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

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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.

This study was approved by the local medical ethical committee (WO-15.116) of Onze Lieve Vrouwe Gasthuis (OLVG) Hospital.

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Level of evidence: Basic Science Study; Kinesiology

Key words: Latissimus dorsi; muscle transfer; massive rotator cuff tear; shoulder kinematics; electromyography; shoulder surgery

A massive irreparable posterosuperior rotator cuff tear (MIRT), in a patient aged < 65 years can be challenging to manage adequately. A massive tear[4,7,10,13,19,24,55,62] does not necessarily mean an irreparable tear,[13] but excessive retraction, loss of elasticity, muscle atrophy, and the inability to achieve fixation in $\leq 60°$ of abduction despite adequate releases make repair impossible.[3,4,24,25,27,29,30,33,46,66] The prevalence of massive tears ranges from 10% to 40% of all rotator cuff tears, and the retear rate of MIRTs is 90% after primary repair.[1,18]

An MIRT is clinically observed by pain in the shoulder with an impairment of active forward flexion, abduction, and external rotation.[1,4,54] The symptoms may vary from mild pain and maintained active shoulder motion to severe pain with pseudoparalysis and loss of strength.[3,4,17,21,24,41,45,53] Pseudoparalysis is generally defined as a limitation of active forward flexion to 90° with no restriction in passive range of motion (ROM).[17,67] 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.[6,17,68]

Different treatment modalities have been reported for MIRTs: physical therapy, tenotomy or tenodesis of the long head of the biceps, débridement, partial repair of the tear, muscle transfer, rotator cuff advancement, graft interposition, superior capsular reconstruction, and reverse shoulder arthroplasty.[1,31,32,48] 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.[4,26,41,65] Several authors have reported inferior outcomes after LDT in patients with preoperative pseudoparalysis,[9,16,24,25,41] and although recent literature has demonstrated good outcomes, it may still be considered controversial to perform LDT in a patient with pseudoparalysis.[14,56,58,63]

Regarding transfers, the often implicit assumption is that the transferred muscles are capable of adapting to their new mechanical role.[22,38,43,54] 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.[40,42] 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.[22,39,40,42,43]

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 for 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[26] with protocolized postoperative care (Supplementary Appendix S1).

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 (Fig. 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

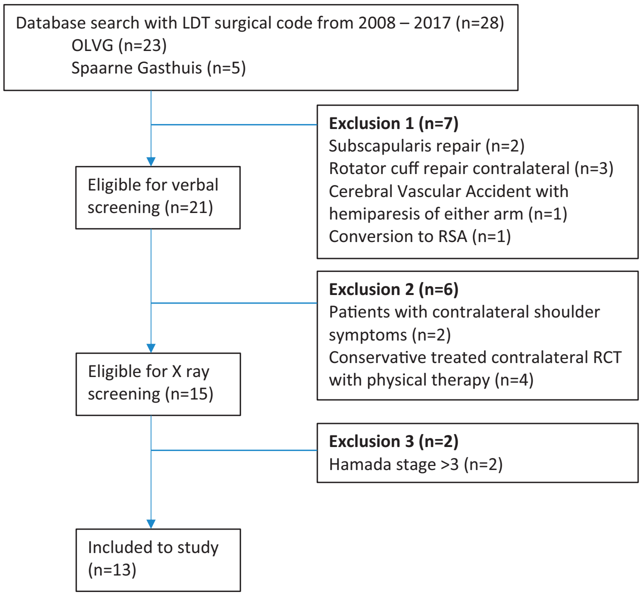


Figure 1 Flowchart of inclusion and exclusion criteria. *LDT*, latissimus dorsi transfer; *OLVG*, Onze Lieve Vrouwe Gasthuis, Amsterdam, The Netherlands; *RSA*, reverse shoulder arthroplasty; *RCT*, rotator cuff tear.

the Hamada stage.[35] 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 I. 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.

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 (Fig. 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[35] (Table II).

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 (Fig. 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[11] and the activities of daily living requiring active external rotation (ADLER) score[5] were collected during the visit at Reade and are reported separately in Supplementary Appendix S1.

Statistical analysis

The maximal active elevation of the shoulder (MAES), which consisted of forward flexion, scapular abduction, and abduction in

Table I Study procedure

	Procedure
First phone contact	Verbal screening was performed, and study information was provided.
Written information	Patients were provided with information folders containing the study rationale and goals, study procedure, minimal health risks of participation, and important contact details in case of questions about the study.
Two-week pause	Patients were given time to consider their 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.

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 Supplementary Appendix S1.

LDT shoulder vs. 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 III, Fig. 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 III). Significantly lower maximal external rotation of the shoulder was seen for the LDT shoulder (26° ± 10° for LDT shoulder vs. 42° ± 10.9° for ACS, $P < .001$).

LD activity

The LD percentage EMG max during MAES did not show any difference between the LDT shoulder and ACS ($F_{1,11} = 0.005$, $P = .946$). An example 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.

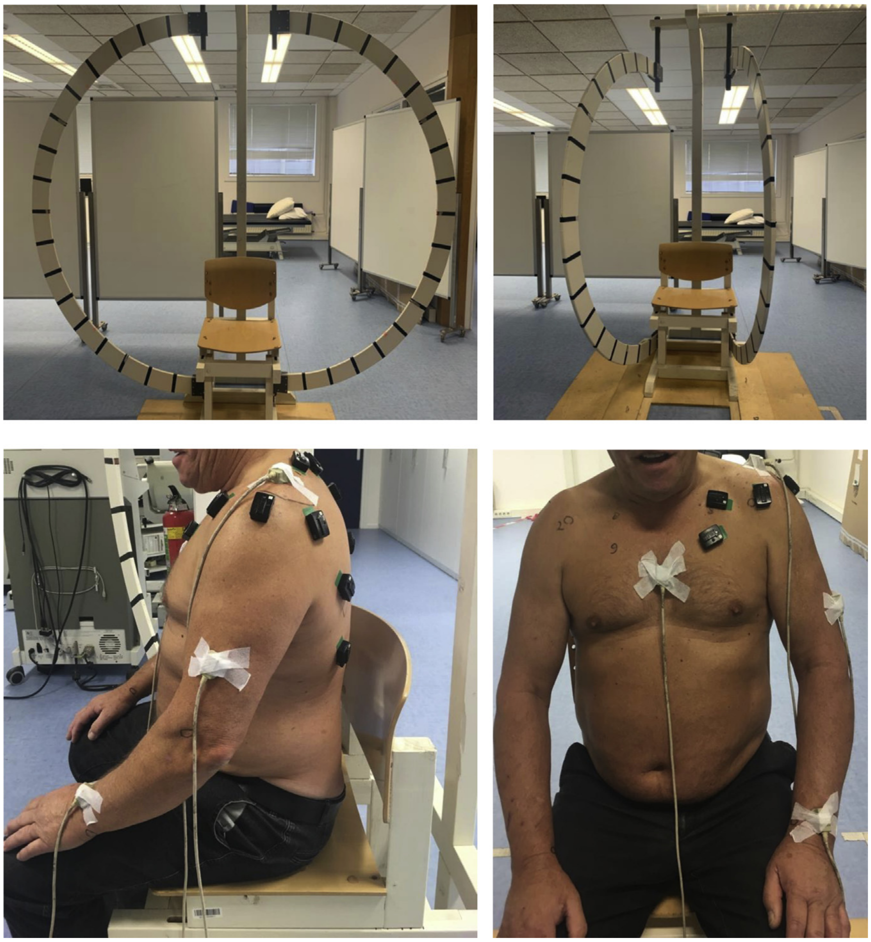


Figure 2 Patient setup.

Table II Bony landmarks for 3-dimensional kinematic analysis

	Landmark
Thorax and spine	Jugular notch
	Xiphoid process
	Seventh cervical vertebra
	Eighth thoracic vertebra
Scapula	Acromial angle
	Scapular trigonum
	Angulus inferior
Humerus	Medial epicondyle
	Lateral epicondyle
Forearm	Radial styloid
	Ulnar styloid

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.

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.[22,40] Galasso et al[22] 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 for the

Table III Comparison of active movement of LDT shoulder vs. ACS

Active movement	n	LDT shoulder	ACS	*P* value
TH ROM, °				
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
GH ROM, °				
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	.511
Grasping cup	13	NA	NA	NA
Combing hair	13	9.3 ± 10.6	5.2 ± 10.6	.182
Deltoid, % EMG max				
Forward flexion	13	73.5 ± 26.2	62.3 ± 23.9	.249
Scapular abduction	13	87.6 ± 19.4	64.0 ± 15.2	<.001
Abduction	13	88.0 ± 16.3	66.1 ± 24.9	.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.

contralateral shoulder.[12] 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.[47,50,68] This restorative effect on joint kinematics was not observed after LDT in our study, which is in accordance with the findings of Galasso et al[22] and Henseler et al.[38]

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.[2,8,23,28,34,39-42,44,59] The method of analyzing LD muscle activity varies among studies, which likely adds to the inconsistency.

Habermeyer,[34] Iannotti et al,[41] Ippolito et al,[42] and Henseler et al[39] 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.[57,60] In addition, De Casas et al[14] and Irlenbusch et al[44] 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 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[8] 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[22] and Hetto et al[40] comparing the LDT shoulder with the ACS with isokinetic movements

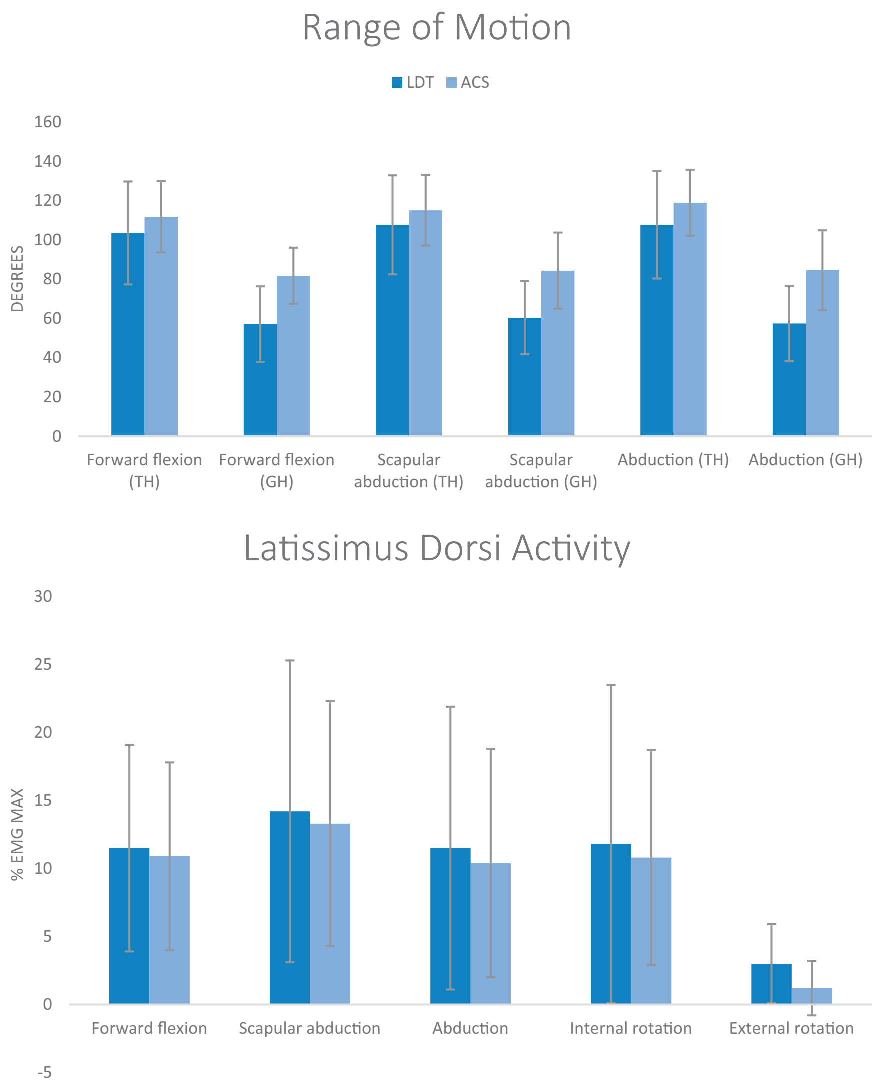


Figure 3 Latissimus dorsi transfer *(LDT)* shoulder and asymptomatic contralateral shoulder *(ACS)*. *TH*, thoracohumeral motion; *GH*, glenohumeral motion; *EMG*, electromyography; *MAX*, maximum.

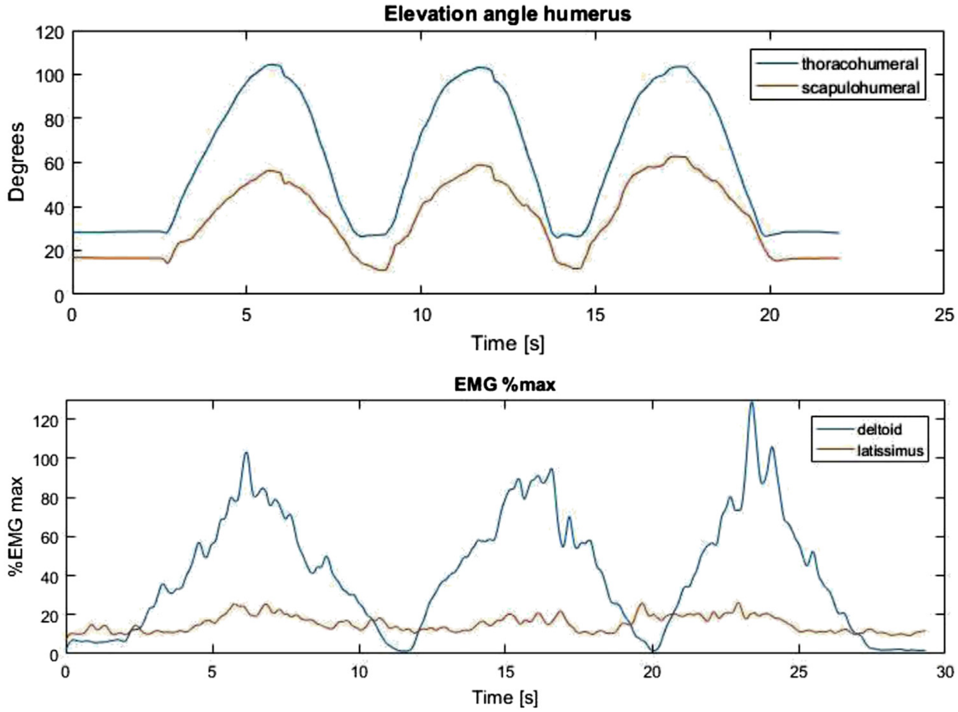
reported similar results to our study, that is, no difference in LD muscle activation after LDT compared with the ACS.

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.[6,17,37] An MIRT is characterized by deficient supraspinatus and infraspinatus muscles and occasionally a deficient teres minor muscle.[56] In the absence of a properly balanced force couple around the glenoid in an MIRT, the humeral head is unstable in the posterosuperior direction during active shoulder movements.[61] 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 lower GH motion 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.[20]

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).[15,37,57] This counteracting effect is not sufficient to restore shoulder function in patients with pseudoparalysis.[17,37,49] It could be that LDT, with its new proximal insertion site, exerts a stronger caudally directed pull, counteracts the cranially directed forces, and stabilizes

Example LDT shoulder



Example ACS

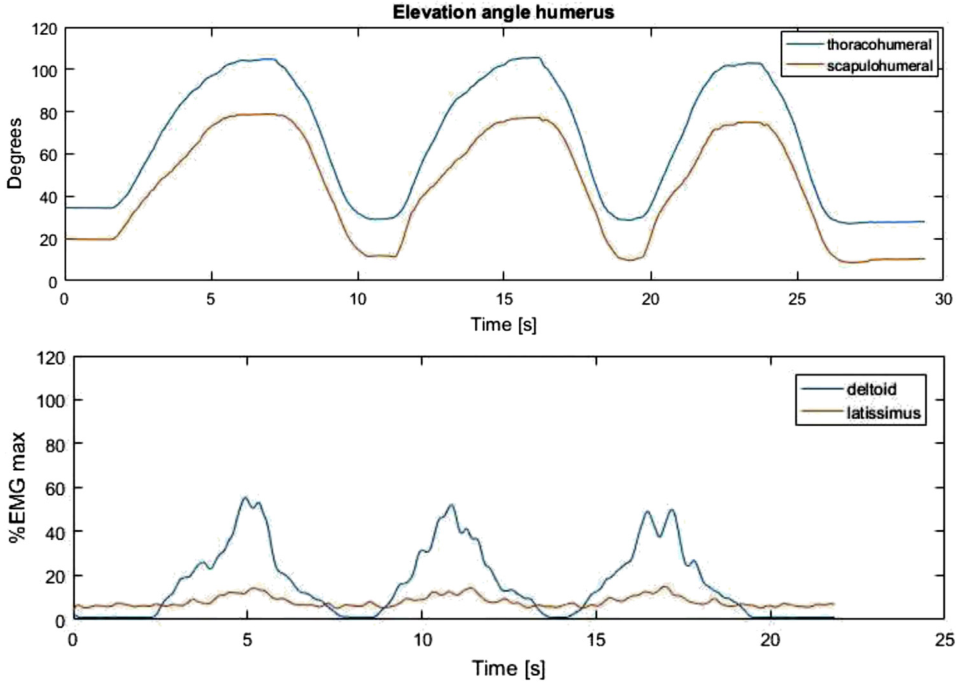


Figure 4 Example curves of elevation (3-dimensional) and surface electromyography *(EMG)* of latissimus dorsi transfer *(LDT)* shoulder and asymptomatic contralateral shoulder *(ACS)*. Scapulohumeral elevation indicates glenohumeral elevation. *max*, maximum.

the GH joint by providing a stable fulcrum for the deltoid.[36,37,51] This is supported by the findings of increased deltoid activity in scapular abduction and abduction after LDT.[36] The smaller GH motion found after an MIRT and/or LDT could be explained by the change in function of the remnant GH muscles from mobilizing the GH joint to increasing the joint reaction force to prevent the cranially directed force of the deltoid during active elevation.[36] 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.[22,52] In future studies, it would be useful to also focus on the function of the thoraco-scapular muscles after LDT.[51,64]

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.

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Supplementary data

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