendons together with the degree of fatty infiltration were scored. The scoring was repeated twice, with a two-month period gap. The intra and inter-observer agreement were statistically tested with Cohen's kappa and Fleiss kappa agreement.

Results

Intra-observer agreement for LDT integrity showed an agreement between κ 0.26 – 0.44. Full-thickness tear of the supraspinatus κ 1.00, infraspinatus κ 0.63-1, subscapularis κ 0.42, teres minor κ 0.53-0.63, and ranging cuff fatty infiltration κ 0.06 - 0.20. The inter-observer agreement showed κ 0.48 for LDT integrity. A full-thickness supraspinatus tear κ 0.71, infraspinatus 0.63, subscapularis κ 0.31, and teres minor κ 0.65. Fatty infiltration of the cuff muscles, depending on Goutallier grade, ranged κ 0.23–0.55.

Conclusion

The intra-observer agreement for LDT integrity ranged between fair to moderate. Intra-observer agreement for full-thickness cuff tears, depending on the tendon, between moderate to almost perfect, and fatty infiltration varied amongst the reviewers indicating inconsistency of the measures. The inter-observer agreement had a moderate agreement for LDT integrity amongst the reviewers. Depending on which tendon of the cuff, the agreement for a full-thickness tendon tear was fair to substantial.

Level of evidence

Level 3, observational study

Key words

Muscle transfer, MRI, inter-observer agreement, rotator cuff tears, tendon integrity

INTRODUCTION

The latissimus dorsi transfer (LDT) is a treatment option for a massive irreparable posterosuperior rotator cuff tear (MIRT). [11, 23, 31] The rationale behind an LDT is to change the function of the latissimus dorsi from an adductor and internal rotator to an abductor and external rotator of the shoulder joint. However, the transfer might work solely through the tenodesis and downward-directed pull of the latissimus dorsi. [11, 13] This procedure increases shoulder elevation, which is necessary for activities of daily living. Surgically, this transfer is performed by releasing the latissimus dorsi tendon at its insertion and fixing it on the footprint of the supraspinatus/infraspinatus, as described by Gerber. [9]

The transfer reports good clinical outcomes after LDT for patients with massive rotator cuff tears.[9, 11, 16] However, a clinical failure rate is reported of 10 %, 9 years after LDT. [4] It is uncertain whether this is solely attributed to failure of the tendon transfer. Natural progression of the cuff tear or osteoarthritis can also contribute to functional deterioration after LDT. [23] Postoperative imaging is needed to understand if clinical failure after LDT is attributed to lost LDT integrity or progression of the remaining cuff tear.

Preoperative assessment of rotator cuff quality is mostly performed based on magnetic resonance imaging (MRI). Currently, the rotator cuff tear is graded by anteroposterior tear size, fatty infiltration, muscle atrophy and tendon retraction. [10, 23, 25, 29] Assessment of rotator cuff tear characteristics with MRI has variable agreement between reviewers in the literature. [19][17][12] After rotator cuff repair the agreement on tendon healing and re-tears only has a moderate interobserver agreement. This may be due to signal change of the tendon after repair, hardware scattering in the scan, scar tissue in the rotator cuff, quality of the MRI scan, or the inability to view the entire tendon footprint on the greater tuberosity. [15]

Several authors have analyzed the tendon integrity with MRI after LDT [1, 22, 30] However, no studies have reported the intra- and interobserver agreement after LDT. The aim of this study was to evaluate the intra- and interobserver agreement of the latissimus dorsi tendon integrity after transfer and the status of the remaining rotator cuff tear on MRI.

METHODS

Recruitment of patients

The study was approved by the local medical ethical committee with number WO-15.116, at the OLVG in Amsterdam, The Netherlands. Patients treated with an LDT were searched by surgical code in the database of our institution. Patients were included after LDT for a massive irreparable rotator cuff tear, which was defined as an anteroposterior tear size larger than 5 cm with fatty infiltration Goutallier stage 3 or more. [19] Patients with a follow-up longer than a year between 2008 and 2017 were approached by phone to participate in a clinical and radiological (MRI) evaluation. Patients were excluded in case of previous surgery in the same shoulder after the LDT transfer. Patients were asked to fill out an informed consent and a consultation after imaging was planned if any new findings were reported on the MRI. If this was not possible, the general practitioner was informed about the abnormality.

Surgical procedure

The LDT was performed with an interscalene brachial plexus block and general anesthesia as described by Gerber.[8] Patients were positioned in the lateral decubitus position with the affected arm on an arm rest. For this procedure, a 5 - 7cm S-shaped incision is made at the posterior axillary fold to harvest the latissimus dorsi (LD) tendon. The distal LD muscle is released from the chest wall with care of mobilizing the thoracodorsal neurovascular pedicle. The tendon is armed with two non-absorbable Ultrabraid sutures (Smith & Nephew, Andover, MA, USA). An anterolateral incision of 5 cm is made to expose the interval between the anterior and middle deltoid muscles. The footprint of the supra- and infraspinatus muscle is debrided. Blunt dissection is performed to create the interval between the long head of the triceps and dorsal deltoid muscle. Two to four double-loaded footprint anchors (Smith & Nephew, Andover, MA, USA) are used to fix the tendon flat covering the infraspinatus footprint and as far as possible anterior on the supraspinatus footprint.

MRI protocol

The exams were performed on a 1.5-T MRI system (Ingenia, Phillips, Best, the Netherlands) with a dedicated transmit-receive shoulder-phased array coil and fast spin-echo sequencing. The scan sequence consisted of a transversal proton density (PD) turbo spin-echo (TSE), 3 mm slice thickness with field of view (FOV) 140x140, coronal PD TSE, 3 mm slice thickness, FOV 140x140, coronal T2 TSE special attenuated inversion recovery (SPAIR), 3 mm slice thickness, FOV 140x140, oblique sagittal PD TSE, FOV 250x250 and an oblique coronal PD, FOV 250x250.

Evaluation of LDT integrity and rotator cuff

Two orthopaedic surgeons, specialized in the shoulder and two dedicated musculoskeletal radiologists with over 12 years of experience reviewed the postoperative MRI scans after LDT independently. The transfer surgery was performed by the orthopaedic surgeons who also participated in the MRI assessment of this study. All reviewers were blinded to the patient information. Assessment of the MRI was completed on a form, scoring the integrity of the LDT (intact or not), the integrity of the rotator cuff tendons (no tear, partial or full thickness tear) and degree of fatty infiltration of the subscapularis, supraspinatus, infraspinatus and teres minor according to Goutallier. [30] The score form can be found in the supplemental data / appendix. Each reviewer was given 2 weeks to complete the form. After a two-month interval, a second form was provided to the reviewers with a randomly altered order of MRI scans. The reviewers were again requested to submit the second form within 2 weeks.

Statistical analysis

The intra-observer agreement for each item was calculated with the Cohen's kappa for each reviewer. The inter-observer agreement for each item in the form was calculated with Fleiss kappa. The statistical calculation was performed with SPSS (IBM). Kappa values were interpreted in accordance with Landis and Koch.[12]

RESULTS

Eighteen patients were invited to participate in the study. Three patients declined postoperative imaging and subsequent participation in the study, due to relocation to a different province (n=2) or if they were revised to a reverse total shoulder arthroplasty (n=1). The 15 included patients consisted of 9 males and 6 females with a mean age of 62.7 years. The interval between LDT and postoperative MRI ranged from 12- 105 months, with an average of 82 months.

Intra-observer agreement

The intra observer-agreement for LDT integrity varied between κ 0.26 – 0.44, an example of an intact LDT is captured in Figure 1. Full-thickness tear of the supraspinatus showed κ 1.00, infraspinatus κ 0.63-1, subscapularis κ 0.42, teres minor κ 0.53-0.63, and fatty infiltration depending on rotator cuff tendon involved between κ 0.06 - 0.20 (Table 1).

Inter-observer agreement

The inter-observer agreement for LDT integrity was κ 0.48. Full thickness supraspinatus tear κ 0.71, infraspinatus κ 0.63, subscapularis κ 0.31 and teres minor κ 0.65. Fatty infiltration depending on the rotator cuff tendon involved, ranged between κ 0.23 – 0.55 (Table 2).

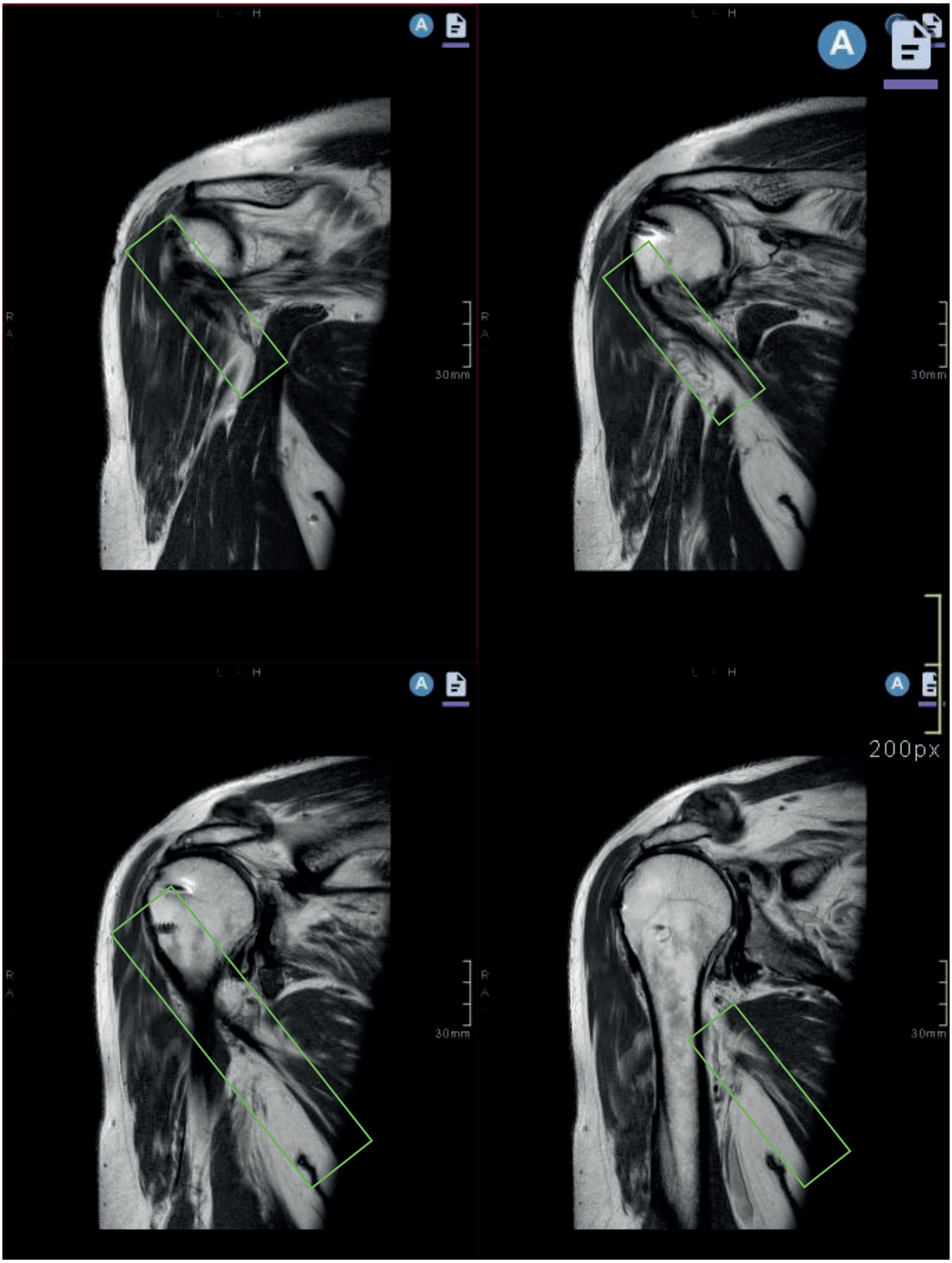
Table 1 Intra-observer agreement

Variable	Kappa
Intact LDT	0.26 – 0.70
Supraspinatus	
Full thickness tear	1.00
Fatty infiltration	0.17 – 0.24
Infraspinatus	
Full thickness tear	0.63 – 1.00
Fatty infiltration	0.06 – 0.04
Subscapularis	
Full thickness tear	0.42 – 0.42
Fatty infiltration	0.20 – 0.39
Teres minor	
Full thickness tear	0.63 – 0.63
Fatty infiltration	0.17 – 0.39

Table 2 Inter-observer agreement

Variable	Kappa	Standard error
Intact LDT	0.48	0.11
Supraspinatus		
Full thickness tear	0.71	0.11
Fatty infiltration	0.44	0.06
Infraspinatus		
Full thickness tear	0.63	0.11
Fatty infiltration	0.24	0.08
Subscapularis		
Full thickness tear	0.31	0.11
Fatty infiltration	0.23	0.70
Teres minor		
Full thickness tear	0.65	0.11
Fatty infiltration	0.55	0.07

Figure 1 Example MRI, intact latissimus dorsi tendon after transfer



Example coronal MRI of a 57-year male, 2 years after a latissimus dorsi transfer

DISCUSSION

Our study reports a fair to moderate intra-observer agreement κ 0.26 – 0.44 for latissimus dorsi tendon integrity after transfer, near perfect agreement for full thickness tear of the supraspinatus κ 1.00, substantial to near perfect agreement for the infraspinatus κ 0.63-1, moderate agreement for subscapularis κ 0.42, moderate to substantial agreement for teres minor κ 0.53-0.63 tendon integrity, and just slight agreement for fatty infiltration of the rotator cuff musculature ranging between κ 0.06 - 0.20. The inter-observer agreement for latissimus dorsi tendon integrity was moderate κ 0.48 after transfer, substantial for full thickness supraspinatus κ 0.71, substantial for infraspinatus κ 0.63, fair for subscapularis κ 0.31 and substantial for teres minor tears κ 0.65. Fatty infiltration of the cuff tendons ranged from fair to moderate κ 0.23 – 0.55.

Although agreement with MRI findings after LDT has not been reported in the literature, it has been reported after primary cuff repair. Ma et al reviewed 42 MRI scans postoperative after primary rotator cuff tear and found relatively high inter-observer repair integrity ranging from κ 0.85 – 0.92. This high agreement was attributed to the definition of reading rules of the scans. [20] Our reviewers received similar instructions before the start of the study. However, we were not able to reproduce the reported high agreement values. A factor that could play a role for our inferior results is the learning curve associated with the interpretation of the LDT, it remains rare to perform an MRI of the shoulder after transfer. Our lower agreement rates could be the result of the altered shoulder anatomy after LDT. Hasegawa et al reviewed cuff integrity after repair in 68 MRI scans and reported low inter- observer agreement κ 0.31 after 6 months and κ 0.49 after 12 months, which are similar to our results. [12] Niglis et al found a similar inter-observer agreement κ 0.39 after reviewing 50 MRI scans, scoring rotator cuff integrity after repair. [24] Although an LDT is a different procedure, similar inter-observer agreements are seen when scoring the rotator cuff after repair. Kany et al [14] developed a classification system for LDT integrity with metal markers inserted during surgery at 3 locations around the LDT tendon. Rupture of the tendon was assumed if the distance between the markers increased on a plain radiograph. However, it is unknown if the tendon length, physiologically, increases over time after LDT. Furthermore, in case of a partial tear of the transferred tendon, the distance between the markers may not always be increased.

The present study reported a substantial to near-perfect intra-observer and a substantial inter-observer agreement for a full-thickness tear of the supraspinatus and infraspinatus. Ninety percent of our patients had cuff repair surgery more than 5 years before their MRI. Therefore, it is possible to compare our results with two types of studies. Studies comparing agreement of tendon integrity for initial cuff tears and studies reporting on re-tears after repair. However, postoperative changes in the cuff tendons that can affect judgment are unlikely to still exist after 5 years, therefore it is plausible to compare agreement values of the supraspinatus and infraspinatus tendons to preoperative rotator cuff tear imaging. Van Dyck reported a κ 0.91 for full-thickness supraspinatus tears using indirect MR arthrography in 67 patients.[3] Kuhn repored a similar high κ 0.95 for supraspinatus and infraspinatus full thickness tears in 30 patients assessed by 12 fellowship trained orthopaedic surgeons. [18] Our study shows similar results for full-thickness supraspinatus and infraspinatus tears, however, the indication for an LDT in our institution is an MIRT, which was known by our reviewers. This could have induced a scoring bias in our study.

Subscapularis tendon integrity showed a slight to fair interobserver agreement κ 0.31 in the present study, which is consistent with the literature. [5, 27] In a study by Smuncy et al, 22 orthopaedic surgeons reviewed 30 patients, with an agreement κ 0.28 for subscapularis tears. The oblique coronal and sagittal views make it difficult to appreciate the insertion of the subscapularis tendon on the lesser tuberosity. Radial slice MRI could increase subscapularis tear agreement. [7] Another factor for low agreement of subscapularis tears, is that tendinopathy alone can give abnormal signal changes which may simulate a full-thickness tear.[28]

This study reports only a slight intra-observer agreement for fatty infiltration in rotator cuff muscles. Our data suggests that the reviewer frequently marked one grade above or below the previously marked Goutallier score, causing disagreement. This is consistent with the current available literature. [15, 19] The five stages of the Goutallier classification could be difficult to separate, making a simpler classification system for fatty infiltration necessary. Fuchs simplified the grading for fatty infiltration down to 3 categories with a better agreement. [6] Other simplified and modified classification systems have been proposed to increase agreement between reviewers. [26] Software to measure and calculate ratios can aid in a more accurate grading of fatty infiltration in the cuff muscles. A cross-sectional software has been described which showed high agreement in detecting cuff tendon degeneration. [21]

The timing of postoperative MRI can also influence intra- and interobserver agreement. Less postoperative signal changes are observed 1 year after surgery [2, 20] Therefore, all our MRI scans have been reviewed at least 1 year after transfer surgery to assess tendon integrity without any significant postoperative signal changes.

Eighty percent of our patients had prior rotator cuff surgery before the LDT. Arguably, the remaining cuff could be compared to the postoperative MRI studies in the literature. These studies were mentioned before as comparative studies to the LD tendon integrity. Additionally, Khazzam et al found substantial agreement (κ 0.70) for supraspinatus, and infraspinatus tendon integrity with 31 MRI scans after primary cuff repair. [15] These findings are consistent with our study. Hasegawa et al compared three different classification systems (Owen, Sugaya and Hayashida) for full-thickness or partial thickness cuff re-tears. They analysed 68 MRI scans, 24 months after primary rotator cuff repair and found no difference in agreement between the systems. [12] They report good to excellent κ values for all classification systems for full-thickness rotator cuff re-tears, however, not which tendon is involved.

Finally, ultrasound is mentioned as an imaging modality to assess LDT integrity, however, technique and agreement are not reported.[1] Therefore, with the lack of appropriate studies, it is not possible to draw strong conclusions from ultrasound imaging for LDT integrity.

Limitation

This study has several limitations. In our institution, LDT transfers are predominantly performed on patients with a massive irreparable rotator cuff tear. The knowledge and assumption of a large posterosuperior rotator cuff tear with high grades of fatty infiltration could have affected the reviewers scoring judgment. A control group was not possible as an LDT was not performed in patients with an intact posterosuperior cuff. To elucidate this, surgeons or radiologists without knowledge of the LDT indication could have been contacted for review. However, only a handful of these physicians understand the shoulder anatomy after an LDT. For this study, a 1.5T MRI scan was utilized, which should be sufficient to diagnose rotator cuff pathology and integrity of the latissimus dorsi tendon after transfer. However, currently, there are institutions using the 3.0T MRI scan, which could improve image quality.

Conclusion

The intra and inter-observer agreement for latissimus dorsi and rotator cuff integrity mainly ranged between moderate to fair after an LDT. Inconsistencies in intra-observer agreement are reported for fatty infiltration of the cuff musculature after an LDT. The changed anatomy in the shoulder, the difficulty of the grading system, and learning curve might contribute to the relatively low agreement in our study.

APPENDIX

Scoring sheet

MRI after Latissimus Dorsi Transfer

Patient name:
Patient number:

Post-operative MRI

Latissimus dorsi transfer visible	Y/N
Latissimus dorsi transfer intact	Y/N
Partial tear of the transfer	1. At footprint
	2. Musculotendinous junction
If complete rupture	3. At footprint
	4. Musculotendinous junction
Supraspinatus intact *	Y/N
Goutallier	0-4
Patte	1-3
Thomazeau	1-3
Infraspinatus intact *	Y/N
Goutallier	0-4
Patte	1-3
Thomazeau	1-3
Subscapularis intact *	Y/N
Goutallier	0-4
Patte	1-3
Thomazeau	1-3
Teres minor intact *	Y/N
Goutallier	0-4
Patte	1-3
Thomazeau	1-3

*Only complete tendon tears are considered as not intact

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8

General discussion

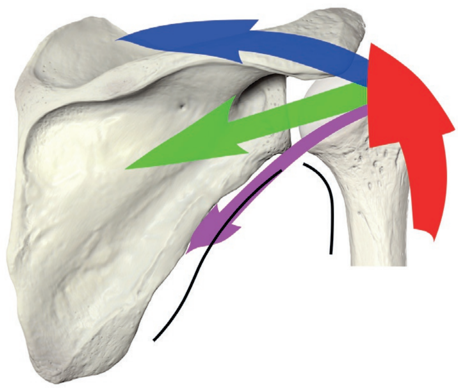
GENERAL DISCUSSION

The main subject of this thesis is: understanding shoulder kinematics and muscle activation after a latissimus dorsi transfer (LDT) in patients with a massive irreparable posterosuperior rotator cuff tear (MIRT) and a clinical pseudoparalysis. The result of this work has shown that the LDT is able to restore active shoulder elevation, although this was achieved with different kinematics. The difference was found in that the glenohumeral (GH) contribution was smaller and the scapulothoracic (ST) contribution larger when compared to the asymptomatic contralateral shoulder (ACS) in active shoulder elevation. The different shoulder kinematics are the result of a likely changed muscle activation pattern. While the mechanical role of the latissimus dorsi (LD) muscle was expected to change after transfer, no difference in activity in comparison to the ACS was found. The LD muscle remained active in its native role, which introduces the theory of the tenodesis effect after transfer. In these patients, the deltoid, the upper and middle trapezius showed a higher activation after an LDT when compared to the ACS in active shoulder elevation. These muscles are thought to play a significant role in the change of shoulder kinematics and maintaining active shoulder elevation after an LDT.

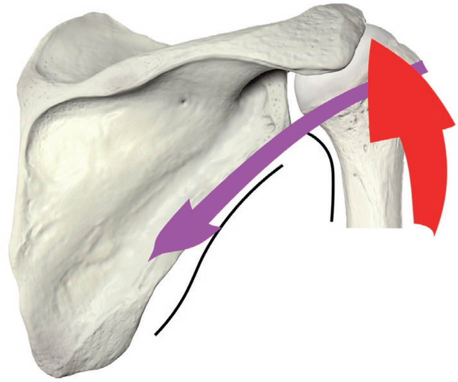
As explained in chapter 5, we expected that the LD muscle would change its mechanical role in active elevation after transfer in patients with an MIRT. That implies that the LDT muscle changes its activation pattern from a shoulder adductor and internal rotator to an abductor and external rotator. However, **this expected change in activation was not found** in our study, after assessing thirteen patients with 3-dimensional kinematics and electromyography (EMG) whom underwent an LDT for an MIRT.

This finding is not completely in accordance with the current literature as several studies found an active change in muscle activation of the LD muscle after transfer. [7, 11, 13, 15] These conflicting findings could be the result of the LD muscle already acting differently in the setting of a rotator cuff tear and the various methods of assessing the LD muscle after transfer. Firstly, it has been reported that the shoulder adductors are activated in active shoulder elevation in patients with an MIRT, which could confuse interpretation of the LD activity after transfer surgery.[9, 25] The theory exists of achieving a stable GH fulcrum to be able to actively elevate the shoulder. Once a large enough rotator cuff tear is present, the remaining intact cuff muscles alone are insufficient to create a stable GH fulcrum for the deltoid to rotate the proximal humerus and elevate the arm. Without a stable GH fulcrum, the deltoid will pull the proximal humerus superiorly, without rotating at the GH joint, which is needed for active shoulder elevation. The adductor muscles have shown to participate in re-creating a stable GH fulcrum for the deltoid in this situation. [25] The remaining cuff muscles and the shoulder adductors, i.e. latissimus dorsi and teres major muscle work together by increasing their activation in shoulder elevation to achieve a stable GH fulcrum (Figure 1) [8, 17, 24, 25] This change in LD activation in a setting of a rotator cuff tear is important to consider when interpreting LD activation after transfer surgery.

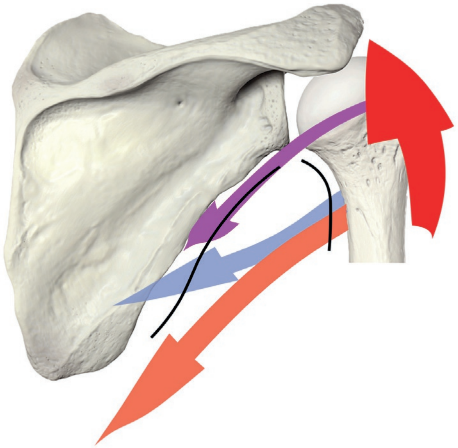
Figure 1 Concavity compression



A Normal shoulder



B Massive rotator cuff tear



C Compensated rotator cuff tear

Arrow	Muscle
Red:	Deltoid
Blue:	Supraspinatus
Green:	Infraspinatus
Purple:	Teres minor
Grey:	Teres major
Orange:	Latissimus dorsi

A) Normal concavity compression from the rotator cuff
B) Decreased concavity compression after massive rotator cuff tear and superior humeral head migration
C) Compensated concavity compression by the shoulder adductors in a massive rotator cuff tear

Some authors have found that the LD does change its mechanical role after transfer in patients with an MIRT. [7, 11, 13, 15] Several of these studies have assessed the LD activity with isometric shoulder testing after transfer. Isometric contraction does not mimic the active range of motion in the shoulder. With maximal isometric contraction, more strength is involved, which could induce a muscle activation pattern not representative for active shoulder elevation. [20, 21] These findings might wrongfully be attributed to the change in LD muscle activation after transfer. Isokinetic assessment of the shoulder is more similar to active shoulder range of motion, which according to our study does not show any change in function of the latissimus dorsi after transfer. Moreover, others studies used the contralateral LD muscle as a reference to scale the 100% EMG max, and reported peak EMG values of LDT shoulder.[2, 16] The LDs on both sides cannot be assumed to be as strong and they are mechanically different owing to the transfer. Activity scaled to only one side is risky: the same activity for both muscles does not refer to the same force level or even mechanical action. In our opinion, it is more accurate to scale muscle activation to the maximal isometric voluntary contraction MIVC of that same muscle. Therefore, our conclusion remains that the LD muscle does not change its role after transfer in patients with an MIRT in active elevation when compared to the asymptomatic contralateral shoulder (ACS).

Subsequently, one can argue that the LD does change its role after transfer when it is compared to the situation of a rotator cuff tear.[25] As explained before, in the setting of an MIRT the LD muscle is active, creating a stable GH fulcrum for the deltoid to elevate the shoulder. According to our study, this activation of the LD is not observed anymore in active elevation after transfer surgery.

Based on this thesis the conclusion seems warranted that the LDT restores active elevation for an MIRT through the tenodesis effect and the LD's native activation, instead of changing its mechanical role. The tenodesis effect in this situation is the passive downward directed pull after the LD tendon is transferred. When transferring the LD tendon, it is fixed onto the greater tuberosity of the humerus. In this new position, the tendon can exert a more downward directed force than in its original insertion. Moreover, the transferred tendon is much closer to the center of rotation of the GH joint. Therefore, when creating a downward directed force at this point, less latissimus dorsi and deltoid torque is needed to upward rotate the proximal humerus. In turn, this decreases the deltoid upward-directed shear force needed to lift the arm (Figure 2). All these actions together might increase the robustness of the GH joint in active elevation. Thus, the LDT is thought to restore active shoulder elevation by increasing the robustness of the GH joint with the tenodesis effect and the LDs native role instead of actively changing to a shoulder abductor and external rotator.

Figure 2

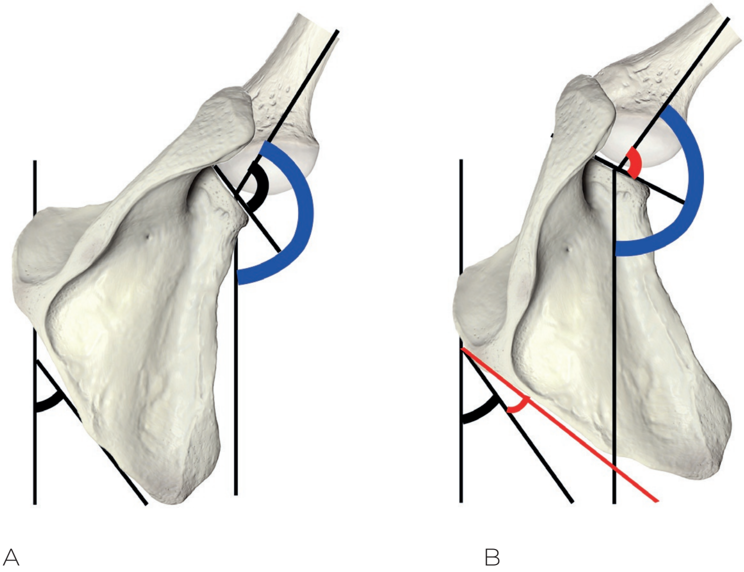
The original and transferred insertion of the latissimus dorsi tendon. The latissimus dorsi transfer has an increased glenoid-directed force, increased downward-directed pull and is closer to the glenohumeral center of rotation.

Chapter 5 reports that an LDT can restore active shoulder elevation in patients with an MIRT, however this is not solely attributed to the tenodesis effect of the LD muscle. When observing shoulder kinematics after an LDT, a decreased GH contribution and increased ST contribution are seen in total shoulder active elevation.[5, 10, 12] The decreased GH contribution can be explained by the missing glenoid-directed compressive forces of the posterosuperior rotator cuff to maintain a stable GH fulcrum in its entire range.[24] As mentioned before, to achieve active shoulder elevation, a stable GH fulcrum is required for the deltoid to be able to elevate the arm. It could be that the contribution of the scapular upward orientation is dependent on the glenoid directed compressive forces to counteract the upward directed deltoid shear force. For example, in the situation of intact rotator cuff, a 2:1 glenohumeral and scapulothoracic rhythm in active elevation is seen. When observing patients with an MIRT, a decreased GH and increased ST contribution is seen in active shoulder elevation (Figure 3).[6] This change can be explained by that the remaining rotator cuff muscles, changing their role from GH rotators to stabilizers. While the remaining rotator cuff muscles increase their force to compress the humeral head in the glenoid fossa, a stable GH fulcrum is created to counteract the vertical shear force of the deltoid to be able to actively elevate the arm. [8] By doing so, the remaining cuff muscles might lose some of their rotational capabilities, which would explain less GH motion seen in patients after a cuff tear. There is a correlation between increasing rotator cuff tear size and increasing ST contribution (with decreasing GH motion) in active shoulder elevation. [23] Therefore, it could be postulated that the stability or robustness of the GH joint may determine the scapulothoracic rhythm. In patients with an MIRT, the remaining cuff muscles are insufficient to create a stable GH fulcrum, additional activation of the shoulder adductor muscles are required for active shoulder elevation. It is believed that the shoulder adductor muscles contribute in creating a stable GH fulcrum in patients with a massive rotator cuff tear for active shoulder elevation.[26] Once too much of the rotator cuff is torn with breaching of the transverse force couple, the shoulder is unable to maintain a stable GH fulcrum for the deltoid and active shoulder elevation could be lost.[18] For these patients an LD can increase the glenoid directed forces after transfer surgery, which in turn could increase GH robustness, making active elevation possible again.

According to the principle of shoulder kinematics, which is also determined by GH stability (robustness), a partly restored scapulothoracic rhythm can be expected after an LDT in active shoulder elevation. Although this change in kinematics may be limited, we do believe that some restoration takes place due to the increased glenoid-directed forces after an LDT. Complete restoration of shoulder kinematics can only be expected after a healed rotator cuff repair, which will not be the case after an LDT for an MIRT. [19]

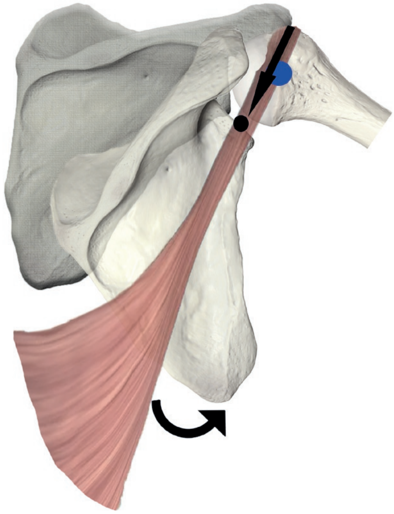
Interestingly, the increased ST contribution seen in patients with an MIRT work favorable for the deltoid, the latissimus dorsi muscle, and overall shoulder elevation. For the deltoid, an increased scapular upward rotation keeps the deltoid muscle length and therefore its force throughout a larger shoulder range of motion. This could facilitate the increased deltoid force needed to actively elevate the shoulder in the setting of an MIRT. [8, 31] Moreover, the increased scapular upward rotation centralizes the LD muscle force towards the glenoid, which might add to increased GH stability or robustness. After transfer surgery, additional GH stability is achieved by centralizing the glenoid directed force of the latissimus dorsi even further (Figure 4). Finally, the increased scapular upward rotation compensates for the decreased GH contribution, which can restore maximal shoulder elevation.

Figure 3 Shoulder kinematics



A Normal kinematics
B Increased scapulothoracic and decreased glenohumeral motion in rotator cuff pathology

Figure 4 Increased scapular upward rotation, centralizes LD force in the glenoid fossa



In chapter 6 the shoulder activation pattern responsible for the increased scapular upward rotation was assessed in active elevation after an LDT. Our study reported an increased upper trapezius, middle trapezius and deltoid muscle activation in active elevation after an LDT for patients with an MIRT. The LD, teres major and serratus anterior did not show an increased muscle activation. As reported in the literature, upward rotation of the scapula is put in motion by mainly the trapezius and serratus muscles.[14, 20] However, an increased activation of the serratus anterior in active elevation after an LDT was not seen in our study. Accurate measurement of the serratus anterior is a known obstacle when utilizing surface EMG. Only the upper part of the serratus anterior muscle was adequately measured due to its challenging surface anatomy. The serratus anterior muscle was not assessed entirely, probably contributing to this conflicting result after an LDT.

As mentioned before the LD muscle does not increase its activity in active elevation after an LDT surgery in patients with an MIRT when compared to the ACS. However, if we assume that our patient population had a preoperative increased LD and teres major activation in active elevation as reported by others, apparently, the tenodesis effect is sufficient enough to create a stable GH fulcrum without activation of the LD and teres major muscles in active shoulder elevation.[30]

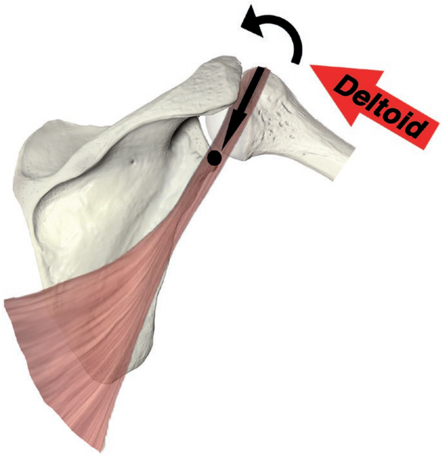
In our study we found that the LDT is able to restore shoulder function in patients with an MIRT and clinical pseudoparalysis, however, the definition of a clinical pseudoparalysis is not clearly stated in the current literature. In the present study, a clinical pseudoparalysis was defined as a loss of shoulder elevation beyond 90 degrees, which is widely used.[27] However, this was reported without administering a subacromial pain reducing injection. In this situation, it could have been that pain was the limiting factor for their limited active shoulder elevation. A true pseudoparalysis is defined as having no shoulder elevation after administering a subacromial lidocaine injection. [27] If after the injection an increased elevation is observed, it should be defined as a pseudoparesis. A pseudoparesis might be more appropriate with our patient population, as in a true pseudoparalysis the subscapularis tendon is usually torn, which was excluded for the LDT surgery. [1]

In chapter 4 the different treatment modalities for an MIRT are reported with their clinical outcome. A sound comparison between all these techniques is not possible due to the widely ranging definition of an MIRT and thus indication for surgery. Interestingly, the mode of function of the LDT is quite similar to other treatment modalities for an MIRT.

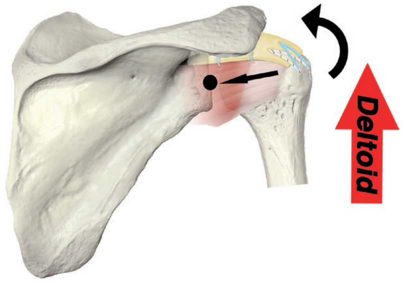
The LDT creates a passive downward-directed pull with a more proximal insertion on the greater tuberosity. This downward directed pull facilitates humeral rotation at the GH joint instead of cranialization with the upward deltoid force (Figure 5A). From this, it is understood that the deltoid needs a counter force to be able to initiate upward rotation at the GH joint. Alternative, treatment options that could also work according to this principle include the superior capsular reconstruction, reverse shoulder arthroplasty and subacromial balloon or spacer.

With a superior capsular reconstruction, the superior capsule is reconstructed with autograft, allograft, or both. The graft is fixed from the superior glenoid to the greater tuberosity of the humerus. This construct, again, creates a superior counterforce to enable the deltoid muscle to rotate the proximal humerus at the GH joint (Figure 5B). The superior capsular reconstruction somewhat restricts superior humeral translation, and therefore requires less muscle force from the GH stabilizing muscles to create a stable fulcrum for the deltoid to elevate the arm. Another theory, is that the thickness of the graft could work as a subacromial spacer, as it sometimes can reach a thickness of more than 7mm. [29] The subacromial balloon or spacer, which is placed in the subacromial space, counteracts superior translation of the humerus in active elevation (Figure 5C). This modality also gives the deltoid the possibility to rotate the proximal humerus at the GH joint. In time, the subacromial spacer dissolves, which might result in shoulder function deterioration. In reverse shoulder arthroplasty, the glenoshpere works as a counterforce for the deltoid to rotate the proximal humerus at the GH joint (Figure 5D). This is a good option for the older patient, however, in the younger more active patient the longevity of the replacement could be limited. Apparently, all these treatment modalities have the same working principle: to create a downward directed force or stable fulcrum for the deltoid so that the proximal humerus can rotate at the GH joint. Novel techniques can be developed according to this principle, e.g. inferior tilted glenoid osteotomy, tenodesis of the long head of the biceps at the greater tuberosity or inferior GH capsular plication.

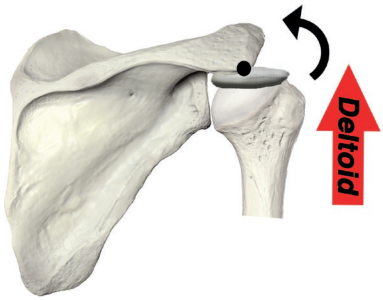
Figure 5



A Latissimus dorsi transfer



B Superior capsular reconstruction



C Subacromial spacer

D Reverse shoulder replacement

Although the LDT has been reported to yield favorable long-term good results, deterioration of the elasticity has been observed leading to decreasing acromiohumeral distance over time. [3, 22, 28] It remains unknown which factors contribute to keep the tendon functional and attached to the greater tuberosity. It could be that the elasticity of the tendon is maintained by the intact innervation of the thoracodorsal nerve. If the innervation is not intact, muscle atrophy and fatty infiltration can occur, leading to tendon tearing and loss of elasticity. It might be worthwhile to train the latissimus dorsi muscle after transfer by strengthening it, which in turn can maintain the acromiohumeral distance. Isometric exercises to strengthen the transferred tendon could maintain the muscle and tendon integrity.

Although we did not find that the LD changes its mechanical role after tendon transfer in the shoulder, it cannot be readily extrapolated to the rest of the human body. Muscle transfers in the upper limb after brachial plexus or peripheral nerve injuries do seem to change their function according to their new insertion site.[4] Somehow, our body adapts and learns how to fire that nerve adequality to its new function. It remains unclear whether the nerve changes its firing pattern or we just learn how to adapt the muscle in its new function.

To compare different treatment modalities for an MIRT it is important to use similar definitions for an MIRT in the future. Similarly, the definition of a shoulder pseudoparalysis and pseudoparesis are used interchangeably in the literature. By using uniform definitions, the different treatment modalities for an MIRT can be compared adequately to find the optimal treatment option for our patients.

According to this thesis, some patients with an MIRT can be treated successfully with conservative measures as long as the shoulder compensation mechanism is activated. It could be worthwhile strengthening the latissimus dorsi and teres major muscles in patients with an MIRT to create a stable GH fulcrum for active shoulder elevation.

We have mentioned that the latissimus dorsi transfer adds to glenohumeral stability in patients with an MIRT. However, the direct effect of the LDT on these patients was not measured, as we only had access to postoperative data. A future study with pre- and postoperative shoulder kinematic and muscle activation data could be a solution.

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9

Summary

SUMMARY

The main aim of this thesis was to gain more insight in shoulder kinematics and muscle activation patterns after a latissimus dorsi transfer (LDT) in patients with a massive irreparable posterosuperior rotator cuff tear (MIRT). Part 1 includes treatment options for the repairable and irreparable rotator cuff tear and part 2 is specifically on the LDT for an MIRT. **Chapter 1** presents the general introduction on the rotator cuff tear and its reparability.

If considered repairable, primary repair can be achieved by different surgical techniques. Moreover, several concomitant procedures may be performed as adjunct to the rotator cuff repair. These techniques and concomitant procedures are described in the review article presented in **Chapter 2**. A systematic review and meta-analysis reporting clinical outcome after primary cuff repair techniques, concomitant surgical procedures and aftercare is presented in **Chapter 3**. Treatment options for irreparable posterosuperior rotator cuff tears are reported and compared in a systematic review in **Chapter 4**. The LDT is a well-known and viable treatment option for an MIRT. However, the mode of function is yet to be understood. 3-Dimensional shoulder kinematics and muscle activation patterns after an LDT for an MIRT are presented in **Chapter 5** and compared to the asymptomatic contralateral shoulder (ACS). The change in shoulder kinematics after an LDT is achieved by reprogramming activation in the muscles that are responsible for active shoulder elevation. Shoulder muscle activation patterns in active shoulder elevation were reported after an LDT and compared to the ACS in **Chapter 6**. Although long-term good results after an LDT are reported, failure is not uncommon. To determine the type of failure after LDT, the intra and interobserver agreement for shoulder pathology after LDT with MRI was assessed in **Chapter 7**. The thesis concludes with a general discussion in **Chapter 8**.

Part 1 The repairable and irreparable rotator cuff tear

Chronic rotator cuff tears (RCT) lead to a significant decrease of quality of life with an ever-increasing economic burden, caused by aging of the general population. This type of shoulder pathology is a significant public health issue, as it belongs to the very common musculoskeletal disorders and most common upper extremity conditions in people over 50 years old. However, the presence of an RCT does not have to be symptomatic. In daily practice, surgical treatment may be considered if a period of non-operative treatment with physical therapy, modification of activities and subacromial cortisone injections have failed to provide substantial improvement. The aim of **Chapter 2** was to review the current surgical techniques for a repairable RCT. The arthroscopic rotator cuff repair was found to show decreased initial postoperative pain, a possible faster recovery and a better cosmetic result, when compared to the mini-open technique. However, no difference in long-term results have been reported. The repair can successfully be performed in either

beach chair or lateral decubitus position, with both techniques having their advantages and disadvantages. Fixation of the rotator cuff tendons onto the greater tuberosity (GT) can be achieved by several different methods: single row anchors, double row anchors as well as transosseous techniques. Although the studies report a higher healing rate with a double row fixation, the clinical outcomes roughly remain the same. Concomitant surgical procedures; long head of the biceps (LHB) tenotomy or tenodesis, acromioplasty, and adding a synthetic or dermal patch to the repair do not have to yield better clinical outcome. In terms of postoperative treatment, starting early passive range of motion exercises or the complete immobilisation after repair do not have to affect clinical outcome or healing rate of the cuff repair.

Surgical treatment of a repairable full thickness RCT is advocated after a failed non-operative treatment. In **Chapter 3**, a meta-analysis including 16 randomized controlled trials with 1221 patients was conducted to assess the efficacy of primary rotator cuff repair. The Constant Murley score, American Shoulder and Elbow score, Simple Shoulder Test and the University of California Los Angeles score, and the Visual Analogue score (VAS) after repair of a full thickness RCT were analysed. Only randomized controlled trials with a minimum follow-up of one year were included. The study included several concomitant surgical procedures to the rotator cuff repair, different fixation techniques and postoperative protocols. Significant increases in all the shoulder-specific indices were reported, indicating that a primary rotator cuff repair is highly effective for treating a full thickness RCT. However, this study was subjected to heterogeneity by different tear specific characteristics, concomitant surgical procedures and fixation techniques.

Primary repair of an MIRT has been reported with failure-to-healing rates up to 90 percent. For elderly patients, a decrease in pain is usually more important than regaining full active range of shoulder motion, therefore, a reverse total shoulder arthroplasty is more frequently advocated. However, in the younger, more active, patients, full active range of shoulder motion is more frequently desired, which can not be achieved with a reverse shoulder replacement. Additionally, the limited survival of the reverse shoulder replacement may pose problems for this category of patients. In **Chapter 4**, different treatment modalities for an MIRT were compared in a systematic review. The MEDLINE, EBBASE, CINAHL, and Cochrane databases were searched for treatment modalities for an MIRT without glenohumeral arthritis between 2007 and 2019 with a minimum of 2 years follow up. A total of 60 studies with 2000 patients were included. The smallest weighted mean preoperative to post-operative improvements in Constant Score were reported for biceps tenotomy/tenodesis and physical therapy. These were followed by debridement and muscle transfer, whereas the largest increases were reported for partial repair, subacromial spacer, rotator cuff advancement, reverse shoulder replacement, graft reconstruction, deltoid flap, and superior capsular reconstruction. Study quality was rated according to the Coleman score and ranged between 54-60, which was only fair at best. Moreover, a large heterogeneity between studies was observed due to different definitions of a clinical pseudoparalysis and an MIRT. Which means that these studies have different indications for their surgical treatment. Therefore, a sound comparison among treatment options cannot be made.

Part 2 The latissimus dorsi transfer for irreparable posterosuperior rotator cuff tears

The latissimus dorsi transfer (LDT) has been proven to be a viable option for an MIRT with a good long-term clinical outcome. It has been suggested that the transferred latissimus dorsi (LD) actively changes its function from an adductor and internal rotator to an abductor and external rotator of the shoulder. However, this concept is frequently debated in the literature. Surgical indication for an LDT is an MIRT with an intact subscapularis tendon, limited degeneration of the teres minor muscle and the absence of glenohumeral arthritis. It remains controversial whether an LDT is indicated in the setting of a clinical pseudoparalysis. The aim of **Chapter 5** was to evaluate whether the LDT can restore active shoulder function in patients with a clinical pseudoparalysis and an MIRT, and whether the LD muscle changes its mechanical role. This was investigated with 3D shoulder kinematics and muscle activation analysis of the LD and deltoid muscles using surface electromyography (EMG) after LDT. Thirteen patients were included, at least one year after an LDT for MIRT and clinical pseudoparalysis. Data was collected in active elevation and rotations which were compared to the asymptomatic contralateral shoulder (ACS).

One of the main findings was that the LDT can restore thoracohumeral active elevation in a pseudoparalytic shoulder, however, this is achieved with a decreased glenohumeral (GH) contribution, when compared to the ACS. Active external rotation was not restored. The second main finding was that the LD muscle activation did not differ between LDT and ACS during maximal shoulder elevation in the different elevation planes. In active external rotation the LD muscle had a significantly higher activation in the LDT group. However, this difference was only a fraction of the EMG max and thus insufficient to consider a change in mechanical role. An additional finding was that the deltoid muscle activation was higher in the LDT group in active elevation. Despite the near-normal maximum thoracohumeral elevation, however, it could not be concluded that this result was associated with a change in the LD's native activity after transfer.

The decreased GH contribution and increased deltoid activation are not specific in shoulder elevation after an LDT as this is also seen in patients with a cuff tear. Active shoulder elevation after an LDT is thought to be possible by restoring a stable GH fulcrum by creating a passive downward directed force at the GH joint. This passive downward directed force after transfer is named the tenodesis-effect. However, this stable fulcrum after transfer, cannot be maintained in the entire GH range, which explains its decreased contribution in active elevation. The thoracohumeral motion remains preserved by the increased scapulothoracic contribution.

The aim of **Chapter 6** was to analyse shoulder muscle activation that might be responsible for the increased active elevation after LDT. Thirteen patients after an LDT for an MIRT with a clinical pseudoparalysis were included with an ACS. Activity of the deltoid, LD, teres major, three parts of the trapezius and serratus anterior muscles were analysed. Muscle activity was assessed with surface electromyography (EMG) sensors during maximal forward flexion, abduction in the scapular plane, and abduction in the sagittal plane, while active elevation was tracked with 3D kinematics. The 100% EMG max was determined by noting the highest value during maximal isometric voluntary contraction (MIVC) in different planes. This was completed for each muscle in both shoulders. During active shoulder elevation the LD muscle activity was not different after transfer when compared to the ACS. Only the deltoid, the upper and middle trapezius muscles showed a significantly higher activity when compared to ACS. The timing of recruitment did not differ between the LDT and ACS shoulders.

This increased deltoid activation seen in active shoulder elevation after LDT in our study is not specific and is also reported in other conditions; rotator cuff pathology, subacromial impingement, and fatigue of the shoulder. The increased deltoid force is thought to be necessary to compensate for the lost abduction torque due to an MIRT. Moreover, it has been reported that in patients with a large rotator cuff tear, the shoulder adductors, i.e. LD, teres major, and pectoralis major are more active during active elevation. These muscles counteract the deltoid upward-directed shear force during active shoulder elevation (co-activation). This results in a stable GH fulcrum, making it possible for the deltoid to actively elevate the shoulder. However, the deltoid has to increase its activity to compensate for the abduction torque due to the MIRT and the additional counteracting forces of the shoulder adductors.

In the present study, no increased activity of the LD or the teres major was observed after transfer during active elevation. It could be that the tenodesis effect after LDT is sufficient enough to counteract the deltoid shear forces in active elevation, not needing additional activation of the adductors to elevate the shoulder.

A higher activity of the upper and middle trapezius during active abduction in the scapular plane was observed, which could partly be responsible for the increased scapulothoracic contribution seen after LDT. The increased scapulothoracic contribution in active elevation after an LDT could work favorable for the passive or active pull of the LD, by being biomechanically more effective in exerting additional GH joint reaction force to counteract the force of deltoid. A more upward rotated scapula directs the compressive forces of LD more towards the glenoid surface, adding to concavity compression and a stable GH fulcrum for the deltoid to elevate the shoulder. Moreover, the increased scapulothoracic contribution maintains a better length tension relationship for the deltoid in active elevation. Thus, making the deltoid effective in a larger range shoulder motion. Importantly, this increased activation of the trapezius is not specific after LDT and is also seen in patients with a rotator cuff tear.

Long term (10 year) good results have been reported after an LDT, however, failure is not uncommon. The mode of failure after an LDT is currently not known: tendon healing failure, rupture of the tendon at the musculotendinous junction, GH osteoarthritis, progression of the rotator cuff tear, and cuff degeneration are all possible causes. To identify these causes, MRI imaging is necessary. However, the shoulder anatomy is altered after an LDT which could make detecting and recognizing pathology challenging with MRI. The goal of **Chapter 7**, therefore, was to assess intra and interobserver agreement with MRI to assess the reliability of detecting pathology after an LDT for an MIRT. In turn, this could identify the mode of failure after an LDT. Two shoulder surgeons and two musculoskeletal radiologists scored the LD tendon and remaining cuff tendons and muscles with MRI. Patients were included at least one year post transfer. The LD tendon and remaining cuff tendon integrity were scored and fatty infiltration of the cuff muscles was graded according to Goutallier. The intra and inter-observer agreement for LD tendon and cuff tendon integrity ranged mainly between fair to moderate according to Landis and Koch. Inconsistencies in scoring for cuff fatty infiltration are observed after LDT, which might be the cause of a complicated scoring system.

Although an MRI is the preferred imaging modality of choice after an LDT we only found a fair to moderate agreement in grading relevant shoulder pathology. The changed anatomy in the shoulder after an LDT, difficulty of the grading system and learning curve might contribute the relatively low agreement in our study.

Finally, **Chapter 8** concludes with a general discussion.

Relevant findings in this thesis:

- There are several different techniques and concomitant procedures reported for a primary cuff repair.
- A rotator cuff repair is a highly effective treatment for a full thickness rotator cuff tear that has failed conservative management
- The massive irreparable posterosuperior rotator cuff can be managed by different treatment modalities. However, in the current literature, the best treatment option cannot be suggested due to inconsistencies in definitions of an MIRT and low study quality.
- The latissimus dorsi transfer is able to restore active shoulder elevation in patients with an MIRT and a pre-operative clinical pseudoparalysis.
- The latissimus dorsi does not actively change its mechanical role to a shoulder abductor and external rotator after transfer in active elevation in patients with an MIRT. Active shoulder elevation is restored by the tenodesis effect or native activation of the latissimus dorsi after transfer.
- The latissimus dorsi transfer does not restore normal shoulder kinematics in active elevation.
- After an LDT for an MIRT, activation of the latissimus dorsi and teres major muscle are no longer necessary for active shoulder elevation.
- Only moderate to fair intra and inter-observer agreement was reported for pathology in the shoulder with MRI after an LDT in patients with an MIRT.

Appendix

Nederlandse samenvatting
PhD portfolio and curriculum vitae
About the author
Acknowledgments

SAMENVATTING

Het primaire doel van dit proefschrift is om meer inzicht te krijgen in schouderkinematica en spieractivatiepatronen na een latissimus dorsi transfer (LDT) bij patiënten met een massieve onherstelbare posterosuperieure rotatorcuffscheur (MIRT). Deel 1 omvat de behandelopties voor herstelbare en onherstelbare rotatorcuffscheuren, en deel 2 richt zich specifiek op de LDT voor een MIRT. In **Hoofdstuk 1** wordt de algemene introductie over de rotatorcuffscheur en de mogelijkheid tot primaire herstel ervan besproken. Indien herstelbaar, kan primair herstel worden bereikt met verschillende technieken en kunnen bijkomende ingrepen als aanvulling op het rotatorcuffherstel worden uitgevoerd. Deze technieken worden beschreven in het reviewartikel dat wordt gepresenteerd in **Hoofdstuk 2**. In **Hoofdstuk 3** wordt een systematische review van de klinische resultaten na de verschillende primaire cuffhersteltechnieken, gelijktijdige additionele ingrepen en nazorg gepresenteerd. Behandelopties voor onherstelbare posterosuperieure rotatorcuffscheuren worden vergeleken in een systematische review en meta-analyse in **Hoofdstuk 4**. De LDT is een bekende behandeloptie voor een MIRT. De manier van functioneren is echter nog niet begrepen. 3-dimensionele schouderkinematica en spieractivatie na een LDT voor een MIRT worden gepresenteerd in **Hoofdstuk 5** en vergeleken met de asymptomatische contralaterale schouder (ACS). De verandering in schouderkinematica na een LDT wordt bereikt door een herprogrammering van activatie in de schouderspieren die verantwoordelijk zijn voor schouderelevatie. Spieractivatiepatronen in actieve schouderelevatie worden na een LDT vergeleken met de ACS in **Hoofdstuk 6**. Hoewel er op lange termijn goede resultaten zijn gemeld na een LDT, is falen niet ongebruikelijk. Om het type falen na LDT te bepalen, werd in **Hoofdstuk 7** de intra- en interbeoordelaarsbetrouwbaarheid van schouderpathologie na LDT met MRI gerapporteerd. Dit proefschrift wordt afgesloten met een algemene discussie in **Hoofdstuk 8**.

Deel 1: De herstelbare en onherstelbare rotatorcuffscheur

Rotatorcuff scheuren komen frequent voor boven de leeftijd van 50 jaar. Door de toenemende kennis van de pathologie, de verbeterde behandelopties en de toename van fysieke activiteiten op oudere leeftijd is er de laatste decennia aanzienlijk meer aandacht voor deze aandoening ontstaan.

De aanwezigheid van een rotatorcuffscheur (RCT) leidt niet altijd tot symptomen. In de dagelijkse praktijk kan chirurgische behandeling worden overwogen als een periode van conservatieve behandeling met fysiotherapie, aanpassing van activiteiten en subacromiale cortisone-injecties niet tot verbetering heeft geleid.

Het doel van **Hoofdstuk 2** was om de huidige chirurgische technieken voor een herstelbare RCT te evalueren. De arthroscopische rotatorcuffhersteloperatie heeft minder initiële postoperatieve pijn, een mogelijke snellere revalidatie en een beter cosmetisch resultaat in vergelijking met de mini-open techniek. Er zijn echter geen verschillen gemeld in de langetermijnresultaten. De arthroscopische ingreep kan zowel in de strandstoelpositie als de laterale decubituspositie uitgevoerd worden, waarbij beide technieken voor- en nadelen hebben. De verankering van de rotatorcuffpees aan het tuberculum majus (GT) kan worden bereikt met verschillende methoden: enkelvoudige, dubbele rijankers of transossale technieken. Hoewel de studies met dubbele rij-fixatie een hoger genezingspercentage rapporteren, blijven de klinische resultaten ongeveer hetzelfde. Gelijktijdige chirurgische ingrepen, zoals een tenotomie of tenodese van de lange kop van de bicepspees (LHB), acromioplastiek en het toevoegen van een synthetisch of homoloog weefsel aan de reparatie, leidt niet tot een beter klinisch resultaat. Wat betreft de postoperatieve behandeling, heeft het vroeg starten van passieve bewegingsoefeningen of volledige immobilisatie na reparatie geen invloed op het klinische resultaat of het genezingspercentage van de cuffhersteloperatie.

Chirurgische behandeling van een herstelbare volledige dikte symptomatische RCT wordt aanbevolen na een niet succesvolle conservatieve behandeling. In **Hoofdstuk 3** werd een meta-analyse uitgevoerd, waarbij 16 gerandomiseerde gecontroleerde studies met 1221 patiënten werden geanalyseerd om de doeltreffendheid van een primaire rotatorcuffreparatie te beoordelen. De Constant Murley-score, de American Shoulder and Elbow-score, de Simple Shoulder Test en de University of California Los Angeles-score, evenals de visuele analoge score na operatie van een volledige dikte RCT werden geanalyseerd. Alleen gerandomiseerde gecontroleerde onderzoeken met een minimale follow-up van een jaar werden opgenomen. Gelijktijdige additionele chirurgische ingrepen; als verankeringstechnieken en protocollen voor postoperatieve zorg werden geïncludeerd. Er werden significante verbeteringen gerapporteerd in alle specifieke schouderscores, welke aangeeft dat een primaire rotatorcuffhersteloperatie zeer effectief is voor de behandeling van een volledige dikte RCT. Deze studie is echter onderworpen aan heterogeniteit als gevolg van verschillende scheureigenschappen, gelijktijdige andere chirurgische ingrepen en verankeringstechnieken.

Primaire reparatie van een MIRT heeft een hoog faalpercentage, in de literatuur variërend tussen 50-90%. Bij oudere patiënten is pijnvermindering meestal belangrijker dan het herstellen van de volledige schouderfunctie, en wordt vaak een omgekeerde totale schouderprothese aanbevolen. Bij jongere, meer actieve patiënten is bij voorkeur herstel van de volledige schouderfunctie gewenst, welke niet door een omgekeerde prothese wordt bereikt. Daarnaast zal de beperkte overleving van de prothese, revisies tot gevolg kunnen hebben voor deze categorie patiënten.

In **Hoofdstuk 4** werden de verschillende behandelmodaliteiten voor een MIRT vergeleken in een systematische review. De MEDLINE, EBBASE, CINAHL en Cochrane-databanken werden doorzocht naar de behandelmodaliteiten voor een MIRT zonder glenohumerale artrose tussen 2007 en 2019, met een minimale follow-up van 2 jaar. In totaal werden 60 studies met 2000 patiënten opgenomen. De kleinste gewogen gemiddelde verbetering van de Constant Score van preoperatief naar postoperatief werd gerapporteerd voor biceps tenotomie en fysiotherapie. Daarna volgden schoudernettoyage en peestransfer, terwijl de grootste verbeteringen werden gerapporteerd voor partiële cuffherstel, subacromiale spacer, deltoideusflap en superieure capsulaire reconstructie. De studiekwaliteit werd beoordeeld volgens de Coleman-score en varieerde tussen 54-60, wat op zijn best als ‘redelijk’ kan worden beschouwd. Bovendien werd een grote heterogeniteit tussen de studies waargenomen als gevolg van verschillende definities van een klinische pseudoparalyse en een MIRT met dus verschillende indicaties voor chirurgische behandeling. Daarom kan er geen degelijke vergelijking worden gemaakt tussen behandelingsmogelijkheden.

Deel 2: De latissimus dorsi transfer voor onherstelbare posterosuperieure rotatorcuffscheuren

De latissimus dorsi-transfer (LDT) is een bewezen optie voor een MIRT met goede lange termijn klinische resultaten. De hypothese is dat de verplaatste latissimus dorsi zijn spieractiviteit verandert in de schouder van een adductor en interne rotator naar een abductor en externe rotator. Dit concept is nog steeds onderwerp van discussie in de literatuur. Chirurgische indicaties voor een LDT zijn een MIRT met een intacte subscapularispees, beperkte degeneratie van de teres minor en afwezigheid van glenohumerale artrose (“cuffscheur arthropathie”). Het blijft controversieel of een LDT geïndiceerd is in geval van een klinische pseudoparalyse. Een pseudoparalyse werd in dit proefschrift gedefinieerd als schouderelevatie van minder dan 90 graden. Het doel van **Hoofdstuk 5** was om te evalueren of de LDT de schouderfunctie kan herstellen bij patiënten met een klinische pseudoparalyse en een MIRT, en of dit actief gebeurt in zijn nieuwe mechanische rol. Dit werd onderzocht door de 3D-schouderkinematica te analyseren in combinatie met de activatie van de latissimus dorsi (LD) en deltoideus met behulp van oppervlakte-elektromyografie (EMG). Dertien patiënten werden geïncludeerd, minstens een jaar na een LDT voor een MIRT en klinische pseudoparalyse. Data werd verzameld voor actieve schouderelevatie en rotaties, welke werd vergeleken met de ACS.

Een van de belangrijkste bevindingen was dat de LDT de thoracohumerale actieve shouderelevatie in een pseudoparalytische schouder kan herstellen, dit werd bereikt door een toegenomen bijdrage in het thoracoscapulaire gewricht ten aanzien van de ACS. De tweede belangrijke bevinding was dat de activatie van de LD-spier niet verschilde tussen LDT en ACS gedurende schouderelevatie in de verschillende elevatievlakken. Bij actieve externe rotatie vertoonde de LD-spier een significant hogere activiteit in de LDT-groep. Dit verschil was echter slechts een fractie van de EMG max en dus onvoldoende om als significant te worden beschouwd. Actieve externe rotatie werd derhalve niet hersteld. Een aanvullende bevinding was dat de activatie van de deltoideusspier hoger was in de LDT-groep bij actieve schouderelevatie. Ondanks de bijna normale maximale thoracohumerale elevatie, kon echter niet worden geconcludeerd dat dit resultaat verband hield met een verandering van de oorspronkelijke LD-activiteit na transfer. De verminderde bijdrage in het GH-gewricht, de toegenomen bijdrage in het thoracoscapulaire gewricht, en de verhoogde deltoideusspieractiviteit zijn niet specifiek voor actieve schouderelevatie na een LDT, omdat dit ook wordt waargenomen bij patiënten met een rotatorcuffscheur. Actieve schouderelevatie na een LDT wordt verondersteld mogelijk te zijn door het herstellen van een stabiel GH-draaipunt. Omdat er geen verschil in activatie van de LD wordt waargenomen tussen de LDT en de ACS-groep, lijkt dit te komen door de passieve, naar caudaal gerichte kracht. Dit wordt het tenodese-effect genoemd. Echter, dit stabiele draaipunt kan niet gedurende het hele GH-bereik worden gehandhaafd, welke de verminderde bijdrage in dit gewricht gedurende actieve elevatie verklaart. De thoracohumerale beweging blijft behouden door de verhoogde scapulothoracale bijdrage.

Het doel van **Hoofdstuk 6** was om de activering van de schouderspieren te analyseren die verantwoordelijk kunnen zijn voor de verhoogde actieve schoulderelevatie na een LDT. Dertien patiënten na een LDT voor een MIRT met een klinische pseudoparalyse werden geïncludeerd zonder symptomen in de contralaterale schouder. De spieractiviteit van de deltoideus, LD, de teres major, de drie delen van de trapezius en de serratus anterior werden geanalyseerd. Spieractiviteit werd beoordeeld met oppervlakte-elektromyografie (EMG) sensoren tijdens maximale voorwaartse schouderelevatie, abductie in lijn met de scapula en abductie in het sagittale vlak. Actieve schouderelevatie werd gemonitord met 3D-kinematica. De 100% EMG max werd bepaald door de hoogste waarde tijdens maximale isometrische contractie (MIVC) in de verschillende vlakken van de schouder. Dit werd gedaan voor iedere spier in beide schouders. Tijdens actieve elevatie van de schouder was de activiteit van de LD-spier niet verschillend na transfer in vergelijking met de ACS. Alleen de deltoideus, de bovenste en middelste trapezius vertoonden een hogere activiteit in vergelijking met ACS. De tijd van spieractivatie verschilde niet tussen de LDT schouder en ACS. De verhoogde deltoideusactivatie die in onze studie werd waargenomen tijdens actieve elevatie van de schouder na LDT, is niet specifiek, en wordt ook gerapporteerd voor andere aandoeningen, zoals aandoeningen scheuren in de rotatorcuff, subacromiale impingement, pijn en vermoeidheid van de schouder. Bovendien is in de literatuur gemeld dat bij patiënten met een grote scheur in de rotatorcuff, de schouderadductoren actief zijn tijdens schouderelevatie. Dit betreft de

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LD, de teres major en pectoralis major. Deze spieren werken de opwaartse schuifkracht van de deltoideus tijdens actieve schouderelevatie tegen (co-activatie), wat zorgt voor een stabiel GH-draaipunt voor de deltoideus. Daarom is er gesuggereerd dat bij patiënten met een MIRT, de verhoogde deltoideusactiviteit tijdens actieve elevatie noodzakelijk is om naast de afwezige abductiekracht van de MIRT, de aanvullende tegenwerkende kracht van de schouderadductoren te compenseren.

Er werd in deze studie echter geen verhoogde activiteit van de LD of teres major tijdens actieve schouderelevatie waargenomen na de transfer. Het zou kunnen zijn dat het tenodese-effect na LDT voldoende is om de schuifkrachten van de deltoideus in actieve schouderelevatie tegen te gaan, zonder dat er aanvullende activatie van de adductoren nodig is. Er werd een verhoogde activiteit van de bovenste en middelste trapeziusspieren waargenomen tijdens actieve abductie in het schouderbladvlak, wat verantwoordelijk zou kunnen zijn voor de verhoogde scapulothoracale bijdrage die na LDT werd waargenomen. De verhoogde scapulothoracale bijdrage tijdens actieve elevatie na een LDT, zou de passieve of actieve trekkracht van de LD kunnen ondersteunen. Dit door biomechanisch effectiever te zijn in het uitoefenen van de GH-gerichte kracht om zo de verticale kracht van de deltoideus tegen te gaan. Een meer omhoog gedraaide schouderblad richt de krachten van de LD meer naar het glenoïdoppervlak, wat bijdraagt aan de concaviteitcompressie en een stabiel GH-draaipunt voor de deltoideus om de schouder op te tillen. Bovendien handhaaft de verhoogde scapulothoracale bijdrage een betere lengte-spanningsverhouding voor de deltoideus bij actieve schouderelevatie. Hierdoor wordt de deltoideus effectiever in een groter bereik van schouderbeweging. Belangrijk is dat de verhoogde activatie van de trapeziusspier niet specifiek is na LDT, dit wordt ook gezien bij patiënten met een scheur in de rotatorcuff.

Lange termijn (10 jaar) goede resultaten zijn gerapporteerd na een LDT, echter, falen is niet ongewoon. De wijze van falen na een LDT is momenteel niet bekend: falen van peesgenezing, ruptuur van de pees in de musculotendineuze overgang, glenohumerale artrose, toename van de scheur en verdere degeneratie van de cuff zijn mogelijke oorzaken. Om deze oorzaken te identificeren, is MRI-beeldvorming noodzakelijk. Echter, de schouderanatomie is veranderd na een LDT, waardoor structuren moeilijker te herkennen kunnen zijn. Het doel van **Hoofdstuk 7** was daarom om de intra- en interbeoordelaar betrouwbaarheid te analyseren van schouderpathologie met MRI na LDT voor een MIRT. Dit zou op zijn beurt de wijze van falen na een LDT kunnen identificeren. Twee schouderchirurgen en twee musculoskeletale radiologen beoordeelden de integriteit van de LD-pees en de resterende cuffspieren op zijn minst 1 jaar na de transfer. Vetinfiltratie van de rotatorcuff werd beoordeeld volgens Goutallier. De intra- en interbeoordelaarsbetrouwbaarheid voor de integriteit van de LD-pees en van de rotatorcuff varieerde voornamelijk van matig tot redelijk volgens Landis en Koch.

Inconsistenties in de beoordeling van vetinfiltratie van de cuff werden voor de intra- en interbeoordelaarsbetrouwbaarheid genoteerd na LDT.

Hoewel een MRI de voorkeursbeeldvormingstechniek is na een LDT, vonden we slechts een redelijk tot matige overeenstemming bij het beoordelen van relevante schouderpathologie. De veranderde anatomie in de schouder na een LDT, de moeilijkheid van het beoordelingssysteem en de leercurve kunnen bijdragen aan de relatief lage overeenstemming tussen beoordeelaars in onze studie.

Tot slot concludeert **Hoofdstuk 8** met een algemene discussie.

Relevante bevindingen in dit proefschrift:
- Er zijn verschillende technieken en gelijktijdige additionele ingrepen gemeld voor een primaire cuffherstel.
- Een rotatorcuffhersteloperatie is een zeer effectieve behandeling voor een volledige dikte cuffscheur waarbij conservatieve behandeling heeft gefaald.
- De massale onherstelbare posterosuperieure rotatorcuff kan worden behandeld met verschillende behandelingsmodaliteiten. Naar de huidige wetenschappelijke stand van zaken kan de beste behandelingskeuze niet worden voorgesteld vanwege inconsistenties in definities van een MIRT en lage onderzoekskwaliteit.
- De transfer van de latissimus dorsi is in staat om actieve elevatie van de schouder te herstellen bij patiënten met een MIRT en een preoperatieve klinische pseudoparalyse.
- De latissimus dorsi verandert zijn mechanische rol niet naar schouder abductor en externe rotator in actieve elevatie bij patiënten na een LDT met een MIRT. Actieve schouder elevatie wordt waarschijnlijk hersteld door het tenodese-effect of de natieve activatie van de latissimus dorsi na transfer.
- De transfer van de latissimus dorsi herstelt de normale schouderkinematica niet in actieve schouderelevatie.
- Na een LDT voor een MIRT zijn activatie van de latissimus dorsi en teres major niet langer nodig bij actieve schouderelevatie.
- Een redelijk tot matige intra- en interbeoordeelaarsbetrouwbaarheid voor schouder-pathologie werd gerapporteerd met MRI na een LDT voor een MIRT.

PHD PORTFOLIO AND CURRICULUM VITAE

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Employment history

June 2023 – Present	**Orthopaedic surgeon** Fellowship: Sports shoulder and arthroplasty	Macquarie University Hospital Hurstville Private Hospital East Sydney Private Hospital Wollongong Private Hospital Wollongong Day Surgery Shellharbour Private Hospital Sydney and Wollongong (AUS)
June 2022 –June 2023 Full-time	**Orthopaedic surgeon** Fellowship: Shoulder and elbow Elective and trauma	Prince of Wales Hospital Concord Hospital Sydney Private Hospital Strathfield Private Hospital Sydney (AUS)
July 2021 – June 2022 Full-time	**Registrar in orthopaedic surgery** Final year of training in shoulder surgery	Spaarne Gasthuis Hoofddorp & Haarlem (NL)
Jan 2020 – June 2021 Full-time	**Registrar in orthopaedic surgery** Shoulder surgery & treatment of orthopaedic infections	Noordwest Ziekenhuisgroep Alkmaar (NL)

Jan 2019 – Dec 2019 Full-time	**Registrar in orthopaedic surgery** Traumatology (including spinal surgery), orthopaedic oncology and paediatrics	Radboud University Medical Centre , Nijmegen (NL) Level 1 Trauma Centre
July 2017 – Dec 2018 Full-time	**Registrar in orthopaedic surgery** Arthroscopic shoulder & knee surgery, shoulder, hip and knee replacements. Foot and ankle surgery	Spaarne Gasthuis Hoofddorp & Haarlem (NL)
Jan 2017 – Jan 2024 Part-time 8 hours/week	**PhD candidate** Thesis: Latissimus dorsi transfer for irreparable rotator cuff tears	VU University Amsterdam (NL)
Jan 2016 – Mar 2016 Full-time	**Emergency care and Intensive care medicine training**	Noordwest Ziekenhuisgroep Alkmaar (NL)
Jan 2016 – July 2017 Full-time	**Core surgical training** Vascular surgery, abdominal laparoscopy, oncology and traumatology	Noordwest Ziekenhuisgroep Alkmaar (NL)
June 2012 – Dec 2016 Full-time	**Clinical fellow** Out-patient clinical care, orthopaedic &general surgery ward, perioperative care and conservative fracture treatment	Haaglanden Medisch Centrum The Hague (NL) OLVG, Amsterdam (NL) Spaarne Gasthuis, Hoofddorp (NL)

Education

2005 – 2012	Medicine	Leiden University Medical Centre, Leiden (NL)
1999 – 2005	Pre-university education	Leidsche Rijn College, Utrecht (NL)

Publications

1. Total knee arthroplasty for acute tibial plateau fractures: a survey amongst 68 Dutch orthopaedic surgeons.
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Courses

2023	Shoulder dissection course – Sydney (AUS)
2023	Clinical classroom – Journal of Bone and Joint Surgery (AUS)
2023	Orthopaedic Technology and Innovation Forum – Sydney (AUS)
2022	University teaching qualification – Amsterdam (NL)
2022	Good clinical practice – Sydney (AUS)
2021	International English Language Testing System – Amsterdam (NL)
2021	Medical radiation course – Nijmegen (NL)
2020	AO Complex elbow fractures (Advanced course) – Leiden (NL)
2019	Shoulder fracture course – Radboud University Medical Centre – Nijmegen (NL)
2019	AO Hand & Wrist (Advanced course) – Leeds (UK)
2019	Spine course - Amsterdam Medical Centre – Amsterdam (NL)
2019	Spine deformity course – Sint Maartenskliniek – Nijmegen (NL)
2019	Knee arthroplasty – Amsterdam Medical Centre – Amsterdam (NL)
2018	Hip arthroplasty – Radboud University Medical Centre – Nijmegen (NL)
2018	Foot and ankle course – Sint Maartenskliniek – Nijmegen (NL)
2016	Basic laparoscopic surgery – Amsterdam Medical Centre – Amsterdam (NL)
2015	AO course: principles of fracture management – Oisterwijk (NL)

Presentations

2023 Sydney Journal Club (AUS)
Shoulder kinematics and muscle activation after a rotator cuff tear and latissimus dorsi transfer

2021 SECEC (Virtual) E-poster presentation
Shoulder kinematics and muscle activity following latissimus dorsi transfer for irreparable posterosuperior rotator cuff lesions

2018 ESSKA (UK) poster presentation
Update: Tenotomy or tenodesis for pathology of the long head of the biceps brachii: a systematic review and meta-analysis. **Gurnani N**, Kooistra BW, van Deurzen DF, van den Bekerom MP.

2018 ESSKA (UK) poster presentation
Suprapectoral or subpectoral Tenodesis for pathology of the long head of the biceps brachii: a systematic review and meta-analysis. **Gurnani N**, Alta T.D, Willems J.H, van Deurzen DF, van den Bekerom MP.

2015 ISAKOS (FR) poster presentation
Tenotomy or tenodesis for pathology of the long head of the biceps brachii: a systematic review and meta-analysis. **Gurnani N**, van Deurzen DF, Janmaat VT, van den Bekerom MP.

2015 SESEC (IT) poster presentation
Tenotomy or tenodesis for pathology of the long head of the biceps brachii: a systematic review and meta-analysis. **Gurnani N**, van Deurzen DF, Janmaat VT, van den Bekerom MP.

2015 ISAKOS (FR) poster presentation
Shoulder-specific outcomes 1 year after nontraumatic full-thickness rotator cuff repair: a systematic literature review and meta-analysis. **Gurnani N**, van Deurzen DFP, van den Bekerom MPJ.

2015 SECEC (IT) poster presentation
Shoulder-specific outcomes 1 year after nontraumatic full-thickness rotator cuff repair: a systematic literature review and meta-analysis. **Gurnani N**, van Deurzen DFP, van den Bekerom MPJ.

2015 NVA (NL) poster presentation
Shoulder-specific outcomes 1 year after nontraumatic full-thickness rotator cuff repair: a systematic literature review and meta-analysis. **Gurnani N**, van Deurzen DFP, van den Bekerom MPJ.

2014 NOV (NL) Shoulder session, oral presentation
Tenotomy or tenodesis for pathology of the long head of the biceps brachii: a systematic review and meta-analysis. **Gurnani N**, van Deurzen DF, Janmaat VT, van den Bekerom MP.

Teaching

Jan 2021 – July 2022 Junior chief of orthopaedic research department – Noordwest Ziekenhuisgroep, Alkmaar (NL)

July 2021 – Apr 2023 Acquiring University Teaching Qualification by teaching medical students and registrars – VU University, Amsterdam (NL)

ECTS (European credit transfer system) points

Research ethics and integrity		**ECTS**
2016	Co-author METC	0.5
2022	Good clinical practice	1
2022	Data science ethics	0.5
Research methods		
2017	Basic statistics	1
2018	Introduction to systematic review and meta-analysis	1
2019	Advanced statistics	1
2020	Introduction to programming with Matlab	2
2020	Clinical shoulder course (NVA)	1
Academic writing or presenting		
2019	Writing a scientific article	1
2022	University teaching qualification (BKO)	3
Writing a data management plan		
2020	Data management plan for clinical research	1
Subject related training		
2018	Introduction to clinical research	1
2020	3-dimensional kinematics	3
2021	Electromyography	3
Conferences and Colloquia		
2016 – 2023	International conferences (oral and poster presentation)	8
2016 – 2022	Interdisciplinary colloquia	6
Training on the job		
2022 – 2023	Australian Orthopaedic Association accredited fellowship	3
2019 – 2023	Mentor for medical students – research projects	1
Personal development		
2021	Sustainable employability for doctors in training	1
2022	International English Language Testing System	1
2022	Hospital management training	2
2019	Research coordinator at Noordwest Ziekenhuisgroep	1
Total		**43 ECTS**

ABOUT THE AUTHOR

Navin Gurnani was born on July 16th 1986 in Kelantan, Malaysia. After his parents decided to move to Europe, he completed his primary school in Brussels, Belgium. Hereafter, he graduated from high school at the Leidsche Rijn College in Utrecht, The Netherlands, and obtained his Medical Degree at Leiden University.

After gaining experience in orthopaedic surgery, working as an unaccredited registrar for three years, he started his accredited training in 2016 at three institutions: Noordwest Zieknhuisgroep (Alkmaar), Spaarne Gasthuis (Hoofddorp and Haarlem) and Radboud University Medical Center (Nijmegen). Alongside his training, he started working on his PhD project: Latissimus dorsi transfer for massive irreparable rotator cuff tears. He has completed courses on statistics, muscle activation, and shoulder kinematics which were necessary for the PhD. The results of the studies have been presented at international meetings and conferences.

Teaching has always been a priority for Navin. He enjoys speaking about his project and he is fond of teaching medical students in their orthopaedic term. Therefore, during the last two years of his orthopaedic training he completed the University Teaching Qualification course. This has qualified Navin to teach and guide students at a university level.

At the end of his orthopaedic training, it became apparent that he endeavored to become a shoulder and elbow surgeon. To increase his exposure, he travelled to Sydney, Australia to work at the Prince of Wales and Concord Hospitals. In these hospitals, he gained experience in treating shoulder and elbow conditions along with new surgical techniques. To consolidate these skills, he is currently working at the Macquarie and Wollongong hospitals.

At this stage he is working and living in and around Sydney, New South Wales, Australia. He is living together with his wife Sonam and are expecting their first child in the near future. For now, he enjoys the cycle rides along the beach before he goes to work.

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As my formal orthopaedic trainer, you have guided me through my training and advised me about future career steps. You are known as an orthopaedic trainer who believes in his trainees and would do a lot to guarantee a high level of education during the training program. Apart from this, as the latissimus dorsi transfer surgery is very rare, you allowed me to include your patients in the study. Thank you.

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dr. B.J. Burger – Dear Bart,
During my orthopaedic training, I have admired your way of teaching. With you as my mentor, I was able to attain my University Teaching Qualification. In turn, this has helped me with international research talks, and guiding medical students with their research projects. Thank you.

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Amsterdam Movement Sciences

VU VRIJE UNIVERSITEIT AMSTERDAM

Amsterdam UMC University Medical Centers

Amsterdam Movement Sciences conducts scientific research to optimize physical performance in health and disease based on a fundamental understanding of human movement in order to contribute to the fulfillment of a meaningful life.