J Shoulder Elbow Surg (2020) 29, 282–290

ELSEVIER

Journal of Shoulder and Elbow Surgery

www.elsevier.com/locate/ymse

Risk of latissimus dorsi tendon rupture after arthroscopic transfer for posterior superior rotator cuff tear: a comparative analysis of 3 humeral head fixation techniques

Jean Kany, MD[a,*], Padmanaban Sekaran, MSc, PT[b], Jean Grimberg, MD[c], Rajkumar S. Amavarathi, DNB, FRCS[d], Philippe Valenti, MD[e], Bassem Elhassan, MD[f], Jean David Werthel, MD[g]

[a]*Shoulder Department, Clinique de l'Union, Ramsay GDS, Saint Jean, France*
[b]*Lakshmi Hospital, Ernakulam, Kerala, India*
[c]*Shoulder Department, LIRCOS, Clinique Jouvenet, Ramsay GDS, Paris, France*
[d]*Division of Arthroscopy and Sports Surgery, Department of Orthopaedics, St John's Medical College and Hospital, Bangalore, Karnataka, India*
[e]*Shoulder Department, Clinique Bizet, Paris, France*
[f]*Shoulder Department, Mayo Clinic, Rochester, MN, USA*
[g]*Shoulder Department, Hôpital Ambroise Pare, Paris, France*

Background: To compare latissimus dorsi tendon rupture rates after arthroscopic transfer for posterior superior rotator cuff tear using 3 different humeral head fixation techniques.
Methods: One-hundred fifty consecutive latissimus dorsi transfers were included. Inclusion criteria were massive irreparable posterosuperior rotator cuff tear with advanced fatty infiltration associated with persistent pain and limited range of motion after failed conservative treatments or surgery. All transfers were arthroscopically assisted and fixed in a transosseous tunnel with a cortical button (group 1, n = 59), ''over the top'' onto the footprint of the supraspinatus (group 2, n = 47), or posteriorly onto the footprint of the infraspinatus (group 3, n = 44) with 2 suture anchors. The tendons were marked with 3 metallic clips placed intraoperatively at a fixed distance of 2, 4, and 6 cm from the tip. Immediate postoperative standard anteroposterior radiographs were performed to confirm the position of the clips and to determine whether the clips displaced on subsequent radiographs during follow-up, indicating tendon rupture.
Results: Repeat radiographs at 3-month follow-up showed higher risk of latissimus dorsi transfer rupture rate in 27/59 patients in group 1 (46%), 11/47 in group 2 (24%), and 7/44 in group 3 (15%).
Conclusion: Posterior anchor fixation of the latissimus dorsi tendon onto the infraspinatus footprint had the lowest rupture rate.

The Institutional Review Board of Clinique de l'Union, Toulouse, France has approved this study (issued to J.K., December 12, 2013).

*Reprint requests: Jean Kany, MD, Clinique de l'Union, Ramsay GDS, 31240 Saint Jean, France.
E-mail address: jean.kany@clinique-union.fr (J. Kany).

https://doi.org/10.1016/j.jse.2019.06.019

Level of evidence: Level III; Retrospective Cohort Design; Treatment Study

Keywords: Latissimus dorsi transfer; rupture rate; arthroscopic humeral fixation; transosseous; metal clips; massive cuff tear; irreparable postero superior cuff

Massive irreparable rotator cuff tears (RCTs) may represent as many as 20%-40% of the total RCTs undergoing surgery and remain a challenging clinical issue,[26,32] especially when they are associated with high-grade fatty degeneration of the supraspinatus, infraspinatus and/or teres minor (stage 3 or 4 according to Goutallier et al[10]), or when prior repair surgery has failed. Many surgical techniques have been proposed for massive irreparable RCTs, including partial cuff repair,[1] cuff augmentation,[5] tendon transfers,[7] superior capsule reconstruction,[23] or subacromial balloon spacers.[30] When Gerber et al[7] published their landmark paper in 1988 reporting the outcome of latissimus dorsi transfer (LDT), they reproduced Hoffer's procedure described in 1975 for Erb palsy to restore active external rotation.[17] Since 1988, LDT has been proposed for other indications rather than for sole restoration of active external rotation, and it has now become an established reconstructive procedure to restore function and reduce shoulder pain in the setting of massive irreparable posterosuperior RCT.[2,11,18]

Patient selection plays an important part in the success of latissimus dorsi surgery. Associated subscapularis tear, anterior deltoid deficit, proximal migration of the humeral head, poor preoperative function of the shoulder, shoulder stiffness, and osteoarthritis are contraindications to this procedure. Several technical modifications have been proposed to reduce failure rates such as single incision,[13] tendon augmentation,[3] bone augmentation,[25] or arthroscopically assisted techniques.[8,12,18,20,24] However, publications reporting the results of this procedure including these modifications have not shown any significant improvement in results.[15,21,22,27,31]

It has been suggested that these inconsistent clinical results may be because of possible ruptures of the LDT.[3,12,25] We have previously reported a high rate of LDT rupture (38%) using a radiographic evaluation of the migration of metallic markers embedded in the transferred tendon.[19] All ruptures were found to take place during the early postoperative period, and no late ruptures were reported after 3 months postsurgery. Moreover, at a mean of 35 months' follow-up, the outcomes were significantly worse in patients with a ruptured transfer compared with those without rupture, confirming the efficacy of such a transfer. The causes of LDT rupture remain unclear. Several methods of fixation of the transferred tendon onto the humeral head have been reported but these have never been compared and the best fixation method is therefore unknown.

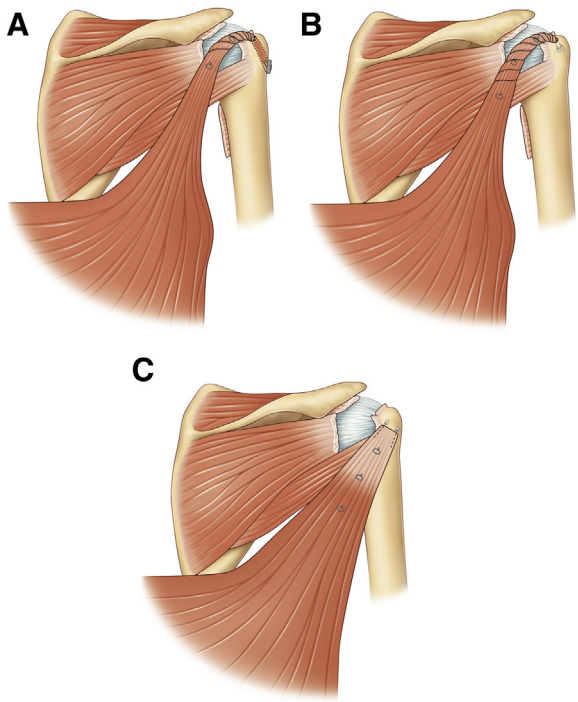

Figure 1 Fixation technique used in the 3 groups. (**A**) Group 1 with tendon tubularization, a tunnel, and a button (rupture rate 46%). (**B**) Group 2 with tendon tubularization, over the top, onto the supraspinatus footprint and anchor fixation (rupture rate 24%). (**C**) Group 3 with a flat tendon, posterior onto the infraspinatus footprint and anchor fixation (rupture rate 15%).

The purpose of this study was to evaluate the rupture rate of arthroscopic LDT using 3 different methods of fixation onto the humeral head. Our hypothesis was that the high rate of LDT rupture could be improved by modifying the fixation technique and latissimus dorsi tensioning onto the humeral head.

Methods

Study population

This retrospective, single institution, clinical level III study was carried out with a single surgeon (J.K.) performing the 3 different techniques of LDT humeral head fixation (Fig 1, *A* through *C*). Between January 2014 and December 2015, the procedure was carried out using "over the top" transosseous tunnel LDT tubularized fixation with a cortical button (group 1). Between January 2016 and December 2016, fixation was

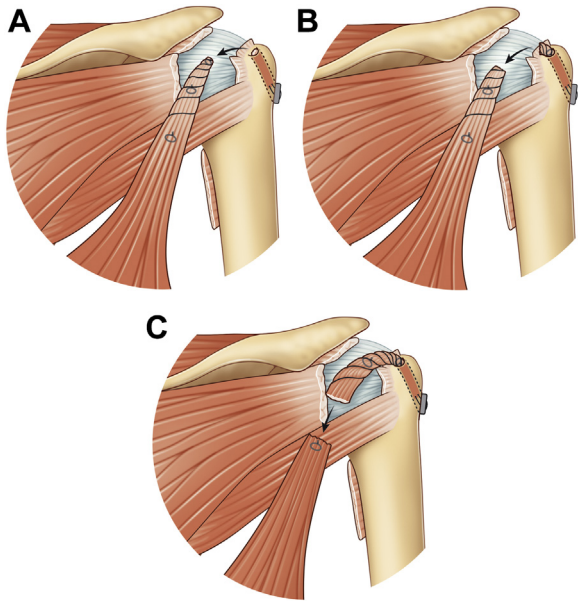

Figure 2 Drawing of the 2 main types of tendon rupture. (**A**) Bone-tendon failure inside the tunnel (type 1). (**B**) Rupture usually located at the interface between the bone tunnel and the tendon (type 2). (**C**) Rupture at the myo-tendinous junction (type 3).

performed using over-the-top LDT tubularized fixation onto the footprint of the supraspinatus with 2 suture anchors (1 classical and 1 knotless) (group 2). Finally, from January 2017 to December 2017, fixation consisted of posterior LDT "flat" fixation onto the footprint of the infraspinatus with 2 knotless suture anchors. This modification decreases the LDT tension in comparison to group 2.

Inclusion and exclusion criteria

Patients were included if they had persistent pain, failure of conservative treatments or previous surgical treatment (including biceps tenotomy, débridement, an attempt at partial or complete repair), at least 1 tendon retracted to the glenoid that could not be pulled to the greater tuberosity after bursal débridement and capsular release, and magnetic resonance imaging (MRI) demonstrating a massive irreparable tear of the posterosuperior rotator cuff with fatty infiltration of grade III or higher according to Goutallier et al[10] on at least 1 of the 2 torn tendons.

Patients were excluded if they had an associated irreparable tear of the subscapularis, a cuff tear arthropathy with glenohumeral arthritis (stage 4 or 5 according to Hamada et al[14]), associated complete and permanent axillary nerve palsy, a pseudoparalytic shoulder (active forward flexion $<70°$ despite 3 months of physiotherapy), and a stiff shoulder (limitation of passive range of motion in forward elevation, external rotation, and internal rotation).

Surgical technique

All surgical procedures were performed in the beach chair position under general anesthesia with an interscalene block.

Latissimus dorsi harvest and passage (groups 1, 2 and 3)

This step has been described previously and was the same for all 3 groups.[19] A 5-cm incision was performed along the anterior (axillary) border of the scapula. The latissimus dorsi (the first visible muscle) was separated from the belly of the teres major muscle and its neurovascular bundle was identified. Once the muscle belly was released from its surrounding structures, the aponeurotic band leading to the latissimus dorsi tendon was identified and carefully followed up to its humeral insertion. The latissimus dorsi tendon was then cut at its axillary insertion and detached from the humerus. The tendon was tubularized for 7 cm using 2 nonabsorbable sutures (Sutureloop No. 2; Vims Inc, Toulouse, France) for groups 1 and 2 (Fig. 2, *A*). The tendon was left flat for group 3 (Fig. 2, *B*). Three metal clips (Suturpack 2/0; Ethicon, Somerville, NJ, USA) were placed systematically inside the tendon and muscle of the latissimus dorsi at a fixed distance of 2 cm (M1), 4 cm (M2), and 6 cm (M3) from the tendon tip. The subcutaneous space was then released under the posterior deltoid and behind the long head of the triceps using blunt scissors from the insertion site of the latissimus dorsi to the subacromial space to prepare the most direct route for transfer.

Arthroscopic fixation

The main arthroscopic portals needed for this procedure were the standard posterior, anterolateral and lateral portals. Débridement of the subacromial space was performed and the long head of the biceps, when present, was tenodesed. The plane between the teres minor, when intact, and the deltoid was developed to allow passage of the transfer.

Group 1: Transosseous tunnel LDT fixation with a cortical button (Fig. 1, *A*). The free sutures of the tubularized latissimus dorsi tendon were retrieved through the newly created space under arthroscopic visualization. A specially designed 2-part guide (Wright Medical Group Inc, Memphis, TN, USA) was then used to drill a bone tunnel of the same diameter as that of the tendon (7 mm). The guide was positioned in order for the tunnel to pass from the posterosuperior aspect of the humeral head to the bicipital groove. The 4 sutures were then inserted into this bone tunnel, and a 2-cm length of latissimus dorsi tendon was introduced from cranial to caudal in the tunnel. The tendon was then fixed with a cortical button (Suture Button, 12 mm; Arthrex Inc, Naples, FL, USA) placed on the bicipital groove. At the end of the procedure, the first metallic marker was located at the entry of the bone tunnel.

Group 2: Over-the-top and tubularized LDT fixation onto the footprint of the supraspinatus with 2 suture anchors (see Fig. 1, *B*). The free sutures of the tubularized latissimus dorsi tendon were retrieved through the newly created space under arthroscopic visualization. No guide was used and fixation was achieved using a knotless anchor (Versalok; DePuy Mitek, Raynham, MA, USA) implanted close to the upper part of the bicipital groove and a second reabsorbable 5.5-mm anchor (ArthroVfix; Vims Inc, Toulouse, France) implanted at the junction between the footprints of the supra- and infraspinatus to enhance compression of the tubularized tendon. At the end of the procedure, the first metallic marker was located 2 cm distally from the Versalok anchor (at the junction between the insertion of the supra- and infraspinatus). In both group 1 and group 2, care was taken to fix the LDT with a similar tension.

Group 3: Posterior and flat LDT fixation onto the footprint of the infraspinatus with 2 knotless suture anchors (see Fig. 1, *C*). The free sutures of the nontubularized latissimus dorsi tendon were retrieved through the newly created space under arthroscopic visualization. No guide was used and fixation was made, keeping the tendon "flat," using 2 knotless anchors (Versalok; DePuy Mitek, Raynham, MA, USA) implanted onto the footprint at the junction between the supra- and infraspinatus to decrease the LDT tension when compared with group 2. At the end of the procedure, the first metallic marker was located 2 cm distally from the Versalok anchors (at the level of the teres minor).

Postoperative care

The postoperative protocol was the same for all 3 groups. Patients were placed in 60° abduction and a neutral-rotation brace for 4 weeks. Pendulum exercises were recommended immediately after surgery. At 4 weeks, the sling was removed and full range of motion was authorized. The patient began active assisted range of motion exercises in every direction for a minimum of 3 months associated with bio-feedback exercises to stimulate the transfer.

Outcome measures

All patients underwent a pre- and postoperative radiologic evaluation of the shoulder with assessment of the subacromial distance (SAD) and grade of glenohumeral arthritis according to the Hamada classification[14] on plain anteroposterior radiographs in neutral rotation with a 30° oblique incidence. All patients underwent either a preoperative computed tomography arthrogram or MRI to assess tendon retraction according to Patte[28] and fatty infiltration according to Goutallier et al.[10]

The postoperative radiographic evaluation was carried out by an independent orthopedic surgeon (J.D.W.). Similar outcome measures to those already published[27] were used. The anatomic integrity of the transferred tendon can be more precisely analyzed on plain radiographs as a result of the metallic markers implanted into the transferred tendon at fixed intervals. The postoperative radiologic evaluation was performed on postoperative standard anteroposterior radiographs in neutral rotation to assess the position of the 3 metallic markers with fluoroscopic positioning for consistency as follows: in the immediate postoperative period and at 3 months postsurgery. As reported previously,[19] an increased distance between 2 metallic markers would mean different possibilities of failure of the procedure as described below. A migration of $\geq$2 cm of one of the markers was considered as a rupture of the transferred tendon. When none of the 3 markers had migrated by at least 2 cm, the transfer was considered to be intact.

Occurrence of LDT rupture

As previously described,[19] 3 types of rupture could occur (Fig. 2, *A-C*):

1. The first type of rupture (type 1, Fig. 2, *A*) was located at the interface between the footprint and the tendon (proximal to the first metallic marker, M1). At this level, the transferred tendon did not heal correctly and migrated distally. In this situation, the distance between the 3 markers did not change but the distance between the top of the humeral head and the first metallic marker (M1) increased.
2. In the second type of rupture (type 2, Fig. 2, *B*), the distance between the most proximal marker (M1) and the second marker (M2) increased but the distance between the second (M2) and third (M3) markers did not change. For group 1 with transosseous fixation, the first metallic marker (M1) was located at the entry of the tunnel. This means that the rupture occurred at the bone tunnel-tendon interface. At this level, the tendon makes a "killer turn," leading to the so-called "guillotine" effect. This type of fixation could be responsible for attrition and/or necrosis of the transferred tendon at the tunnel entrance. For groups 2 and 3 fixed with suture anchors, the rupture was located through the whole tendon, which is probably the consequence of excessive tensioning.
3. A third mechanism is rupture at the musculotendinous junction (type 3, Fig. 2, *C*) probably due to excessive tensioning through the muscle fibers possibly leading to necrosis. In this situation, the distance between the second (M2) and third metallic markers (M3) increased. In this third mechanism (rupture at the musculotendinous junction, type 3), the rupture was outside the joint.

Statistical analysis

The primary objective of the analysis was to understand whether failure of LDT could be predicted by preoperative factors, including patient characteristics (age, sex, smoking status, type of work, work compensation), injury characteristics (number of tendons involved, teres minor atrophy, infraspinatus fatty infiltration, associated subscapularis repair, SAD, and Hamada stage), and surgical technique (type of fixation).

Regression analysis was performed to determine the significance of preoperative factors at predicting LDT rupture. Regression analysis was performed for the study population overall as well as for the individual groups across all preoperative factors. As a secondary analysis, relative risks (RRs) and odds ratios (ORs) were calculated for all preoperative factors, in particular Hamada classification, SAD <6 mm, and teres minor atrophy, to understand their influence on LDT healing. The χ^2 test was used to determine the significance of the relationship. A statistical analysis was also undertaken to compare whether healing was better in the different groups based on the fixation technique. Postoperative migration/SAD at review was used for the between-group comparisons (group 1 vs. group 2 vs. group 3). Statistical significance was determined using the Wilcoxon signed-rank test, a nonparametric test chosen as our patients were not randomly assigned to the operative procedures.

Statistical significance was set at $P < .05$ and all analyses were performed by an independent statistician not involved in the documentation of outcomes. Statistical software package SPSS version 20.0 (IBM, Armonk, NY, USA) was used for all statistical analyses.

Results

Demographic and preoperative results

One hundred fifty patients met the inclusion criteria. One patient died and was lost to follow-up. There were 84 male and 66 female patients, with a mean age of 63 years at the

Table I Demographic characteristics of the study population (N = 150)

Characteristic	n
Work type	
Retired	71
Sedentary	22
Manual labor	57
Previous surgery	
No	88
Once	51
Twice	6
Three times	5
Management of LHB	
LHB absent (previous surgery)	64
LHB tenotomy	84
LHB tenodesis	2
Workers' compensation	
Yes	42
No	108
Type of previous surgery	
Open cuff repair	18
Arthroscopic cuff repair	42
Acromioplasty with LHB tenotomy	1
Bone block	1

LHB, long head of biceps.

time of surgery (range: 46-83). The dominant arm was involved in 136 cases. The mean duration of symptoms before the surgical procedures was 24 months (range: 6-120). For 88 patients, LDT was the first surgical procedure (59%). Sixty-two patients (41%) had already undergone 1 (51 patients) or more (11 patients) previous operations, including arthroscopic cuff repair (42 patients), open cuff repair (18 patients), isolated acromioplasty (1 patient), and a bone-block procedure (1 patient). The demographic characteristics of the study population are shown in Table I.

In 115 patients, 2 tendons were involved in the tear (supraspinatus and infraspinatus) and in 35 patients, 3 tendons (supraspinatus, infraspinatus, and teres minor) were involved. Among the selected patients, 21 subscapularis tears were considered significant enough to be repaired and were therefore repaired during the procedure.

When involved, mean (SD) retraction stage was 3 (±0.1) for the supraspinatus and infraspinatus and 0.8 (±0.9) for the teres minor. Mean fatty infiltration stage was 3.7 (±0.5) for the supraspinatus, 3.5 (±0.5) for the infraspinatus, and 0.8 (±0.9) for the teres minor.

Group characteristics

Fifty-nine patients (39%) were treated with a tubularized transfer, bone tunnel, and a button (group 1), 47 patients (31%) were treated with an over-the-top tubularized transfer with 1 knotless and 1 classical fixation anchor (group 2), and 44 patients (30%) were treated with a flat transfer fixed by 2 posterior knotless anchors (group 3). The 3 groups were comparable in terms of preoperative age at surgery, Hamada stage, fatty infiltration, tendon retraction, and number of involved tendons (Table II).

Risk factors for poor outcome

Forty-five ruptured LDTs (30.6%) were reported in the entire series. When the LDT was ruptured, the mean distance between the 2 metallic markers was 4 cm (range: 2-9). The risk factors for poorer outcome are summarized in Table III.

Primary objective: preoperative predictive factors for LDT failure

None of the patient characteristics were significant predictors of migration ($R^2 = 0.02$, $F(8, 127) = 0.25$; $P = .98$). Individual groupwise analysis revealed that the rate of rupture was not predicted by preoperative factors in group 1 ($R^2 = 0.14$, $F(8, 45) = 0.92$; $P = .50$), group 2 ($R^2 = 0.23$, $F(8, 33) = 1.2$; $P = .28$), and group 3 ($R^2 = 0.16$, $F(9, 29) = 0.6$; $P = .77$). Among the injury characteristics, preoperative SAD influenced the rate of rupture ($B = 0.31$; $P = .003$); however, we could not obtain a significant model of prediction for the other preoperative factors, including teres minor atrophy, Hamada stage, subscapularis repair, previous interventions, and number of involved tendons ($R^2 = 0.11$, $F(10, 101) = 1.3$; $P = .24$). However, regression analysis revealed a significant model where LDT healing was predicted by the type of fixation ($R^2 = 0.07$, $F(1, 147) = 11.93$; $P = .001$).

Between-group analyses of postoperative healing (migration/SAD) found a statistically significant difference between the groups, with group 3 reporting the least migration (mean difference 1 cm [95% CI: 0.16-1.2]; $P = .01$) and postoperative SAD (mean difference 8 mm [95% CI: 7.3-8.5]; $P = .001$). Hence, it can be inferred that tendon healing was better with posterior anchor fixation.

Secondary objective: RR and OR

Univariate ORs and RRs were calculated for LDT healing and preoperative patient and injury characteristics (Table III). However, this relationship did not reach statistical significance.

With an OR <1 (OR = 0.36), patients who had a Hamada score of <2 had a lower rate of rupture (36.7%) when compared with those with a Hamada score of >2 (63.3%).

With an OR >1 (OR = 3.5), patients who had a preoperative SAD of <6 mm had an increased rate of rupture when compared with patients with an SAD of >6 mm (60.5% vs. 39.5%, respectively). Risk estimates suggested that the RR of rupture with an SAD of <6 mm was greater

Table II Comparison of the characteristics of the 3 study groups

Characteristic	Group 1	Group 2	Group 3
Number of patients	59	47	44
Sex ratio, male/female	26/33	33/14	25/19
Age at surgery, y, mean (range)	64 (46-83)	62 (43-81)	64 (43-81)
Fatty infiltrations*			
Supraspinatus	3.7 (0.5)	3.6 (0.6)	3.8 (0.4)
Infraspinatus	3.5 (0.6)	3.3 (0.5)	3.7 (0.5)
Teres minor	0.9 (1.1)	0.7 (0.9)	0.9 (0.9)
Tendon retractions†			
Supraspinatus	3 (0.2)	3 (0.2)	3
Infraspinatus	3 (0.1)	3 (0.2)	3
Teres minor	0.9 (1.1)	0.7 (0.9)	0.9 (0.9)
Involved tendons	2.2 (0.4)	2.2 (0.4)	2.3 (0.5)
Involved subscapularis, n	8	4	9
Subscapularis fatty infiltrations	0.4 (0.7)	0.3 (0.5)	0.6 (0.8)
SAD, mm	6.4 (2.7)	7.2 (2.2)	8 (2.2)
Mean Hamada stage	1.8 (0.7)	1.7 (0.7)	1.8 (0.6)

SAD, subacromial distance.
Unless otherwise noted, values are mean (standard deviation). Group 1: tubularized transfer with a bone tunnel and button fixation; group 2: tubularized transfer with an over-the-top fixation and 2 anchors; group 3: flat transfer with posterior fixation and 2 knotless anchors.
* According to Goutallier's classification.[10]
† According to Patte's classification.[28]

and this relationship was statistically significant (RR = 2.0 [95% CI: 1.3-3.0]; $P = .002$). No significant relationship between teres minor atrophy and rate of rupture was observed.

Comparison between groups

LDT healing was better in group 3 vs. group 1 and vs. group 2. Statistically significant differences in metallic marker migration were observed in all groups postoperatively with the least migration in group 3 (1 ± 1.7 cm [95% CI: 0.1-1.2]; $P = .01$) followed by group 2 (1 ± 1.2 cm [95% CI: 0.4-1.2]; $P = .001$), and group 1 with the highest migration (2 ± 2.2 cm [95% CI: 1.2-2.4]; $P = .001$). However, the mean difference between the groups was not statistically significant (group 1 vs. group 2 [mean difference 1 ± 2.6 cm; $P = .12$], group 1 vs. group 3 [mean difference 1 ± 3.1 cm; $P = .13$], and group 2 vs. group 3 [mean difference 0 ± 2.3 cm; $P = .79$]) (Table IV). This study may be underpowered to find such a difference.

Group 1: transosseous tunnel LDT fixation with a cortical button

Twenty-seven of the 59 patients in this group (46%) had a ruptured LDT at 3 months postsurgery. Among these 27 ruptures, 20 (74%) were type 2, located at the tunnel-tendon interface (between the first [M1] and second [M2]

Table III Univariate odds ratios and risk ratios for LDT rupture

Factors	Odds ratio	Relative risk	95% CI	Significance (*P* value)
Age <65 y	0.83	0.92	0.4-1.6	.60
Male sex	1.0	1.0	0.5-2.2	.82
Smoker	1.1	1.1	0.3-3.3	.80
Manual worker	0.8	1.0	0.4-1.7	.66
Work compensation	1.6	1.4	0.7-3.4	.20
Previous surgery	1.1	1.0	0.5-2.1	.90
No. of tendons <3	1.2	0.9	0.5-2.7	.65
Subscapularis repair	0.8	0.9	0.3-2.3	.74
Fatty infiltration of IS	0.5	0.7	0.3-1.1	.09
TM atrophy	0.8	0.9	0.4-1.6	.48
SAD <6 mm	1.3	1.2	0.2-8.0	.77
Hamada stage <2	0.7	0.8	0.3-1.5	.35

LDT, latissimus dorsi transfer; *IS*, infraspinatus; *TM*, teres minor; *SAD*, subacromial distance; *CI*, confidence interval.
Odds ratio >1: factor associated with a greater risk of LDT rupture; odds ratio <1: factor associated with a lower risk of LDT rupture.

Table IV Comparison of the success rate between the different groups

Characteristics	Group 1 (n = 59)	Group 2 (n = 47)	Group 3 (n = 44)
Ruptured LDT, n (%)	27 (46)	11 (24)	7 (15)
Rupture location, n			
Type 1	0	0	2
Type 2	20	6	3
Type 3	7	5	2
Migration distance (cm), mean (SD)	2 (2.2)	1 (1.2)	1 (1.7)
Significance (*P*)	.001	.001	.01

LDT, latissimus dorsi transfer; *SD*, standard deviation.
Group 1: tubularized transfer with a bone tunnel and button fixation; group 2: tubularized transfer with over-the-top fixation and 2 anchors; group 3: flat transfer with posterior fixation and 2 knotless anchors.
Type 1: the rupture is proximal to the first (M1) metallic marker at the bone-tendon interface; type 2: the rupture is located between the first (M1) and second (M2) metallic marker (into the whole tendon); type 3: the rupture is located between the second (M2) and third (M3) metallic marker (at the muscle-tendon interface).

metallic markers). Seven (26%) of these ruptures were type 3, located at the muscle-tendon interface (between the second [M] and third [M3] metallic markers). There were no migrations of the cortical button.

Group 2: over-the-top tubularized-LDT fixation onto the footprint of the supraspinatus with 2 suture anchors

Eleven of the 47 patients in this group (23%) had a ruptured LDT at 3 months postsurgery. Of these 11 ruptures, 6 (54%) were type 2, located at the bone-tendon interface (proximal from the first [M1] metallic marker). Five (46%) of these ruptures were type 3, located at the muscle-tendon interface (between the second [M2] and third [M3] metallic markers). There was no suture anchor migration.

Group 3: posterior "flat"—LDT fixation onto the footprint of the infraspinatus with 2 knotless suture anchors

Seven of the 47 patients in this group (15%) had a ruptured LDT at 3 months postsurgery. Of these 7 ruptures, 3 (43%) were type 2, located in the tendon (between the first [M1] and second [M2] metallic markers). Two (28%) of these ruptures were type 3, located at the muscle-tendon interface (between the second [M2] and third [M3] metallic markers). Two (28%) of these ruptures were type 1 and involved the anchor fixation (proximal from the first [M1] metallic marker).

Acute complications and failure rate

There were 27 complications overall (18%). Fourteen patients had a hematoma localized on the lateral thoracic side in front of the axillary approach. Among these patients, 10 healed uneventfully with nonsurgical treatment (7 patients) or with surgical drainage (3 patients), whereas 4 patients underwent revision surgery for a deep infection (*Staphylococcus aureus* and *Cutibacterium acnes*). Surgical débridement and intravenous antibiotic therapy followed by oral antibiotics for these 4 infected cases resulted in uneventful healing in 2 (very satisfied and nonruptured LDT) and in an unsatisfactory result for the remaining 2 patients (disappointed and ruptured LDT).

One patient had a subscapularis retear after trauma leading to an anterosuperior escape of the humeral head with a poor result (disappointed and ruptured LDT), but this patient is not willing to undergo revision surgery to date.

One patient died 5 days after surgery without any direct relation to the procedure. Another patient receiving treatment with low-molecular-weight heparin for another disease had a transient ischemic attack 1 month after surgery without any sequelae.

Discussion

This study suggests a strong correlation between LDT healing and mode of humeral head fixation: the technique with the lowest rate of failure was reported in group 3: a flat tendon fixed with 2 knotless anchors onto the footprint of the infraspinatus with a 15% failure rate. When fixation was performed with a tubularized tendon and 2 anchors onto the footprint of the supraspinatus (group 2), the rupture rate was 24%. Our findings confirm previous results[27] of a high failure rate (46%) with tubularized tendons into a transosseous tunnel and cortical button fixation (group 1).

Although the tubularized tendon with transosseous fixation has been reported to be the strongest type of fixation in a biomechanical in vitro study,[4] it fails to demonstrate a better rate of tendon healing in vivo. This is probably due to the ''guillotine'' effect described previously.[19] A flat fixation (group 3) offers a larger contact surface and appears to be more physiological for tendon healing. Moreover, a higher tension after tendon fixation may be responsible for transfer rupture and could explain our lower rate of failure when fixation was onto the infraspinatus footprint instead

of the supraspinatus footprint. It is important to note that the same axillary open approach and the same latissimus dorsi insertion scapula apex release had been performed in each group. Finally, our data demonstrate that anchor fixation is strong enough and that physiological tensioning applied through the LDT may be one of the keys to tendon healing.

These data suggest that the original fixation technique of Gerber[7] onto the supraspinatus footprint close to the subscapularis insertion should be modified to a more posterior area as proposed by Herzberg et al.[16] This site of reinsertion probably decreases the tension applied to the transferred tendon and therefore facilitates healing.

The purpose of an LDT could be to ''re-balance'' the shoulder rather than to act as a ''depressor'' of the humeral head as considered previously.[24] This hypothesis could explain the importance of a strong and functional subscapularis as suggested in previous publications.[1] Transfer is supposed to not only have a dynamic effect but also a tenodesis effect and could stabilize the shoulder to prevent the Hamada stage worsening as suggested by the long-term follow-up study of Gerber et al.[6]

Our 3 groups were comparable in terms of preoperative characteristics. This study confirms previous publications[31] that state that patients had a higher risk of suffering an LDT rupture in the case of previous rotator cuff repair. These data might be helpful when considering patients with 2 or 3 large tendon tears eligible for primary tendon transfer. Conversely, patients had a higher chance of LDT healing if the Hamada stage was <2, if they were <65 years old, and if the subscapularis was repaired (RR < 1).

The harvested latissimus dorsi tendon can be very thin and tenuous[3] and is often under some tension, which may contribute to impaired tendon-bone healing, poor outcomes, and erratic results.[26] Since the landmark paper published by Gerber et al in 1988,[7] many alterations to the original technique have been described, consisting mainly of altering the technique of fixation of the tendon with either suture anchors, tendon augmentation,[3,33] tendon extension,[29] bone chips,[25] or a combination of different techniques with mixed results. This could be an option to reduce the risk of type 2 ruptures (ie, in the tendon). Nevertheless, these augmentations cannot prevent type 1 (at the tendon-bone interface) or type 3 ruptures (at the musculotendinous junction), which may represent at least 26% of our failures whatever the technique. To our knowledge, no previous publications have pointed out the importance of tensioning applied through the transferred tendon and the risk of rupture.

We have been considering LDT as a tendon transfer per se, and notice was taken of the principles of tendon transfer.[9] In our experience, the tendon was long enough (5-7 cm) in all cases after release from the apex of the scapula and never required any extension. Posterior flat knotless LDT fixation has become our routine procedure. We have moved to a combined fully arthroscopic (without any axillary portal) latissimus dorsi-teres major double transfer that could prevent the remaining 15% of LDT ruptures and 19% complications such as hematoma and/or infections. This technical modification could reinforce both the very thin latissimus dorsi and global strength, which is currently being investigated.

Limitations

There are several limitations to this study, including a lack of randomization, lack of clinical data, and a short follow-up period. However, it has been reported that failures always occur between the first and third months postoperatively without any symptoms.[19] Furthermore, it has already been shown that healed LDTs have a better clinical outcome than failed LTDs.[19] The purpose of our study was not to report clinical data that have already been published but to specifically compare 3 different techniques of humeral head fixation to better understand the modes of LDT failure using a validated technique[19] of investigation with metallic markers. Another limitation of the study could be the lack of randomization; nevertheless, we were not able to find any similar studies in the literature with a randomized protocol. Finally, our study was monocentric, without any interobserver reliability assessment. However, these surgical techniques were performed within a short but continuous period of time, by a senior shoulder surgeon with significant experience in arthroscopy-assisted LDT and the results were analyzed by an independent observer.

Conclusions

The posterior knotless anchor fixation technique onto the infraspinatus footprint appears to significantly decrease the rate of ruptured LDTs, followed by over-the-top fixation. However, transosseous fixation showed the highest rate of LDT rupture at the bone-tendon interface. Based on these results, the senior authors have stopped using transosseous fixation and now favor and recommend fixing the latissimus dorsi tendon using posterior knotless fixation onto the footprint of the infraspinatus.

Acknowledgments

The authors thank Newmed Publishing Ltd. for providing English editing services. Ramsay GDS funded the English editing service.

Disclaimer

The authors, their immediate families, and any research foundations with which they are affiliated have not

received any financial payments or other benefits from any commercial entity related to the subject of this article.

References

1. Burkhart SS, Athanasiou KA, Wirth MA. Margin convergence: a method of reducing strain in massive rotator cuff tears. Arthroscopy 1996;12:335-8.
2. Checchia C, Domos P, Grimberg J, Kany J. Current options in tendon transfers for irreparable rotator cuff tears. J Bone Joint Surg Rev 2019; 7:e6. https://doi.org/10.2106/JBJS.RVW.18.00044
3. Debeer P, De Smet L. Outcome of latissimus dorsi transfer for irreparable rotator cuff Latissimus dorsi transfer augmented with allograft tears. Acta Orthop Belg 2010;76:449-55.
4. Diop A, Maurel N, Chang VK, Kany J, Duranthon LD, Grimberg J. Tendon fixation in arthroscopic latissimus dorsi transfer for irreparable postero-superior cuff tears: an in vitro biomechanical comparison of interference screw and suture anchors. Clin Biomech 2011;26:904-9. https://doi.org/10.1016/j.clinbiomech.2011.05.011
5. Ferguson DP, Lewington MR, Smith TD, Wong IH. Graft utilization in the augmentation of large-to-massive rotator cuff repairs: a systematic review. Am J Sports Med 2016;44:2984-92. https://doi.org/10.1177/0363546515624463
6. Gerber C, Rahm SA, Catanzaro S, Farshad M, Moor BK. Latissimus dorsi tendon transfer for treatment of irreparable posterosuperior rotator cuff tears. J Bone Joint Surg Am 2013;95:1920. https://doi.org/10.2106/JBJS.M.00122
7. Gerber C, Vinh TS, Hertel R, Hess CW. Latissimus dorsi transfer for the treatment of massive tears of the rotator cuff. A preliminary report. Clin Orthop Relat Res 1988;232:51-61.
8. Gervasi E, Causero A, Parodi PC, Raimondo D, Tancredi G. Arthroscopic latissimus dorsi transfer. Arthroscopy 2007;23:1243.e1-e4. https://doi.org/10.1016/j.arthro.2006.12.021
9. Goldstein Y, Grimberg J, Valenti P, Chechik O, Drexler M, Kany J. Arthroscopic fixation with a minimally invasive axillary approach for latissimus dorsi transfer using an EndoButton in massive and irreparable postero-superior cuff tears. Int J Shoulder Surg 2013;7:79-82. https://doi.org/10.4103/0973-6042.114223
10. Goutallier D, Postel JM, Bernageau J, Lavau L, Voisin MC. Fatty muscle degeneration in cuff ruptures. Pre- and postoperative evaluation by CT-scan. Clin Orthop Relat Res 1994;304:78-83.
11. Grimberg J, Kany J. Latissimus dorsi tendon transfer for irreparable postero-superior cuff tears: current concepts, indications, and recent advances. Curr Rev Musculoskelet Med 2014;7:22-32. https://doi.org/10.1007/s12178-013-9196-5
12. Grimberg J, Kany J, Valenti P, Amaravathi RS, Ramalingam AT. Arthroscopic-assisted latissimus dorsi tendon transfer for irreparable posterosuperior cuff tears. Arthroscopy 2015;31:599-607. https://doi.org/10.1016/j.arthro.2014.10.005
13. Habermeyer P, Magosch P, Rudolph T, Lichtenberg S, Liem D. Transfer of the tendon of latissimus dorsi for the treatment of massive tears of the rotator cuff: a new single-incision technique. J Bone Joint Surg Br 2006;88:208-12. https://doi.org/10.1302/0301-620X.88B2.16830
14. Hamada K, Fukuda H, Mikasa M, Kobayashi Y. Roentgenographic findings in massive rotator cuff tears. A long-term observation. Clin Orthop Relat Res 1990;254:92-6.
15. Hart R, Barta R, Nahlik D. Latissimus dorsi transfer for the treatment of irreparable craniodorsal tears of the rotator cuff. Acta Chir Orthop Traumatol Cech 2010;77:215-21 [in Czech].
16. Herzberg G, Urien JP, Dimnet J. Potential excursion and relative tension of muscles in the shoulder girdle: relevance to tendon transfers. J Shoulder Elbow Surg 1999;8:430-7.
17. Hoffer MM, Wickenden R, Roper B. Brachial plexus birth palsies. Results of tendon transfers to the rotator cuff. J Bone Joint Surg Am 1978;60:691-5.
18. Kany J, Anis H, Werthel JD. Massive irreparable rotator cuff tears: treatment options, indications, and role of fully arthroscopic latissimus dorsi transfer. Obere Extremität 2018;13:246-54. https://doi.org/10.1007/s11678-018-0478-9
19. Kany J, Grimberg J, Amaravathi RS, Sekaran P, Scorpie D, Werthel JD. Arthroscopically-assisted latissimus dorsi transfer for irreparable rotator cuff insufficiency: modes of failure and clinical correlation. Arthroscopy 2018;34:1139-50. https://doi.org/10.1016/j.arthro.2017.10.052
20. Kany J, Kumar HA, Chang VK, Grimberg J, Garret J, Valenti P. Mini invasive axillary approach and arthroscopic humeral head interference screw fixation for latissimus dorsi transfer in massive and irreparable posterosuperior rotator cuff tears. Tech Shoulder Elbow Surg 2010;11: 8-14. https://doi.org/10.1097/BTE.0b013e3181cabdab
21. Lehmann LJ, Mauerman E, Strube T, Laibacher K, Scharf HP. Modified minimally invasive latissimus dorsi transfer in the treatment of massive rotator cuff tears: a two year follow-up of 26 consecutive patients. Int Orthop 2009;34:377-83. https://doi.org/10.1007/s00264-009-0782-5
22. Lichtenberg S, Magoch P, Habermeyer P. Are there advantages of the combined latissimus dorsi transfer according to L'Episcopo compared with the isolated latissimus dorsi transfer according to Herzberg after a mean follow-up of 6 years? A matched-pair analysis. J Should Elb Surg 2012;21:1499-507. https://doi.org/10.1016/j.jse.2012.01.002
23. Mihata T, Watanabe C, Fukunishi K, Ohue M, Tsujimura T, Kinoshita M. Arthroscopic superior capsular reconstruction restores shoulder stability and function in patients with irreparable rotator cuff tears: a prospective study (SS-15). Arthroscopy 2011;27:e36-7. https://doi.org/10.1016/j.arthro.2012.10.022
24. Millett PJ, Yen YM, Huang MJ. Arthroscopically assisted latissimus dorsi transfer for irreparable rotator cuff tears. Tech Shoulder Elbow Surg 2008;9:76-9. https://doi.org/10.1016/j.clinbiomech.2011.05.011
25. Moursy M, Forstner R, Koller H, Resch H, Tauber M. Latissimus dorsi tendon transfer for irreparable rotator cuff tears: a modified technique to improve tendon transfer integrity. J Bone Joint Surg Am 2009;91: 1924-31. https://doi.org/10.2106/JBJS.H.00515
26. Namdari S, Voleti PB, Baldwin K, Glaser D, Huffman GR. Latissimus dorsi tendon transfer for irreparable rotator cuff tears. J Bone Joint Surg Am 2012;94:891-8. https://doi.org/10.2106/JBJS.K.00841
27. Nové-Josserand L, Costa P, Liotard JP, Safar JF, Walch G, Zilber S. Results of latissimus dorsi tendon transfer for irreparable cuff tears. Orthop Traumatol Surg Res 2009;95:108-13. https://doi.org/10.1016/j.otsr.2008.10.002
28. Patte D. Classification of rotator cuff lesions. Clin Orthop Relat Res 1990;254:81-6.
29. Pearsall AW, Madanagopal SG, Karas SG. Transfer of the latissimus dorsi as a salvage procedure for failed debridement and attempted repair of massive rotator cuff tears. Orthopedics 2007;30:943-9.
30. Savarese E, Romeo R. New solution for massive, irreparable rotator cuff tears: The subacromial "biodegradable spacer". Arthrosc Tech 2012;1:e69-74. https://doi.org/10.1016/j.eats.2012.02.002
31. Valenti P, Kalouche I, Diaz LC, Kaouar A, Kilinc A. Results of latissimus dorsi tendon transfer in primary or salvage reconstruction of irreparable rotator cuff tears. Orthop Traumatol Surg Res 2010;96: 133-8. https://doi.org/10.1016/j.jse.2009.12.017
32. Wong I, Burns J, Snyder S. Arthroscopic graft jacket repair of rotator cuff tears. J Shoulder Elbow Surg 2010;19:104-9. https://doi.org/10.1016/j.jse.2009.12.017
33. Zafra M, Carpintero P, Carrasco C. Latissimus dorsi transfer for the treatment of massive tears of the rotator cuff. Int Orthop 2008;33:457-62. https://doi.org/10.1007/s00264-008-0536-9