



# Options of bipolar muscle transfers to restore deltoid function: an anatomical study

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## Abstract

**Purpose** To outline the technical details and determine the ranges of two pedicled functioning flaps that are the upper pectoralis major (UPM) and latissimus dorsi (LD) to elucidate their respective indications with regards to deltoid impairment.

**Methods** The UPM and LD bipolar transfers were performed in 14 paired cadaveric shoulders, one on each side. The UPM was flipped 180° laterally over its pedicle to be placed onto the anterior deltoid. The LD flap was elevated on its pedicle to be rotated and positioned onto the deltoid mid-axis. Their respective spans were defined according to the deltoid muscle origin and insertion.

**Results** The UPM outreached the lateral edge of the anterior deltoid origin with a mean distance of 7.3 cm (range 4–9.1 cm) off the lateral edge of the clavicle. Distally, the flap consistently overcame the proximal end of the deltoid tuberosity for a mean distance of 2.1 cm (range 0.9–3.2 cm). The LD flap mdi-axis could be consistently placed onto the deltoid mid-axis; spans of the anterior and posterior borders of the LD flap averaged 1 cm (range –1 to 2.3 cm) and 0.2 cm (range –1.8 to 1.9 cm), respectively.

**Conclusions** The UPM flap optimal indications would be cases with deltoid defects limited to its anterior portion, whereas the LD bipolar transfer could be used in more extensive lesions. Additionally, the distal span of both transfers appears to allow their use in the setting of a reverse shoulder arthroplasty with subsequent humeral lengthening.

**Level of evidence** Non-applicable—basic science study, cadaver dissection.

**Keywords** Latissimus dorsi · Pectoralis major · Pedicled flap · Bipolar transfer · Deltoid palsy

## Introduction

Deltoid paralysis is a disabling condition and its management may be challenging. Depending on the axillary nerve, the deltoid muscle plays an essential role in shoulder

stability and motions, especially regarding abduction and flexion [1]. Several conditions may cause deltoid palsy, including inflammatory diseases as well as traumatic and iatrogenic injuries [8, 17, 28].

Depending on the remaining function, the preoperative delay and the lesions associated with the deltoid impairment, different therapeutic options may be contemplated. In acute and isolated cases, satisfactory results might be yielded using axillary nerve repair or nerve transfers [21]. However, if the preoperative interval is longer than 6–12 months, neurological procedures are no longer recommended due to irreversible loss of motor endplates [31]. If the palsy is limited to the deltoid, satisfactory shoulder function may be observed without the need for surgery [32]. However, in the setting of associated lesions such as glenohumeral osteoarthritis or rotator cuff impairments (e.g., muscle palsy and/or extensive and irreparable tendon tear), palliative procedures may be required to yield satisfactory outcomes. If prosthetic replacement of the joint might alleviate the pain

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in such situations, insufficient deltoid function is commonly considered as a contra-indication to shoulder arthroplasty. Glenohumeral arthrodesis has been advocated by different authors as a salvage solution to stabilize the glenohumeral joint in cases of extensive brachial plexus palsies or septic joint destruction [26]. Nonetheless, since postoperative motions rely exclusively on the scapulothoracic joint, limited outcomes are usually observed [3]. To restore the deltoid function, several unipolar tendon transfers have been used in clinical practice, such as the upper trapezius transferred with its acromial insertion to the proximal humerus, the short head of the biceps and the long head of the triceps to the anterior and posterior edges of the acromion, respectively [11, 27]. However, none of these transfers properly recreate the deltoid anatomy and thus fail to fulfill tendon transfer principles (e.g., similar line of pull, similar strength and similar excursion between the transferred muscle and the recipient), with subsequent limited postoperative motions as well [12].

Allowing an optimal positioning of the transferred muscle at the origin and insertion sites of the paralyzed deltoid, functioning flaps need to be performed to reproduce the exact line of pull of the deltoid. Two pedicled functioning flaps have been previously described, that are the upper pectoralis major (UPM) and the latissimus dorsi (LD) [11, 15]. In addition, such transfers may even be performed in association with a shoulder arthroplasty, allowing addressing cases with traumatic or degenerative alterations of the glenohumeral joint [10]. Despite the different advantages listed above, clinical studies reporting on such transfers have been sporadic [5, 10, 15, 22], and the underlying anatomical features of these procedures remain unclear.

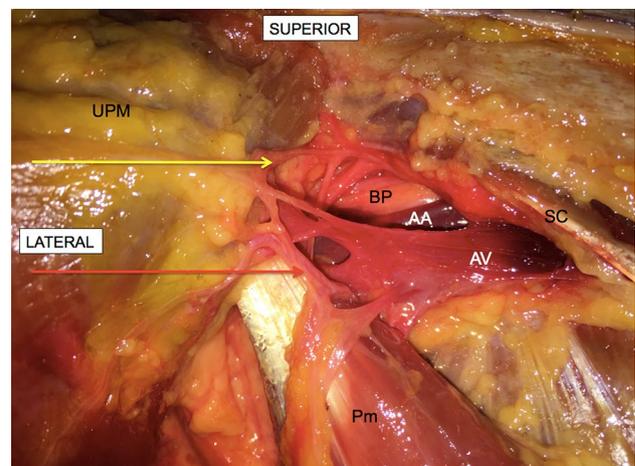
The purpose of this study was to provide an anatomical description of these transfers focusing on their respective potentials of span with regards to their neurovascular pedicle, to assess their feasibility in a native glenohumeral joint and in the setting of a shoulder arthroplasty.

## Materials and methods

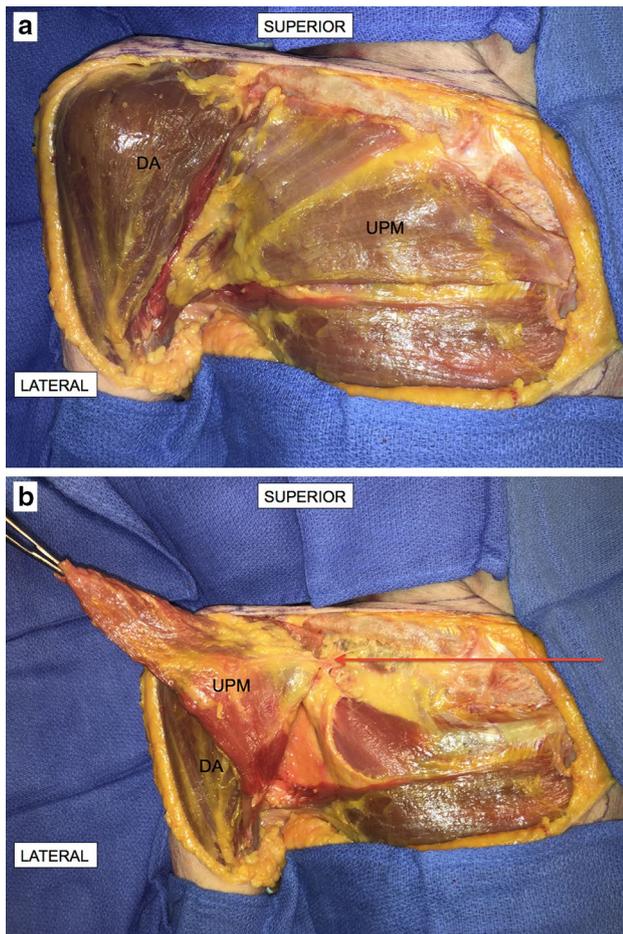
Seven fresh-frozen cadaveric torsos (five female, two male) were obtained by our institutional anatomical bequest program with Biospecimen committee approval. The average age of the donors was 87 years (range 73–96 years), with a mean weight of 59.7 kg (range 43–83 kg) and a mean height of 163 cm (range 152–176 cm). Specimens were thawed overnight at room temperature before the dissections; one transfer was performed on each side, randomly.

## Pedicled UPM transfer

Placed in the supine position, an extensive curved incision was made, starting medially at the level of the second intercostal space, extended at first superiorly on the clavicle and anterior acromion lower borders, and then laterally towards the deltoid insertion. A large skin flap was elevated and retracted inferiorly, so that the UPM and the anterior deltoid were exposed. The pectoral flap was then elevated, starting proximally by elevating the clavicular head and the upper part of the sternal head, which was separated from the lower part at the level of the second sternocostal joint, according to muscle fibers orientation. The dissection was continued distally, and the tendon was split in the coronal plane in two parts, anterior and posterior; the posterior tendon was left attached on the humerus with the inferior part of the sternal head, while the anterior tendon was harvested with the upper sternal head and the clavicular head. Once fully mobilized, the flap was elevated on its pedicle, which was identified entering the flap most commonly on the lateral half of its deep surface (Fig. 1). With blunt dissection, the artery was gradually mobilized until its origin on the thoracoacromial artery, while the nerve was followed until the inferior edge of the clavicle; the dissection of the nerve was not extended to the supraclavicular fossa to reproduce surgical conditions. Finally, the procedure was completed by flipping laterally the upper PM of 180° over its pedicle, the deltopectoral interval becoming the transfer pivot point, so that the deep surface became superficial (Fig. 2). The flap



**Fig. 1** Anatomic dissection showing the pedicle of the upper pectoralis major (UPM) once the flap is flipped laterally, passing over the pectoralis minor tendon (Pm), with the lateral pectoral nerve (yellow arrow) and a branch from the thoracoacromial artery (red arrow) with its concomitant vein (right shoulder). The axillary bundle is exposed, with the axillary artery (AA) and vein (AV) anteriorly and the brachial plexus (BP) posteriorly, under the subclavian muscle (SC). (Color figure online)

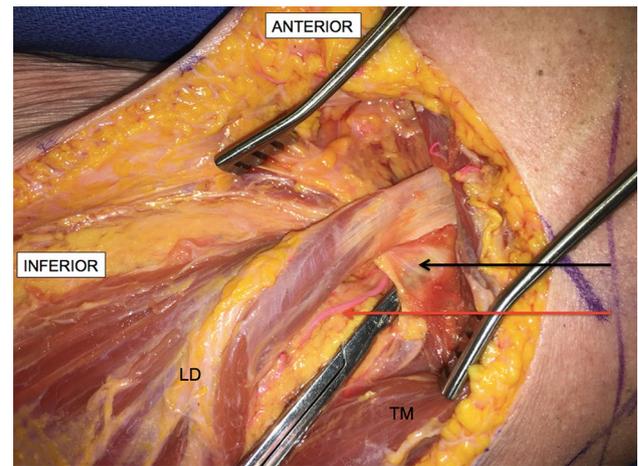


**Fig. 2** Anatomic dissections of a right shoulder showing the upper pectoralis major flap (UPM) in its anatomic position (**a**) and then flipped laterally (**b**) to be positioned over the anterior deltoid (DA). Please note that the flap can be flipped without difficulty, but the lateral translation is limited by the shortness of the pedicle (red arrow). (Color figure online)

was thus positioned proximally onto the distal third of the clavicle and the anterolateral aspect of the acromion, and distally onto the anterior aspect of the deltoid tuberosity; the UPM superior border thus corresponded to the lateral border of the anterior deltoid, while the UPM inferior border matched the medial border of the anterior deltoid.

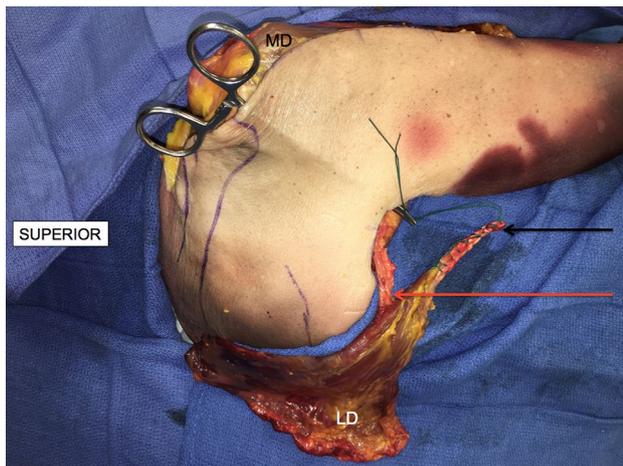
### Pedicled LD transfer

Once the specimen was placed in the lateral position, two approaches were necessary. The first incision was made on the lateral aspect of the shoulder; starting on the upper trapezius contour approximately 10 cm proximal to the lateral edge of the acromion, it was extended distally to the deltoid insertion. The two cutaneous flaps were elevated anteriorly and posteriorly so that the three heads of the deltoid muscle were fully exposed. With the arm in neutral rotation at

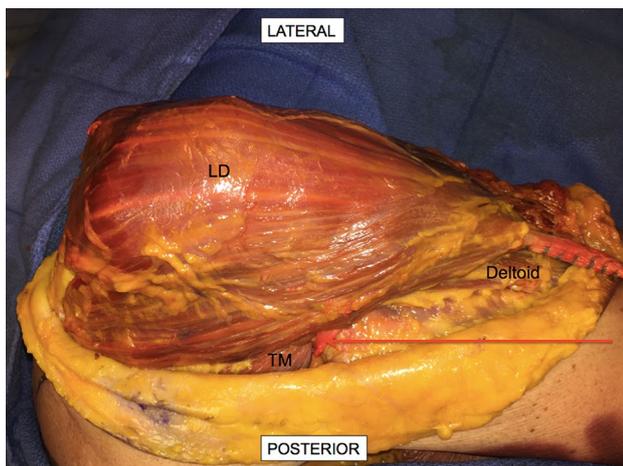


**Fig. 3** Anatomic dissection demonstrating the latissimus dorsi (LD) muscle along with the thoracodorsal artery (red arrow), once sharply separated from the teres major (TM) muscle (left shoulder). A dense fibrous band (black arrow) was consistently found between the LD tendon anteriorly and the pedicle posteriorly, and needed to be released to allow a full rotation of the flap without compression or kinking of its pedicle. (Color figure online)

the side of the body, the length of the deltoid mid-axis was measured (i.e., from the mid-point of the acromion lateral edge to the distal end of the deltoid tuberosity). A posterior axillary incision was then made, starting from the posterior axillary fold and extended inferiorly and medially towards the L4 spinous process. The LD tendon was separated from the teres major (TM) tendon and released from its humeral insertion; the dense fibrous band surrounding the LD and TM muscles was cut to expose the pedicle and enable its further mobilization (Fig. 3). The pedicle was identified on the deep surface of the muscle, and dissected in a retrograde fashion until its origin; collateral arteries to other muscles issued by the flap artery were cut to allow full mobilization of the pedicle. The LD muscle was then sectioned perpendicular to its mid axis, so that the length of the muscular part of the flap was equal to the mid deltoid length, rounded up to the superior centimeter unit. Once fully mobilized, the flap was rotated on its pedicle to be transferred to the lateral incision. Two potential routes were successively assessed, with first the anterior route that consisted in passing the pedicled LD deep to the anterior skin flap and superficial to the PM tendon and to the anterior deltoid superficial aspect (i.e., counterclockwise rotation in a right shoulder). The second route was posterior to the joint and subcutaneous as well (Fig. 4), between the posterior skin flap and the superficial aspect of the posterior deltoid (i.e., clockwise rotation in a right shoulder). Through both routes, the LD mid-axis could be aligned with the mid-axis of the deltoid muscle without noticeable tensioning of the pedicle, with the LD medial and lateral borders corresponding to the anterior and posterior



**Fig. 4** Anatomic dissection showing the latissimus dorsi (LD) flap once fully mobilized, attached only by its pedicle (red arrow), ready to be transferred subcutaneously to the lateral aspect of the shoulder through a posterior route, to be positioned over the middle deltoid (MD) (right shoulder). Please note the tendon prepared in a Krackow fashion (black arrow) to ease further mobilization and fixation. (Color figure online)



**Fig. 5** Anatomic dissection showing the latissimus dorsi (LD) flap positioned over the deltoid muscle through a posterior route, allowing a complete coverage (right shoulder). The pedicle (red arrow) is visualized at the inferior border of the teres major (TM) muscle. (Color figure online)

borders of the deltoid, respectively (Fig. 5). The LD muscle section was positioned onto the deltoid origin, whereas the LD musculotendinous junction was positioned onto the deltoid tuberosity.

### Cadaveric measurements

Using a tape ruler (1-mm accuracy), different measurements were made throughout the dissections. Regarding the UPM transfer, the lengths of the origin and of the medial

and lateral borders of the anterior deltoid were measured before the transfer (Table 1); additionally, the lengths of the origin and of the superior and inferior borders of the UPM flap were measured as well, along with the length and width at insertion of its tendon (Fig. 6). Then, the main neurovascular pedicle was identified while gradually elevating the clavicular and upper sternal heads; distances from the clavicular and sternal origins to the pedicle entry were measured, along with the distance from the humeral insertion. Accessory arteries were noted when present and the lengths of the main nerve and artery were measured (i.e., distances from the clavicular inferior edge and from the artery origin to their entry into the flap, respectively). At the end of the transfer, the maximal lateral span of the flap was assessed, measuring the distance from the clavicle lateral edge to the sternal head inferior border; positive values were noted when the flap outreached the clavicle and could overlay the acromion. Likewise, the maximum distal span of the transfer was noted, with positive values indicating that the flap insertion outreached the proximal end of the deltoid anterior tuberosity.

Regarding the LD transfer, the lengths of the origin, mid-axis, anterior and posterior borders of the deltoid were measured before the transfer. In addition, the lengths of the origin and of the medial and lateral borders of the LD muscle were measured, along with the length and width at insertion of its tendon; the length of its mid-axis was determined according to the length of the deltoid mid-axis, as previously stated (Fig. 7). When the pedicle origin was reached, the lengths of the main nerve and artery were measured. Finally, once the transfer was positioned on the mid-axis of the deltoid, the anterior span of the flap was assessed by measuring the distance from the anteromedial edge of the flap origin to the anteromedial edge of the deltoid origin, with positive values corresponding to the flap outreaching the deltoid; similar measurements were made posteriorly to assess the flap posterior span.

### Statistical analysis

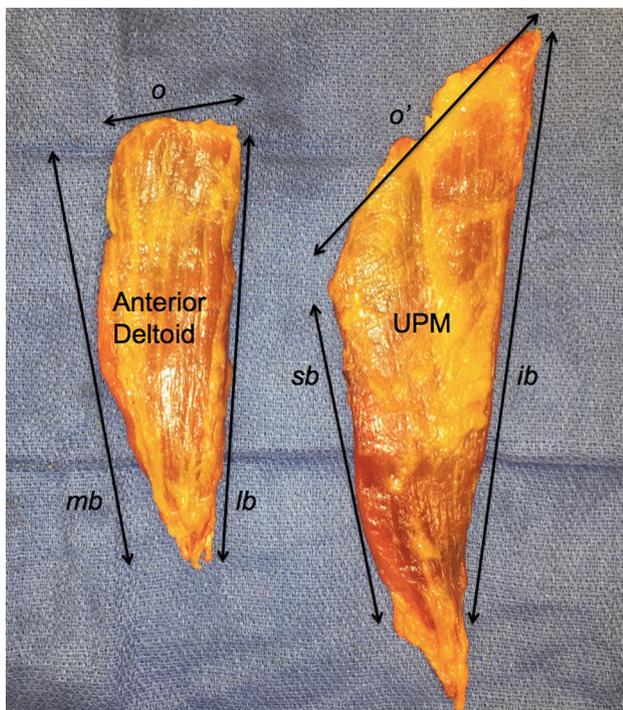
The Shapiro–Wilk test was used on UPM, LD and deltoid measurement data and confirmed their normal distribution; subsequently, comparisons were conducted with paired Student's *t* tests. Results were presented as the mean (range), unless otherwise stated. The level of significance was defined as  $P < 0.05$ , for all tests.

**Table 1** Definitions of muscular measurements

Upper pectoralis major transfer	
Upper pectoralis	
Major	
Origin	Clavicular and sternal origins width
Superior border	Distance from the MTJ superior edge to the clavicle origin lateral edge
Inferior border	Distance from the MTJ inferior edge to the sternal origin inferior edge
Anterior deltoid	
Origin	Clavicular insertion width
Medial border	Distance from the clavicle origin medial edge to the deltoid tuberosity proximal end
Lateral border	Distance from the clavicle origin lateral edge to the deltoid tuberosity distal end
Latissimus dorsi transfer	
Latissimus dorsi	
Origin	Muscle section width
Medial border	Distance from the MTJ to the muscle section medial edge
Lateral border	Distance from the MTJ to the muscle section lateral edge
Deltoid	
Origin	Clavicular, acromion, and spinous insertions width
Mid-axis	Distance from the mid-acromion origin to the deltoid tuberosity distal end
Anterior border	Distance from the clavicle origin medial edge to the deltoid tuberosity distal end
Posterior border	Distance from the spinous origin lateral edge to the deltoid tuberosity distal end

All measurements were made before the transfers, with the arm at the side of the body in neutral rotation

MTJ musculotendinous junction



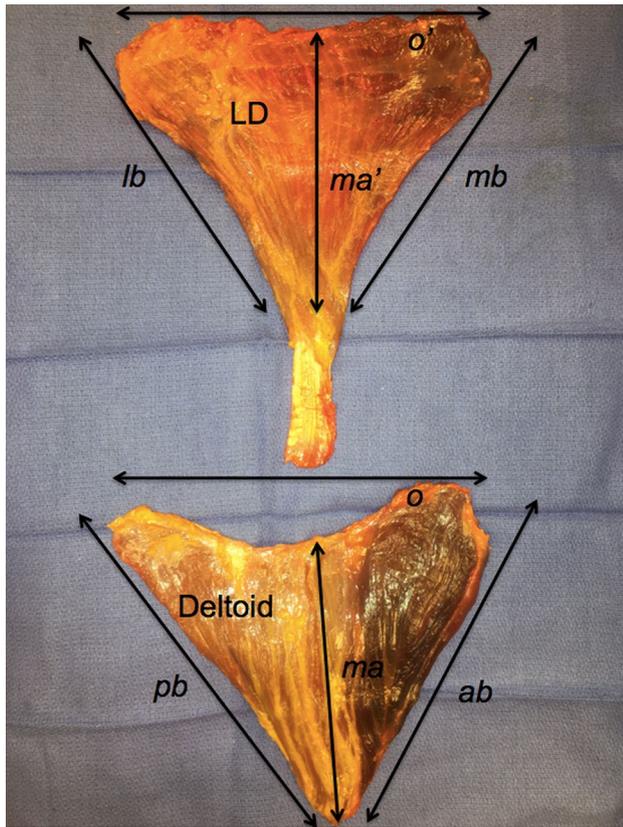
**Fig. 6** Anatomic dissection demonstrating the similarity of the shapes between the upper pectoralis major (UPM) flap and the anterior deltoid muscle, once dissected away from the shoulder. The different measurements of interest are highlighted, with the origin ( $o$ ), medial ( $mb$ ) and lateral ( $lb$ ) borders of the anterior head of the deltoid, and the origin ( $o'$ ), superior ( $sb$ ) and inferior borders ( $ib$ ) of the UPM flap

## Results

### UPM flap

The tendinous insertion of the upper PM could be separated from the lower PM tendon in all cases but one. In this case, the tendon was divided longitudinally in the axial plane; the superior part was harvested along with the flap, leaving the inferior part with the remaining PM muscle. In all dissections, the origin of the UPM was noted larger than the origin of the anterior deltoid (Table 2), allowing the flap to outreach the clavicle for an average distance of 7.3 cm (range 4–9.1 cm). The UPM inferior border tended to be smaller than the lateral border of the anterior deltoid but without statistical difference, whereas the superior border of the flap was found significantly inferior to the anterior deltoid medial border. However, when adding the length of the tendon to the muscle measurements, these discrepancies were reversed in favor of the UPM flap, with a mean superior length of 15 cm (range 12.6–18.5 cm) and a mean inferior length of 19.6 cm (range 16.5–23.7 cm), with  $P=0.043$  and  $P=0.001$ , respectively. This was confirmed by the flap distal span, with positive values in all cases, averaging 2.1 cm (range 0.9–3.2 cm).

The main blood supply was identified in all cases as a branch of the thoracoacromial artery coming from the deltopectoral interval, averaging 2.4 cm (range 1.9–3.1 cm).



**Fig. 7** Anatomic dissection demonstrating the similarity of the shapes between the latissimus dorsi (LD) flap and the deltoid muscle, once dissected away from the shoulder. The different measurements of interest are highlighted, with the origin (*o*), mid-axis (*ma*, which is the reference to determine the LD mid-axis needed length), anterior (*ab*) and posterior (*pb*) borders of the deltoid muscle, and the origin (*o'*), mid-axis (*ma'*), medial (*mb*) and lateral borders (*lb*) of the LD flap

Although secondary arteries to the upper sternal head issued proximally from the intercostal arteries were observed in all dissections, only one shoulder presented with an accessory pedicle coming from the superior thoracic artery that entered the clavicular head at 2 cm from its origin. The lateral pectoral nerve innervated the flap in all cases, with a mean length of 3 cm (range 2–4.1 cm) to the clavicle. The pedicle entry was identified in the distal half of the flap in all specimens but one; mean distances of 8.6 cm (range 6.5–11.1 cm), 9.7 cm (range 8.8–10.5 cm) and 3.7 cm (range 2.8–4.8 cm) separated the pedicle entry from the flap humeral insertion, sternal and clavicular origins, respectively.

### LD flap

The tendon of the flap was distinct from the TM tendon in all dissections, with a complete separation in two specimens (i.e., blunt dissection only) and some fascia adhesions in five (i.e., sharp dissection necessary). There were no significant difference between the length of the LD flap borders and the deltoid borders. However, the origin of the flap (i.e., muscle section perpendicular to the longitudinal mid-axis of the flap) was found significantly larger than the deltoid origin. This was confirmed by the flap spans, with mean values of 1 cm (range –1 to 2.3 cm) anteriorly and 0.2 cm (range –1.8 to 1.9 cm) posteriorly; nonetheless, the coverage of the deltoid origin was incomplete in two specimens only posteriorly and in one specimen both anteriorly and posteriorly.

The thoracodorsal pedicle entered the LD muscle at a mean distance of 12.5 cm (range 9.3–15.2 cm) from its humeral insertion. The nerve was issued from the brachial plexus posterior cord in all specimens, and averaged 10.3 cm (range 9.1–13.7 cm) in length. The artery was a terminal

**Table 2** Anatomical characteristics

Upper pectoralis major transfer				<i>P</i> values
Upper pectoralis major		Anterior deltoid		
Origin	13.3 (10.9–17.1)	Origin	5.5 (4–8.3)	<0.001
Superior border	11.5 (10.1–14)	Medial border	14 (11.2–18.1)	0.003
Inferior border	16.1 (13.8–19.2)	Lateral border	16.6 (13.3–21.7)	0.456
Tendon length	3.5 (2.5–4.5)	–	–	–
Tendon width	3.9 (2.1–5.2)	–	–	–
Latissimus dorsi transfer				<i>P</i> values
Latissimus dorsi		Deltoid		
Origin	24.2 (21.2–32.4)	Origin	21.6 (16.9–30.1)	0.006
Medial border	21.3 (17.5–27.3)	Anterior border	20.7 (16–28.9)	0.394
Lateral border	22.2 (17.8–30.1)	Posterior border	23.2 (19.3–31.9)	0.168
Mid-axis	18.3 (15–24)	Mid-axis	17.7 (14.2–23.4)	–
Tendon length	7.5 (5.8–9.2)	–	–	–
Tendon width	3.5 (2.9–4.2)	–	–	–

All data are presented in cm, as mean (range)

branch of the subscapularis artery in all cases, with a mean length of 8.3 cm (range 6.4–10.6 cm). In four specimens, only one artery was branching out towards the serratus anterior (SA) muscle, whereas there were two arteries to the SA in the three others; in addition, one branch to the TM muscle was observed in two specimens.

## Discussion

In this study, we reviewed the anatomic bases of two pedicled functioning flaps used clinically to reanimate shoulder function in cases of deltoid palsy. With a relatively short neurovascular pedicle, the upper part of the pectoralis major muscle was showed to provide a satisfactory reproduction of the anterior deltoid. With a longer pedicle and larger dimensions, the LD flap was demonstrated to allow a full reconstruction of the deltoid muscle, with two possible routes of transfer.

### Reliable functioning flaps

With the thoracoacromial and thoracodorsal arteries as respective primary supplies and intercostal arteries as secondary segmental pedicles, the UPM and LD are both arterial type V muscles according to the Mathes–Nahai criteria. In an anatomical study of 105 human pectoralis muscles, Tobin confirmed this reliable vascularization pattern [29]. Aszmann and colleagues [2] reported a consistent innervation of the UPM in 29 brachial plexuses, depending on the lateral pectoral nerve (i.e., composed by the superior pectoral nerve and the superficial branch of the middle pectoral nerve, according to Aszmann), as we observed in our dissections. Likewise, the consistency of the LD pedicle has been highlighted in large anatomic series [25, 30]. These reliable neurovascular patterns explain the great versatility of these muscles and their early use in numerous indications, including coverage solutions but also as functioning transfers.

### The UPM bipolar transfer

Based on the flap lateral and distal spans that were outlined in this study, the UPM flap appears to allow recreating close to anatomy only the anterior part of the deltoid muscle. In a cadaveric study of eight specimens, Ackland et al. [1] demonstrated that the flexion moment arm of the anterior deltoid was larger than the middle deltoid flexion moment arm during the whole flexion motion, whereas the abduction moment arm of the middle deltoid was larger than the anterior deltoid abduction moment arm during the first 100° of abduction; furthermore, the posterior deltoid had negative or

close to zero abduction and flexion moment arms. In another cadaveric study, Kuechle and colleagues [18] outlined the positive internal rotation moment arm of the anterior deltoid, with the arm at the side of the body and at 90° of abduction, scaption and flexion of the shoulder. It is thus safe to assume that the sole use of this transfer may provide satisfactory shoulder flexion and internal rotation, but other shoulder motions may be limited. In addition, Holzbaur and colleagues [14] highlighted that the deltoid muscle had the greatest volume and cross-sectional area of the shoulder girdle. Therefore, using approximately half of the pectoralis major muscle to address the entire deltoid function seems unrealistic. However, an additional transfer providing external rotation of the arm may be valuable to add muscle mass and stabilize the humeral shaft in rotations; indeed, by focusing the mechanical force of the transfer on its aimed actions (i.e., shoulder flexion and abduction), the flap efficacy may be increased [4]. This was confirmed clinically by Hou and Tai who first described this UPM functioning flap in the setting of deltoid palsy in 1991. The authors reported a mean shoulder abduction of 40° when the UPM transfer was used alone whereas 70°–90° of abduction and 60°–150° of flexion were obtained when adding the transfer of the upper trapezius insertion to the posterior aspect of the deltoid tuberosity [13]. More recently, Lin and colleagues reported the successful use of the UPM functioning flap in patients with brachial plexus palsy, with a mean postoperative abduction of 74°; unfortunately, the authors did not specify if only the scapulohumeral motion was considered, or if their analysis included the scapulothoracic motion as well [22].

Interestingly, the lateral span of the UPM flap in these previous papers seemed to be significantly larger than what was observed in the present study [13, 22]. In fact, Lin et al. [22] reported that the clavicular head was transposed to the lateral side of the shoulder and the upper sternal head was transposed to the posterolateral side of the shoulder, with the deep surface of the flap facing toward the lateral aspect of the shoulder. In the present study, we found that the pedicle was relatively short, which limited the lateral translation of the flap to the anterior aspect of the shoulder.

### The LD bipolar transfer

The volume measurement of the LD muscle in Holzbaur's study [14] demonstrates the same inadequacy with the deltoid volume; the proportion of this volume that is actually harvested during this transfer is more difficult to evaluate, however, since it is a custom-made flap based on the initial deltoid measurement. In addition, Hertzberg and colleagues demonstrated that the mean length of LD muscle fibers was 33.9 cm, whereas the mean length of the deltoid fibers was 12 cm, indicating that the LD has theoretically a greater excursion but less strength [12].

In clinical practice, the LD unipolar transfer is well known to compensate posterior and anterior cuff deficiencies [6, 9]. Therefore, the anatomy of its distal insertion has been the subject of extensive research. The anatomic study conducted by Morelli et al. [23] is of particular interest, outlining the different landmarks and their relation with the thoracodorsal pedicle, which were consistent with our findings. In contrast, its use as a pedicled bipolar functioning flap has been sporadic in the shoulder [5, 11, 16]. Itoh et al. [15] developed this procedure in 1987 and reported on 10 patients, providing an abduction over 90° in 6 of them and a grade-4 abduction strength with a good shoulder contour in 9 of them; the last patient was limited to 70° of flexion due to partial necrosis of the flap. In their original description, the flap and its pedicle were shuttled deep to the pectoralis major tendon, since the transfer was meant to reanimate only the anterior deltoid. While reporting on five more cases 20 years later using the same technique, De Smet noted that three patients presented delayed wound healing, including one who required a secondary debridement due to partial necrosis as well [5]. The author suggested that this deep routing could be partially accountable for such complications. By transferring the flap more laterally, this traumatic and potentially dangerous maneuver is avoided. Furthermore, the posterior route necessitates even less rotation of the flap, which was another concern raised by De Smet [5].

### Reverse shoulder arthroplasty

In 2013, Lädermann and colleagues [19] reported on satisfactory outcomes following a reverse shoulder arthroplasty (RSA) in the setting of an isolated palsy of the anterior deltoid, demonstrating that not all the deltoid function is needed to obtain shoulder motion once a RSA is implanted. Indeed, by medializing the joint rotational center, the muscle lever arm is increased and the strength required to perform the same motion is decreased. In addition, the joint is transformed from an unconstrained to a semi-constrained configuration, converting translation movements to pure rotational movements. Based on these biomechanical considerations, several authors suggested to perform tendon transfers in association with RSA implantation to better restore the deltoid function [7, 10, 16]. However, it is worth mentioning that common RSA shortcomings may be experienced when choosing this option [20, 24]. As an example, in a recent clinical series of 31 bipolar UPM transfers, Elhassan and colleagues [7] reported two cases of acromial fractures at the junction of the acromion and scapular spine, which greatly limited these patients' functional outcomes.

### Limitations

This study suffers from different limitations, including a small sample size that may have been accountable for statistical type 2 errors during the comparison of the borders of the flaps to their respective muscles. Furthermore, the lack of muscular passive stiffness may have skewed our measurements; we tried to limit this bias by conducting all the muscular measurements in the anatomic position. Moreover, even if the UPM was closer than the LD to the deltoid in terms of bulkiness, we were unable to quantify such observational findings, considering that having accurate values of the muscles thickness in their anatomic position was not feasible. Finally, this cadaveric model limits our ability to predict the clinical outcomes of such transfers, especially with the LD transfer where a wide subcutaneous shuttle is necessary to position the flap, which may lead to delayed healing of the wound and extensive scarring adhesions.

### Conclusion

This study outlines the technical details of two pedicled functioning muscle transfers that can be used to recreate the deltoid muscle close to anatomic fashion, that are the LD and UPM. If the lateral span of the UPM limits its use to the reconstruction of the anterior part of the deltoid, the LD flap may be transferred either anteriorly to recreate the anterior deltoid, or posteriorly to recreate the entire deltoid. In addition, both transfers allow their use in the setting of a humeral lengthening, questioning the deltoid impairment as a primary contra-indication in reverse shoulder arthroplasty.

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**Author contributions** MLH: protocol development; data collection; data analysis; manuscript writing. JL: protocol development; data collection; data analysis; manuscript editing. ERW: data analysis; manuscript editing. BTE: protocol development; data analysis; manuscript editing.

### Compliance with ethical standards

**Conflict of interest** The authors declare that they have no conflict of interests. None of them has a financial interest in any of the products, devices, or drugs mentioned in this manuscript. They have not received or will receive any financial aid, in any form, for this study, from any of the following organizations: National Institutes of Health (NIH); Wellcome Trust; Howard Hughes Medical Institute (HHMI); or other(s).

## References

- Ackland DC, Pak P, Richardson M, Pandy MG (2008) Moment arms of the muscles crossing the anatomical shoulder. *J Anat* 213:383–390
- Aszmann OC, Rab M, Kamolz L, Frey M (2000) The anatomy of the pectoral nerves and their significance in brachial plexus reconstruction. *J Hand Surg Am* 25:942–947
- Atlan F, Durand S, Fox M, Levy P, Belkheyar Z, Oberlin C (2012) Functional outcome of glenohumeral fusion in brachial plexus palsy: a report of 54 cases. *J Hand Surg Am* 37:683–688
- Brand PW (1988) Biomechanics of tendon transfers. *Hand Clin* 4:137–154
- De Smet L (2009) Bipolar latissimus dorsi flap transfer for reconstruction of the deltoid. *Acta Orthop Belg* 75:32–36
- Elhassan BT, Christensen TJ, Wagner ER (2014) Feasibility of latissimus and teres major transfer to reconstruct irreparable subscapularis tendon tear: an anatomic study. *J Shoulder Elb Surg* 23:492–499
- Elhassan BT, Wagner ER, Werthel JD, Le Hanneur M, Lee J (2018) Outcome of reverse shoulder arthroplasty with pedicled pectoralis transfer in patients with deltoid paralysis. *J Shoulder Elb Surg* 27:96–103
- Ferrante MA, Wilbourn AJ (2017) Lesion distribution among 281 patients with sporadic neuralgic amyotrophy. *Muscle Nerve* 55:858–861
- Gerber C, Vinh TS, Hertel R, Hess CW (1988) Latissimus dorsi transfer for the treatment of massive tears of the rotator cuff. A preliminary report. *Clin Orthop Relat Res* 232:51–61
- Goel DP, Ross DC, Drosdowech DS (2012) Rotator cuff tear arthropathy and deltoid avulsion treated with reverse total shoulder arthroplasty and latissimus dorsi transfer: case report and review of the literature. *J Shoulder Elb Surg* 21:e1–e7
- Harmon PH (1950) Surgical reconstruction of the paralytic shoulder by multiple muscle transplantations. *J Bone Jt Surg Am* 32-A:583–595
- Herzberg G, Urien JP, Dimnet J (1999) Potential excursion and relative tension of muscles in the shoulder girdle: relevance to tendon transfers. *J Shoulder Elbow Surg* 8(5):430–437
- Hou CL, Tai YH (1991) Transfer of upper pectoralis major flap for functional reconstruction of deltoid muscle. *Chin Med J (Engl)* 104:753–757
- Holzbaun KR, Murray WM, Gold GE, Delp SL (2007) Upper limb muscle volumes in adult subjects. *J Biomech* 40:742–749
- Itoh Y, Sasaki T, Ishiguro T, Uchinishi K, Yabe Y, Fukuda H (1987) Transfer of latissimus dorsi to replace a paralysed anterior deltoid. A new technique using an inverted pedicled graft. *J Bone Jt Surg Br* 69:647–651
- Kermarrec G, Werthel JD, Canales P, Valenti P (2018) Review and clinical presentation in reverse shoulder arthroplasty in deltoid palsy. *Eur J Orthop Surg Traumatol* 28:747–751
- Kline DG, Kim DH (2003) Axillary nerve repair in 99 patients with 101 stretch injuries. *J Neurosurg* 99:630–636
- Kuechle DK, Newman SR, Itoi E, Niebur GL, Morrey BF, An KN (2000) The relevance of the moment arm of shoulder muscles with respect to axial rotation of the glenohumeral joint in four positions. *Clin Biomech (Bristol Avon)* 15:322–329
- Läderrmann A, Walch G, Denard PJ, Collin P, Sirveaux F, Favard L, Edwards TB, Kherad O, Boileau P (2013) Reverse shoulder arthroplasty in patients with pre-operative impairment of the deltoid muscle. *Bone Jt J* 95-B:1106–1113
- Läderrmann A, Walch G, Lubbeke A, Drake GN, Melis B, Bacle G, Collin P, Edwards TB, Sirveaux F (2012) Influence of arm lengthening in reverse shoulder arthroplasty. *J Shoulder Elb Surg* 21:336–341
- Leechavengvongs S, Malungpaishorpe K, Uerpairojkit C, Ng CY, Witoonchart K (2016) Nerve transfers to restore shoulder function. *Hand Clin* 32:153–164
- Lin H, Hou C, Xu Z (2009) Transfer of the superior portion of the pectoralis major flap for restoration of shoulder abduction. *J Reconstr Microsurg* 25:255–260
- Morelli M, Nagamori J, Gilbert M, Miniaci A (2008) Latissimus dorsi tendon transfer for massive irreparable cuff tears: an anatomic study. *J Shoulder Elb Surg* 17:139–143
- Neyton L, Erickson J, Ascione F, Bugelli G, Lunini E, Walch G (2018) Scapular fractures in reverse shoulder arthroplasty (Grammont style): prevalence, functional, and radiographic results with minimum 5-year follow-up. *J Shoulder Elbow Surg*. <https://doi.org/10.1016/j.jse.2018.07.004>
- Rowell AR, Davies DM, Eisenberg N, Taylor GI (1984) The anatomy of the subscapular-thoracodorsal arterial system: study of 100 cadaver dissections. *Br J Plast Surg* 37:574–576
- Rühmann O, Schmolke S, Bohnsack M, Flamme C, Wirth CJ (2005) Shoulder arthrodesis: indications, technique, results, and complications. *J Shoulder Elb Surg* 14:38–50
- Saha AK (1967) Surgery of the paralysed and flail shoulder. *Acta Orthop Scand* 97:5–90
- Shah AA, Butler RB, Romanowski J, Goel D, Karadagli D, Warner JJ (2012) Short-term complications of the Latarjet procedure. *J Bone Jt Surg Am* 94:495–501
- Tobin GR (1985) Pectoralis major segmental anatomy and segmentally split pectoralis major flaps. *Plast Reconstr Surg* 75:814–824
- Tubbs RS, Loukas M, Shahid K, Judge T, Pinyard J, Shoia MM, Slappey MM, McEvoy WC, Oakes WJ (2007) Anatomy and quantitation of the subscapular nerves. *Clin Anat* 20:656–659
- Tung TH, Mackinnon SE (2010) Nerve transfers: indications, techniques, and outcomes. *J Hand Surg Am* 35:332–341
- Werthel JD, Bertelli J, Elhassan BT (2017) Shoulder function in patients with deltoid paralysis and intact rotator cuff. *Orthop Traumatol Surg Res* 103:869–873