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SHOULDER FUNCTION ASSESSMENT AFTER FALD FLAP BREAST RECONSTRUCTION: COMPARING ULTRASOUND RESULTS AND PATIENTS' SELF PERCEPTION

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Summary

Background. The Fat-Augmented LD (FALD) flap is a workhorse flap for autologous breast reconstruction (BR). Latissimus Dorsi muscle is responsible for upper limb medial rotation, adduction and extension and contributes to the glenohumeral joint stabilization. To date, controversial conclusions have been reached about shoulder impairment following BR with FALD flap.

Methods. The study prospectively enrolled 36 patients (46 flaps) who underwent BR with FALD flap. Participants underwent a shoulder ultrasound imaging, analysing the acromio-humeral interval (AHI) measurement pre-operatively (t_0), at 6 (t_1) and 12 (t_2) months after surgery and completed the DASH questionnaire. Teres major thickness was determined with dorsal ultrasound, preoperatively and at least 12 months after surgery. Statistical analysis using linear mixed effects model was performed with significant values < 0.05.

Results. Comparing the mean AHI value of each follow-up time (*t1 and t2*) to the mean AHI value at the baseline (*t0*) the pattern remained quite the same, with a non-significant reduction between *t0-t1* ($p = 0.873$) and a little increase between *t0-t2* ($p = 0.468$). Self-reported outcomes showed a similar trend with a reduction in upper limb function initially compared to pre-operative status (t_0), followed by an improvement at the subsequent intervals (all $p < 0.05$). Dorsal US showed an increase in TM thickness postoperatively compared to preoperative values (11.4 *vs* 12.4 mm; $p = 0.01984$).

Conclusions. BR with FALD flap is a safe procedure since no long-term shoulder disability was found according to AHI, dorsal US, and DASH questionnaire assessments.

Key words: autologous breast reconstruction, FALD flap, latissimus dorsi flap, shoulder outcomes, acromio-humeral interval, teres major muscle

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INTRODUCTION

The DIEP flap is currently the favoured method in a broad spectrum of patients due to similarity between abdominal and breast subcutaneous tissue in terms of shape, consistency, and low donor site morbidity [1-3]. Nevertheless, there do exist more reconstructive options which are indicated to patients with high-risk comorbidities [4], contraindications to microsurgery [5,6], and either insufficient or inappropriate abdominal tissue for DIEP flap [7]. FALD flap represents a suitable alternative in such cases as, being a myocutaneous flap [8], it offers a huge availability of soft tissues and gives the plastic surgeon the possibility of a total autologous reconstruction of small to moderate sized breasts without implants [9-13]. The latissimus dorsi (LD) muscle, muscular component of FALD flap, is a wide triangular structure originating on the spine and ilium and extending across the upper and mid-back to insert on the humerus [14]. Functionally, it belongs to the muscles of scapular motion and plays a fundamental role, in cooperation with teres major muscle (TM), in the execution of upper limb movement such as medial rotation, adduction and extension, cooperating in the stabilization of the glenohumeral joint [15]. As such, shoulder motion is the result of the complex interplay of static and dynamic stabilizers [16]. The dynamic stabilisation is provided firstly by the rotator cuff muscles, that attaching to the humerus tuberosities act to compress the humeral head into the glenoid cavity. Additionally, the LD muscle with its tendinous insertion on the great sulcus of the humerus, pulls its head downwards [17]. In this way, the LD muscle influences the height of the acromio-humeral interval (AHI), which is the reason why muscle transposition in FALD flap procedure can cause the humeral head to slip upwards, possibly altering shoulder joint functionality. The pressing need of investigating shoulder outcomes after LD flap harvesting have been already emphasized [18-20], although scientific evidence does not allow a definitive conclusion to be drawn. In this context, previous prospective studies are affected by flaws of methodology, small sample size and inter-individual variability, thus preventing authors from conducting reliable statistical analyses [14,16]. Moreover, other studies conducted, rely only on DASH (Disability of the Arm, Shoulder and Hand) questionnaire, WOSI (Western Ontario Shoulder Instability Index) and BREAST-Q, tools designed for capturing patients' self-perception, being hence subjective and not decisive enough due to short follow-up [17,21].

The aim of our study was to prospectively perform an anatomo-functional evaluation of shoulder function with specific tools following total autologous breast reconstruction (BR) with FALD flap.

MATERIALS AND METHODS

Between April 2021 and April 2023, we prospectively selected and included in our study 36 patients who underwent autologous BR with FALD flap (26 unilateral and 10 bilateral, with a total of 46 flaps) at Policlinico Tor Vergata University Hospital. Inclusion criteria were small to moderate breast volume, abdominal free flaps harvesting contraindications, and refusal of other types of BR, either autologous or prosthetic. Previous pathological conditions involving the shoulder joint and competitive sport activities players were the main exclusion criteria. Data collected for each patient were demographics, such as age, tobacco use, body mass index, handedness, pre-operative shoulder issues, comorbidities, and intra-operative details like mastectomy type, timing of reconstruction, and dorsal donor side. Each surgical procedure was performed by a single surgeon (B.L.) using the same surgical technique [22,23]. Pre-operatively (*t0*), each patient was asked to perform a shoulder ultrasound examination, to measure the acromio-humeral interval (AHI), and to fill in the DASH questionnaire so to assess the subjective baseline conditions. Data resulting were recorded in a designated database throughout time.

Acromio-humeral interval (AHI) evaluation

To obtain an easily reproducible evaluation of any shoulder's outcome after BR with FALD flap, we decided to measure the acromio-humeral interval (AHI). The AHI is defined as the shortest distance between the inferior surface of the scapular acromion and the most proximal articular cortex of the humeral head (Fig. 1). Normally, it ranges between 8 and 11 mm [24], and it is of diagnostic interest in the orthopaedic field due to its high specificity and low sensibility. According to Goutallier et al., an AHI narrower than 7 mm indicates rotator cuff tear with 75% specificity [25].

The ultrasound (US) examination we utilized is specifically designed for shoulder conditions assessment. It is performed on an Esaote MyLab X9 machine by single radiologist specialized in diagnostic musculoskeletal US examinations, using a linear transducer probe with a 5-14 MHz frequency range and dedicated US software preset for the shoulder. To measure AHI, each arm was examined in subacromial impingement position with patient sitting. The US examinations were performed for each patient of the study group, preoperatively (*t0*), and at 6 (*t1*) and 12 (*t2*) months post-operatively. The AHI distance was carefully measured and recorded in our system.

Dorsal ultrasound: additional evaluation

Spear S.L. et al. advanced the hypothesis that after

LD transfer, the synergistic action of the teres major muscle (TM) leads to muscle hypertrophy, compensating for the loss of the LD function [26]. Aiming at understanding the significance of their assumption, we carried out a dorsal US as an additional evaluation. All the patients had the ultrasound examination done preoperatively and at 12 months post-operatively. The patient was asked to lie in prone position, with their arms bended and abducted at 90° to the thorax. We used a specific muscle-skeletal linear probe (8 MHz) to identify the scapular spine first, and the TM insertion then. To standardize the procedure, we measured TM thickness at 1.5 cm from the muscle scapular insertion in all patients (Fig. 2).

DASH questionnaire (Disability of Arm, Shoulder and Hand): subjective evaluation

The Disability of Arm, Shoulder, and Hand (DASH) questionnaire is a standardized measure which captures the patients' own perspective of their upper extremity health status [27]. The questionnaire goal is to collect patients' self-perception regarding activity limitations, as well as restrictions for both leisure and work activities. It is composed of 38 questions useful to investigate difficulties perceived by the patient in doing daily life activities such as writing, turning a key, preparing a meal; within the questions there are two optional modules exploring working and sportive/recreational activities. To each question the patient is asked to answer scoring from 1 to 5 (1= no difficulty, 2= mild difficulty, 3= moderate difficulty, 4= severe difficulty, 5= unable). The maximum score is equal to 198, the higher the score, the more severe the disability. We administered the questionnaire pre-operatively (*t0*), and at 1 (*t1*), 3 (*t3*), 6 (*t6*) and 12 (*t12*) months after surgery. With regards to patients undergoing bilateral BR, patients filled in two questionnaires, one for each shoulder.

STATISTICAL ANALYSIS

Regression analyses were performed using linear mixed effect models with and without adjustment for body mass index and age. A subject-specific random intercept was used to take into account dependence arising from repeated measurements on the same subject (i.e. bilateral procedure on the same patient). The resulting p values were adjusted for multiplicity using Bonferroni correction. We report the adjusted p values, so that a value of $p < 0.05$ can be deemed as statistically significant after multiplicity correction. All analyses were performed using R version 4.0.2 software.

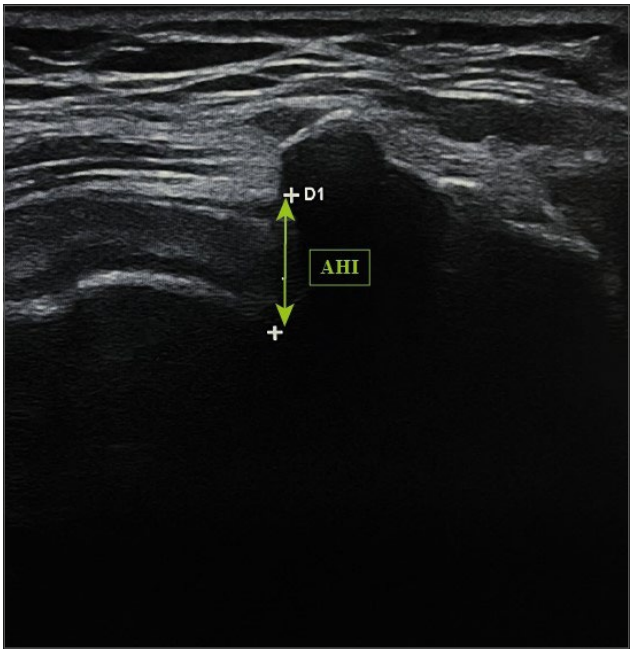

Figure 1. Illustration showing the acromio-humeral interval (AHI) measured on shoulder US imaging.

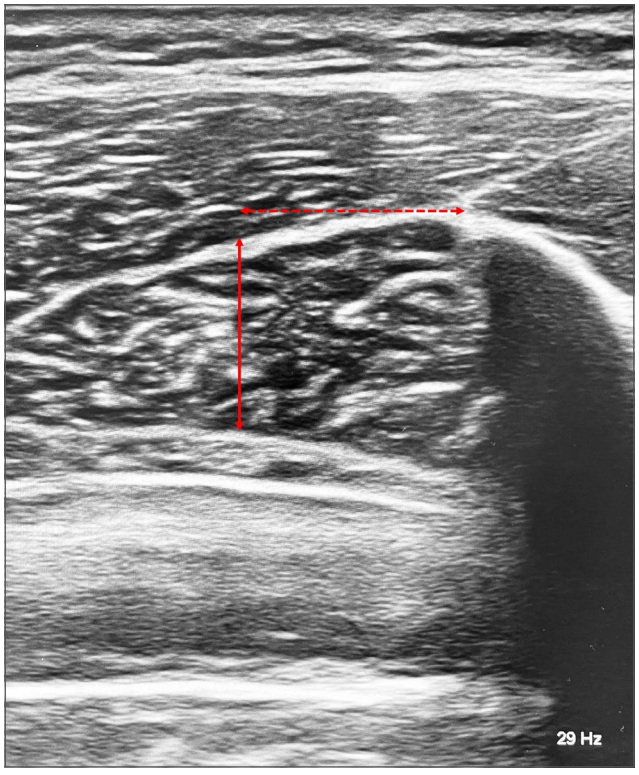

Figure 2. Dorsal ultrasound image showing TM thickness measurement (continuous line), acquired 1.5 cm (dashed line) from the scapular spine.

RESULTS

Patients' and surgical data

Our study population had a mean age of 49.3 years old (min-max: 33 y.o -70 y.o). In 52.8% of the patients (n = 19) a primary autologous BR with FALD flap was performed, while 47.2% of the population (n = 17) underwent a secondary BR. Among these, 10 patients underwent bilateral reconstruction, whereas 26 unilateral. Overall, 46 FALD flaps were harvested. The donor site was represented by the right dorsal region in 66.7% (n = 24) of the cases, whereas in 33.3% (n = 12) by the left one. The handedness, together with the upper limb involved in the surgical procedure were taken into consideration, so that we could optimally estimate how much shoulder impairment after surgery might affect patients' daily life; 35 patients out of 36 referred to be right-handed, therefore, within unilateral reconstructions, 14 procedures involved the dominant side, while 12 involved the non-dominant side. Bilateral reconstructions entailed both the dominant and non-dominant upper limbs. Overall, in 63.9% (n = 23) of the procedures the dominant upper limb was concerned, while 36.1% (n = 13) of the procedures entailed the non-dominant upper limb (Tab. I).

Acromio-humeral interval (AHI)

Considering the mean AHI value for each follow-up time it was highlighted a very small reduction of AHI value between *t0-t1*, followed by an increase of the interval between *t1–t2* (Tab. II). Comparing the mean AHI value of each follow-up time (*t1* and *t2*) to the mean AHI value at the baseline *(t0)* the pattern remained quite the same, with a non-significant reduction between *t0-t1* (p-value = 0.873) and a little increase between *t0-t2* (p-value = 0.468) (Tab. III, Fig. 3). After using pairwise T-test to finalise the statistical analysis of AHI variation in time, to implement the significance of the statistical analysis, it was used a mixed-effects linear regression model, which allowed us to assess not only the AHI variation throughout time, but also the dependence between AHI and other factors such as age, handedness, reconstructive timing. Interestingly, it turned out that patients undergoing FALD flap harvesting involving the non-dominant arm, had a constant, although small, increase of AHI in time, resulting statistically significant (p-value = 0.031). It was also highlighted a significant difference between AHI values in patients operated on the dominant upper limb compared to patients operated on the non-dominant one: the latter, in fact, appeared to have AHI values constantly higher than the first ones. However, it is noteworthy that when the donor site corresponded to the non-dominant arm, AHI measures were already higher preoperatively (*t0*) (Tab. IV).

Dorsal ultrasound

The main goal of this additional evaluation was to determine whether any compensatory anatomo-functional modification had occurred, or body scheme variations had developed after surgery. A total of 35

Table I. Demographic data of the study population.

	Overall (n = 36)
Mean age [y]	49.3
BR timing	Primary: 19 (52.8%)
	Secondary: 17 (47.2%)
Laterality	Unilateral: 26 (72.2%)
	Bilateral: 10 (27.8%)
Operated side	Right: 24 (66.7%)
	Left: 12 (33.3%)
Handedness	Right: 35 (97.2%)
	Left: 1 (2.8%)
Dominant upper limb involved	Yes: 23 (63.9%)
	No: 13 (23.1%)

Table II. Mean AHI value at the 5 follow-up times.

Follow-up time	t0	t1	t2
Mean AHI [mm]	11.88	11.75	12.36

Table III. Comparison between each follow-up time and baseline conditions (*t0*).

Comparison	Difference	Pairwise t-test (p-value)
t1 – t0	-0.007	0.873
t2 – t0	0.033	0.468

Table IV. Comparison between mean AHI in patients operated on the dominant and non-dominant upper limb.

Follow-up time	t0	t1	t2
Mean AHI [mm] Dominant yes	11.27	11.08	12.31
Mean AHI [mm] Dominant no	12.59	12.44	12.43

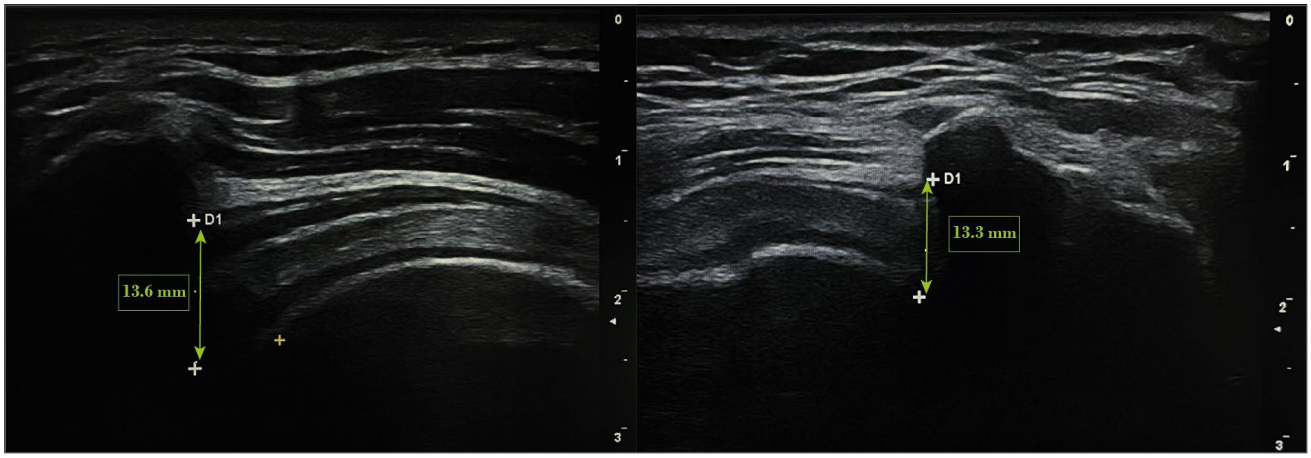

Figure 3. Comparison between a patient's AHI measured pre-operatively (t0) on the left side, and post-operatively at 12 months (t12) after surgery on the right side.

patients underwent dorsal ultrasound pre-operatively and 12 months after the unilateral FALD flap breast reconstruction evaluating the ipsilateral TM muscle. The average TM thickness pre-operatively was 11.4 mm (range 8.7-16.6 mm; SD 1.82), while the mean TM thickness 12 months after the surgery was 12.4 mm (range 9.1-17.0 mm; SD 2.14). This outcome was statistically significant at $p < 0.05$ using the T-student test ($p = 0.01984$) (Table V).

Table V. Dorsal US results.

	Pre-op value	Post-op value	P value
Mean TM thickness [mm]	11.4 (SD 1.82)	12.4 (SD 2.14)	**0.01984**

DASH QUESTIONNAIRE

The statistical analysis of self-reported outcomes performed by means of Mann-Whitney U-test showed that trend was quite similar to AHI variation in time, in fact, at the first follow-up time (*t0*), almost the majority of the answers corresponded to the lowest score (1= no difficulty), whereas 1 month after surgery (*t1*) it was possible to appreciate a gradual worsening of shoulder mobility perception through the score worsening, involving almost all the answers, exception made for answer 2 and 3, which score remained constant enough in time. Mann-Whitney U-test done for consecutive follow-up time turned out to be always significant (p-value < 0.05) between *t0-t1* and *t1-t3*, while gradually less significant between *t3-t6* and especially between *t6-t12* as proof of DASH score improvement over time (Fig. 4).

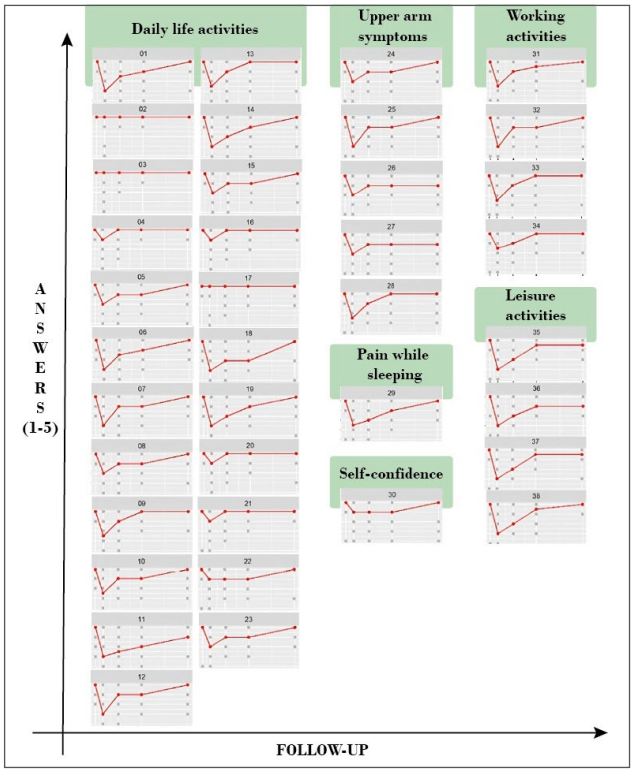

Figure 4. Illustration showing DASH self-reported questionnaire results.

DISCUSSION

The achievement of aesthetically pleasant results in reconstructive surgery represents a priority for both patients and surgeons [28]. However, such results should be obtained without compromising other anatomical regions [29,30]. As such, it is crucial to investigate the impact

of FALD flap procedure on the dorsal donor site [31,32]. Steffenssen et al conducted a systematic review and meta-analysis reporting that studies on shoulder impairment after BR with LD flap are limited and may compromise the true outcome concerning shoulder function due to three major issues: small sample size, population heterogeneity and lack of long-term follow up [21]. Authors stressed the importance of performing further studies, reporting accurately patients' demographic data, and function of both the operated and non-operated healthy side. Eventually, they recommended a longer follow up using subjective patient's evaluation.

To the best of our knowledge, our study is the first in this context that overcomes these limitations, being a prospective long-term study with a significant sample size of 46 FALD flaps performed. Furthermore, the following demographic data were collected from each patient: age, handedness, timing of reconstruction and preoperative shoulder issues, enrolling a homogeneous population in terms of demographics and surgical procedure, while testing repeatedly both operated and non-operated healthy shoulders at three different times (*t0, t1, t2*). Aiming at reporting a thorough assessment of shoulder outcomes after BR using FALD flap, we decided to use 3 main parameters: acromiohumeral interval (AHI), Dorsal Ultrasound, and DASH questionnaire. The rationale behind the choice of AHI measurement to assess shoulder impairment is because the variation of such distance is directly linked with the complex biomechanical interplay acting on shoulder joint. The translatory forces acting on the humeral head are represented by the rotator cuff muscles, among which the supraspinatus muscle mostly causes humeral head compression in the glenoid cavity, and deltoid muscle that during the initial phase of upper limb elevation synergically provokes superior humeral head translation [33]. These forces appear to be balanced by the action of antagonist muscles, such as the LD muscle and TM muscle that translate the humeral head downwards [17]. As a result, all the muscular forces applied on the humeral head influence the AHI, guaranteeing the maintenance of the distance in a physiological range (8-11 mm) [17]. Although not supported by clinical investigations, previous study tried to speculate on the vicariant action of TM on balancing the absence of the LD muscle following its transfer to the breast site and Spear et al. postulated a compensatory hypertrophy of TM muscle after LD transposition as a physiological consequence for shoulder stability [26]. In our study dorsal US confirmed that our cohort of patients developed a significant ($p = 0.01984$) increase in TM thickness of 1 mm over a period of 12 months (11.4 mm to 12.4 mm), confirming it as a biological consequence of the functional compensation of TM muscle as a medial rotator and adductor of the humerus in the absence of LD muscle. Tenna et al. were the first to identify the importance of AHI in evaluating shoulder outcome after BR using FALD flap, concluding that the interval decrease could anticipate a shoulder impingement [17]. Unfortunately, we do agree with the authors that the main bias of their work remained the reduced number of AHI valuable measurements, acquired from AP chest X-rays preoperatively and postoperatively only. In our study the AHI measure was assessed using a shoulder ultrasound imaging, which is considered an appropriate exam for such investigation. From our imaging analyses, it emerged that while in the first six months after surgery patients do experience a slight AHI reduction, afterwards it shows gradual and constant increase in such distance at 12 months post-operatively corresponding to almost complete restoration of shoulder functionality. The evaluation was supported by the self-reported assessment done through the DASH questionnaire filled in by the patients, reporting a subjective shoulder impairment in the first three months, with a consequent progressive improvement of daily life activities execution till the twelfth month [34]. Furthermore, we also addressed and corroborated the hypothesis formulated by Spear et al. [26] regarding the compensatory TM hypertrophy following LD muscle transfer, which seemed to be the most logical explanation to shoulder function restoration and preservation in the long run. Although we recognize the limitations of the study related to operator-dependent variability associated to the use of ultrasound, this high-resolution ultrasound allows us to identify fixed points represented by the bone, differently from mobile soft tissues. For this reason, we consider this method reliable and with an advantage over previous studies published in literature.

CONCLUSIONS

Autologous breast reconstruction with FALD flap represents a safe surgical procedure for donor and recipient site. Musculoskeletal US examinations do confirm that even though a mild shoulder impairment has been observed in the early post-operative period, complete restoration of shoulder functionality is achieved at 12 months after surgery, with no disability in the long run. Compensatory TM hypertrophy seems to be a direct consequence of LD muscle transfer being a further protective factor for shoulder function preservation.

Conflict of interest statement

The authors declare no conflict of interest.

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Author contributions
BL: A, W
LV: D, W
GD'O: D, S
AP: DT
MG: D, W
EG: D, W
MV: D, W
LP: DT
GDG: DT
GV: D, W
OCB: A, W
VC: A, W

Abbreviations
A: conceived and designed the analysis
D: collected the data
DT: contributed data or analysis tool
S: performed the analysis
W: wrote the paper
O: other contribution (specify contribution in more detail)

Ethical consideration
The research was conducted ethically, with all study procedures being performed in accordance with the requirements of the World Medical Association's Declaration of Helsinki.
Written informed consent was obtained from each participant/patient for study participation and data publication.

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