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Neurovascular Anatomy of the Split Latissimus Dorsi Muscle Flap for the Purpose of Smile Restoration

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ABSTRACT

Background: Patients with facial paralysis experience functional and cosmetic problems related to facial muscles inactivity. Free micro neurovascular functional muscle transfer offers the best prospect for restoring both voluntary and emotional facial expressions. The transferred muscle replaces some of the paralyzed muscles, mainly the lip elevators. If the lip depressors are not replaced, asymmetry of the mouth persists. This study investigates splitting of the latissimus dorsi muscle to replace lip elevators and depressors in different vectors to reanimate the smile.

Methods: We studied 10 latissimus dorsi muscle specimens obtained from five fresh cadavers. Intramuscular dissection for the branches of the nerve and blood vessels was performed. A radio-opaque lead oxide mixture was injected to obtain radiograms. Splitting of the muscle was done parallel to the muscle fibers and neurovascular branches. The nerve pedicle was split into two fascicles by intrafascicular dissection along its whole length.

Results: We split all muscle specimens into neurologically independent segments with each segment containing one of the main branches of the neurovascular bundle. Splitting of the whole length of the thoracodorsal nerve into two branches was performed in all specimens.

Conclusions: This study suggests that the latissimus dorsi muscle is suitable for segmental splitting into completely independent muscle slips that can be rotated into entirely different vectors to reanimate the smile, including both upward and downward pulls on the oral commissure.

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Key Words: *Latissimus dorsi flap – Smile restoration.*

INTRODUCTION

Facial expression and movement involves 16 pairs of facial muscles **[1]**. In facial palsy, the majority or all of these muscles may not be functioning. Despite recent refinements in reconstructive surgery of the paralyzed face, it is impossible to replace the function of all paralyzed muscles.

The latissimus dorsi muscle is a highly reliable muscle flap characterized by the fairly consistent and ideal size and length of its primary neurovascular pedicle **[2]**. Therefore, It has been used for facial reanimation by many surgeons **[2-9]**. The transferred muscle replaces some paralyzed muscles (e.g., zygomaticus major muscle) of the face; however, the depressors of the lip are not usually replaced, so asymmetry of the mouth persists, and the smile remains unnatural. This is especially noticeable in patients with a full denture smile (Rubin) **[10]**. Digastric muscle transfer and other local dynamic transfers to the lower lip have been proven unsatisfactory **[11]**.

Several trials to split the free muscles used for facial reanimation have been reported. O'Brien et al. **[11]** separated the distal end of the gracilis muscle into two segments to be attached to the lateral aspect and angle of the mouth. They insisted that it was necessary to separate the muscle into two motor units to reanimate both the upper and lower face. Mackinnon et al. **[4]** reported splitting the whole length of the latissimus dorsi muscle but only part of its nerve. The procedure was performed in two stages with a possible third. However, overlapping of territories caused mass movements because of incomplete division of the nerve. In agreement with O'Brien et al. **[11]** splitting of the whole nerve and muscle is necessary to avoid dyskinesia and mass movements.

Harii et al. **[12]** split the distal end of the gracilis muscle longitudinally and sutured the upper portion to the upper lip and lower portion to the lower lip. Harrison **[13]** divided the insertion of the pectoralis minor muscle into three elements: One was inserted into the alar base and the other two were inserted into upper and lower lips. Koshima et al. **[14]** divided the distal end of the transferred rectus femoris muscle into two segments and sutured it to the lateral aspect of the upper and lower lips. Sassoon et al. **[15]** separated the lower end of the gracilis muscle into three main slips, namely, two

deep ones to go through the upper and lower lip tunnels and a more superficial and shorter one to be sutured to the modulus and nasolabial fold. Wei et al. **[16]** used the distal part of the latissimus dorsi muscle based on its segmental anatomy, which enabled them to get an ultra-long vascular pedicle (13-17.5cm) and consequently perform the entire procedure in one stage. In the above studies, neither the transferred muscle nor its nerve was split completely along its whole length, and the resultant movement was one movement (one vector of pull). Therefore, dyskinesia and persistent lower lip deformity were noticeable.

Kumar and Hassan **[17]** used the free gracilis muscle to reanimate the paralysed face in one and two-stage procedures. In both techniques, they applied the transferred muscle only to the angle of the mouth. Animation of the lower lip was not addressed. Therefore, we started a series of anatomical studies on different donor muscles aimed at animation of the lower lip.

In this Study, we hypothesized that the latissimus dorsi muscle could be split into independent neuromuscular motor units for the purpose of facial reanimation and smile restoration.

MATERIAL AND METHODS

This is an experimental study based on sequential samples. We obtained muscle specimens from fresh cadavers (within 3 days of death and without any injected preservatives) between September 2016 and April 2018. The study was approved by the Ethical Committee of Minia University Hospital, Minia, Egypt. A written consent from relatives was necessary. This is a continuation of the research started earlier in Whiston Hospital, Liverpool, UK, during the scholarship awarded to the first author.

Microsurgical dissection and dye injection was performed in the microscope room of Minia University Hospital. Radiographs were taken in the X-ray department of the same hospital. A medical photographer performed the photography.

Position of the cadaver:

An assistant was needed to keep the cadaver in the midprone position, with the arm abducted 90º during the dissection. If an assistant was not available, a wooden block was wedged behind the body to keep it in this position.

Muscle harvest technique:

The incision started in the midaxillary line and extended distally for 20cm. It curved posteriorly and horizontally to the paravertebral muscles.

Skin flaps were raised in a plane superficial to the muscles on either side of the incision, as the same incision was used to harvest serratus anterior muscle for a concomitant study. The lateral edge of the latissimus dorsi muscle was identified and raised, the neurovascular pedicle was traced to its origin and divided, and the muscle insertion into the floor of the bicipital groove was divided. The latissimus dorsi muscle was divided distally about 30cm from the insertion. The insertion of the Serratus anterior muscle was divided, and the muscle was detached anteriorly from its origin from the ribs with care not to damage the neurovascular pedicle. The latissmus dorsi muscle was then raised from proximal to distal until both muscles were harvested as one unit on a common vascular pedicle with two nerves.

Microsurgical dissection to split the muscle:

Branches from the thoracodorsal vessels to the Serratus anterior muscle were divided to separate the latissimus dorsi from the serratus anterior muscle. Using a surgical microscope, the fatty tissue surrounding the neurovascular pedicle of the latissimus dorsi was carefully to clearly identify the proximal neurovascular branching patterns. On reaching the neurovascular hilum, the intramuscular dissection for branches of nerve and blood vessels was started. Branches were traced until they sank deeply into the muscle.

Injection technique:

The injection technique described by Rees and Taylor, 18 which includes preparing a mixture of 200g lead oxide, 3mL gelatin, and 100mL warm water (50°C), was used. The gelatin powder was added to warm water and stirred until dissolved. An electric frying pan with a thermostat was used to provide a warm water bath (Fig. 1). 500mL of normal saline was heated in the pan and used as a warm water bath. Warm saline was used to perfuse and flush the arterial tree just before injecting the lead oxide mixture. The lead oxide mixture was then injected into the main muscle artery in a pulsatile manner using a 50mL syringe and a pink venflon, and radiographs were obtained.

Further microsurgical dissection to split muscle and nerve:

Based on the branching pattern of the vessels and nerves seen during dissection and in the radiographs, the muscle was split. Splitting of the muscle was done parallel to the muscle fibers and neurovascular branches. At least one of the main branches of the vessels and nerve was included in each segment. The nerve pedicle was split into two

fascicles by intrafascicular dissection along its whole length. Photographs and radiographs were then taken.

Fig. (1): Injection materials, from right to left: weighing scale, pack of gelatin powder, bottle of normal saline, box of lead oxide (PbO), thermostatically controlled frying pan as a water bath and 100gm of PbO in a mixing bowl with a thermometer respectively.

Statistical analysis:

Data were tested for normal distribution using the Kolmogorov-Smirnov test, comparing ideal normal data (generated by a computer using Stat-View statistical package) and actual data. An alpha value of 0.1 was used to determine the significant variance from normal distribution. The Mann-Whitney U-test was used to compare data that were normally distributed whereas the Wilcoxon signed-rank test was used to compare skewed data.

RESULTS

The mean age of the cadavers was 62 (SD 20.14; range: 38-91) years.

Thoracodorsal vessels:

The thoracodorsal artery entered the proximal triangular part of the muscle on its ventral (deep) surface. Arterial bifurcation was found to lie at a mean distance of 9.98cm (SD 0.17) from the muscle insertion and nearly midway between the muscle borders. The mean length of the thoracodorsal artery from its origin to the vascular bifurcation was 8.8cm (SD 0.29). The mean external diameter of the artery at its origin and bifurcation was 2.68 (SD 0.14) and 1.81 (SD 0.20) mm, respectively.

The thoracodorsal vein mean length from the vascular hilum to termination into the subscapular vein was 8.94cm (SD 0.38). Vein bifurcation was lower at the muscle hilum than the bifurcation of the artery [median distance 10.15 (IQR: 10.1-10.3) cm from muscle insertion and midway between the muscle borders]. The mean external diameter of the vein at its origin and just before bifurcation was 2.79 (SD 0.11) and 1.75 (SD 0.15) mm, respectively (Table 1).

Thoracodorsal nerve:

The thoracodorsal nerve runs deep and ventral to the vascular pedicle. The mean length of the thoracodorsal nerve was 13.86cm (SD 0.36) from its origin from the posterior cord of brachial plexus to its bifurcation at the hilum of the latissimus dorsi muscle. The nerve divided into main branches at a mean distance of 2.51cm (SD 0.48) proximal to the vessels' division (Table 1).

Intramuscular neurovascular branching pattern:

The branching pattern was identical for the artery, vein and the nerve in all specimens and was in the form of bifurcation into superior and lateral branches.

The superior branch first ran transverse and parallel to the superior border of the muscle at a mean distance of 3.2cm from its upper border and then ran downward and medially. The lateral branch first ran obliquely and then longitudinally parallel to and at a mean distance of 2cm from the lateral muscle border (Table 1).

The lateral neurovascular branch was usually larger and formed a 50° (mean) with the superior branch. It gave one or more segmental branches that are parallel to the superior branch. This neurovascular branching pattern supplied the muscle with long parallel branches that were also parallel to the muscle fibres.

We split nine of the muscle specimens into two segments and one specimen was split into three segments. Each segment contained one of the main branches of the neurovascular bundle. Intrafascicular splitting of the whole length of the thoracodorsal nerve into two branches was performed in all dissections (Figs. 3-5). The mean span between the split muscle segments with the neurovascular branches was 4.79cm (SD 0.76).

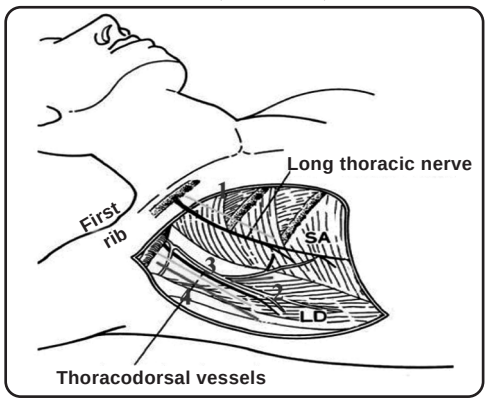

Fig. (2): Diagrammatic representation of the neurovascular pedicles of latissimus dorsi and serratus anterior muscles (1 = Length of long thoracic nerve from outer border of first rib to its bifurcation; 2 = Length of thoracodorsal vessels branch to serratus anterior; 3 = Length of thoracodorsal nerve form its origin to its bifurcation; 4 = Length of thoracodorsal vessels form its origin to its bifurcation).

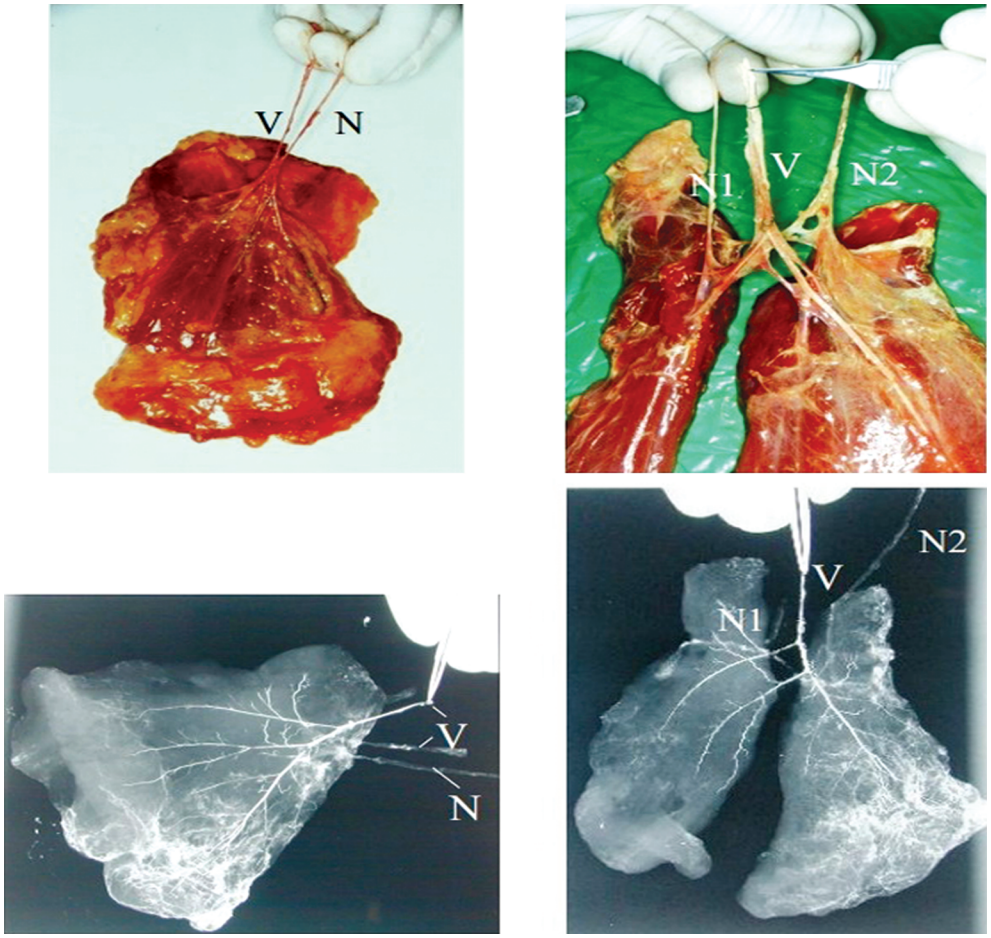

Fig. (3): Left latissimus dorsi muscle specimen; Above left, fresh specimen showing vascular pedicle and nerve pedicle. Above right, split muscle and its nerve. Below left, X-ray showing vascular branching pattern of the same specimen after dye injection. Below right, X-ray of the split muscle after dye injection. (V = Vascular pedicle (thoracodorsal vessels); N = nerve pedicle (thoracodorsal nerve); N1 & N2 = The split nerves; SB = Superior branch; LB = Lateral branch).

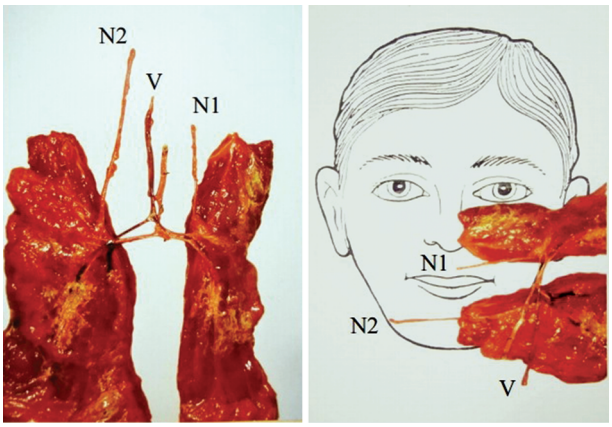

Fig. (4): Right latissimus dorsi muscle specimen; left, split muscle and its nerve and single neurovascular pedicle. Right, split muscle and its nerve is applied on a face diagram. (V= Vascular pedicle; the thoracodorsal vessels; N1 & N2 = The split nerves).

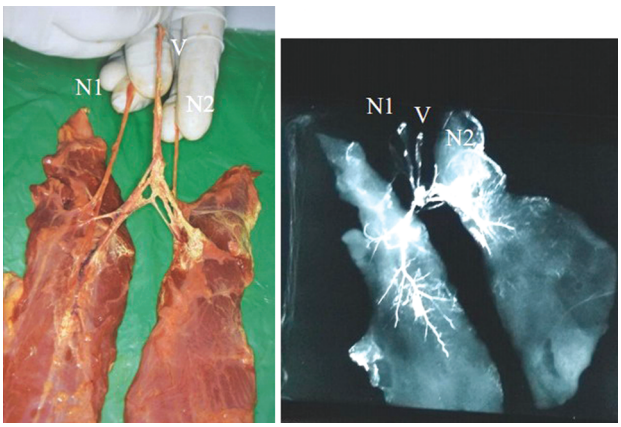

Fig. (5): Right latissimus dorsi muscle specimen; left, split muscle and its nerve. Right, X-ray showing vascular branching pattern of the same specimen after dye injection. (V = Vascular pedicle; the thoracodorsal vessels; N1 & N2 = The split nerves).

Comparison of muscle segments:

An aspect of our approach for smile reanimation that could result in a high failure rate would be the uneven occurrence of dimensions between the two muscle segments (superior and lateral branch external diameters being none randomly different). Therefore, we tested the above reported variables of the muscle segments namely, external diameters of the main branches of the artery, vein, and nerve for normal distribution (Table 1). In no case did any of the examined variables show a significant difference between segments (Table 2).

Table (1): Latissimus dorsi muscle data.

Parameter	Mean ± (SE)	Standard Deviation (SD)	Normally Distributed (*p*-value)	Range	Median (IQR)
TD artery length (cm)	8.8±0.09	0.29	Yes (*p*=0.85)	8.5-9.3	
TD artery diameter at origin (mm)	2.68±0.04	0.14	Yes (*p*=0.44)	2.5-2.9	
TD artery diameter at bifurcation (mm)	1.81±0.06	0.20	Yes (*p*=0.44)	1.6-2.1	
TD artery bifurcation-muscle insertion (cm)	9.98±0.05	0.17	Yes (*p*=0.60)	9.8-10.3	
TD vein length (cm)	8.94±0.12	0.38	Yes (*p*=0.81)	8.4-9.4	
TD vein diameter at origin (mm)	2.79±0.04	0.11	Yes (*p*=0.25)	2.6-3.0	
TD vein diameter at bifurcation (mm)	1.75±0.05	0.15	Yes (*p*=0.81)	1.6-2.0	
TD vein length bifurcation to muscle insertion (cm)	10.1	0.75	No (*p*=0.08)	10-12.1	10.15 (10.1-10.3)
TD nerve length (cm)	13.86±0.11	0.36	Yes (*p*=0.96)	13.4-14.5	
TD nerve diameter (mm)	2.26±0.05	0.16	Yes (*pv*=0.52)	2-2.5	
TD nerve bifurcation to vascular bifurcation (cm)	2.5±0.15	0.48	Yes (*p*>0.99)	1.4-3.2	
Artery superior branch diameter (mm)	1.29±0.09	0.28	Yes (*p*=0.92)	0.9-1.7	
Artery superior branch (number of branches)	3	1	Yes (*p*=0.16)	2-3	
Vein superior branch diameter (mm)	1.18±0.02	0.08	Yes (*p*=0.40)	1.1-1.3	
Vein superior branch (number of branches)	3	1	Yes (*p*=0.16)	2-3	
Nerve superior branch diameter (mm)	1.43±0.13	0.40	Yes (*p*=0.81)	0.8-1.8	
Nerve superior branch number of branches	3	1	Yes (*p*=0.16)	2-3	
Artery lateral branch diameter (mm)	1.14±0.06	0.19	Yes (*p*=0.99)	0.95-1.5	
Artery lateral branch number of branches	3.9±0.43	1.37	Yes (*p*=0.60)	2-7	
Vein lateral branch diameter (mm)	1.24±0.07	0.23	Yes (*p*=0.91)	1.1-1.8	
Vein lateral branch number of branches	3.9±0.43	1.37	Yes (*p*=0.60)	2-7	
Nerve lateral branch diameter (mm)	1.71±0.11	0.35	Yes (*p*=0.99)	0.9-2.2	
Nerve lateral branch number of branches	4.2±0.53	1.69	Yes (*p*=0.16)	2-7	

TD = Thoracodorsal. Diameter = External diameter.

Table (2): Mann-Whitney U test for external diameters of the two main neuromuscular branches of Latissimus Dorsi muscle.

Data	*p*-Value (Mann-Whitney U test)
Artery superior branch diameter / Artery lateral branch diameter	$p = 0.28$
Vein superior branch diameter / vein lateral branch diameter	$p = 0.82$
Nerve superior branch diameter / nerve lateral branch diameter	$p = 0.16$

Table (3): Comparison between anatomical studies on latissimus dorsi muscle.

	Present study Mean (range)	Bartlett **[21]** Mean (range)	Tobin **[19,20]** Mean (range)	Rowsell **[22]** Mean (range)
Number of specimens	10 muscles	50 muscles	115 muscles	100 muscles
TD artery length (cm) from TD origin to its bifurcation	8.8 (8.5-9.3)	9.3 (6-16.5)	8.7 (6-11.5)	8.4 (5.9-14)
TD artery diameter at origin (mm)	2.68 (2.5-2.9)	2.7 (1.5-4)	–	3 (2-5)
TD artery diameter at end (mm)	1.81 (1.6-2.1)	1.6 (0.5-3.5)	–	–
TD vein length (cm) from TD bifurcation to its termination	8.94 (8.4-9.4)	9.1 (5-16.5)	8.7 (6-11.5)	–
TD vein diameter at origin (mm)	2.79 (2.6-3)	3.4 (1.5-4.5)	–	–
TD vein diameter at bifurcation (mm)	1.75 (1.6-2)	1.6 (0.5-3.5)	–	–
TD nerve length (cm)	13.86 (13.4-14.5) from 1st rib	12.3 (8.5-19) from 1st rib	7.4 (4-10.5) from subscapular artery origin	–
TD nerve bifurcation to vascular bifurcation (cm)	2.5 (1.4-3.2)	–	1.3	–
Name of branches	Lateral & superior	Lateral & superior	Lateral & medial	–
Number and % of major branches	2 (100%)	2 (86%) 14% no major superior branch	2 (94%) 6% 3-4 major branches	–
Branch size	Lateral > superior	Superior > lateral	Lateral > medial	–
Origin of TD artery	Subscapular in 100%	–	–	Subscapular 94% Axillary 5% Lateral Thoracic 1%
No of neurovascular hila	1 hilum in 100%	1 hilum in 100%	1 hilum in 99% 2 hila in 1%	–
Other findings	–	In 14% no major superior branch but a small one	–	–
Artery, superior branch diameter (mm)	1.29 (0.9-1.7)	1.1	–	–
Artery, lateral branch diameter (mm)	1.14 (0.95-1.5)	0.8	–	–
Vein, superior branch diameter (mm)	1.18 (1.1-1.3)	1.2	–	–
Vein, lateral branch diameter (mm)	1.25 (1.1-1.8)	1	–	–

TD = Thoracodorsal. Diameter = External diameter.

DISCUSSION

In the last few decades, the latissimus dorsi muscle flap has become a significant tool in the armamentarium of reconstructive surgeons. It has been used as a free flap for facial reanimation by many surgeons **[2-9]** but none have completely split the whole muscle and its motor nerve to produce independent neuromuscular units. Some surgeons have partially split the distal muscle end, but dyskinesia and mass movements were significant problems **[4,7]**.

The results of previous studies on the neurovascular branching patterns of the latissimus dorsi muscle were very similar to our findings. Zhao et al. **[2]** looked into dividing the muscle into several flaps (4-6) based on the neuromuscular branching pattern to get a muscle flap with a long pedicle for facial reanimation. They could obtain a distal muscle segment with an ultra-long pedicle and used it successfully to reanimate the face in a single stage. Tobin et al. **[19,20]** divided the latissimus dorsi muscle and overlying skin into two myocutaneous segments based on the neurovascular branching pattern for reconstruction purposes other than facial reanimation. Bartlett et al. **[21]** recorded detailed descriptions and measurements of the neurovascular branching pattern of the latissimus dorsi muscle. However, none of the above studies addressed the issue of complete splitting of the muscle and its nerve into two motor units. Table (3) shows a comparison between results of the previous anatomical studies on the latissimus dorsi and the present study.

We showed that neurovascular pedicle of the latissimus dorsi muscle divided into two main branches namely, the lateral and the superior branches. The lateral branch was always larger and ran parallel to the superior branch. According to these findings, we could split the muscle into two segments in nine cases and into three segments in one case. This finding could be applied clinically to patients with facial palsy by attaching one segment to the lower lip to provide tone and downward pull and reanimate the depressor function and attaching the other segment obliquely to the upper lip and modulus to provide upward pull on the angle of the mouth. Whether these segments would function without dyskinesia, this can only be answered by animal or clinical studies.

Following facial reanimation, some clinicians depend on contralateral lower lip weakening techniques to stop the lower lip from attaining a lopsided vector during smiling. Noninvasive injection of botulinum toxin type A and resection of lower lip depressors are examples of such techniques.

For the normally distributed data of the muscle segments, 95% of all dimensions that we would expect to encounter were within the observed range. In all cases, the dimensions did not prevent splitting of the muscle. Therefore, we predict that this would not be a limiting factor to our approach to facial reanimation. Given that, most of the data were normally distributed, these anatomical features of the latissimus dorsi muscle appear fairly constant.

For the variable of vein length; however, the dimensions were not normally distributed. We cannot predict whether a larger study would have identified samples for which splitting of the muscle would be impossible based on this factor; nonetheless, variations in vein length would not be expected to cause issues concerning muscle splitting or successful microvascular anastomosis as a vein graft would be used in cases where the vein is too short.

Another hypothetical aspect that could result in high levels of failure of muscle function after splitting is the possibility of the uneven occurrence of dimensions between the diameters of the two main neurovascular branches of the muscle segments. However, in no case did any of the factors examined show a significant difference between segments (Table 2).

For the muscle segments, most dimensions of the neurovascular tree were normally distributed suggesting that our sample was representative (i.e. no extremes or outliers). Nerve diameter, the factor most likely to affect complete muscle splitting if too small, was normally distributed in all specimens, and all were completely split. Although extremes may occur, our data suggest that they would be rare.

Although Rubinstein et al. **[22]** suggested preoperative arteriographic visualization of the latissimus dorsi vascular anatomy, the current study indicates that preoperative arteriograms are not necessary unless the muscle has suffered any kind of trauma because of the fairly constant and identical branching pattern of both the thoracodorsal vessels and the nerve. This is an advantage of our approach.

A nerve pedicle long enough to reach the contralateral intact facial nerve is an ideal perquisite to perform a single-stage cross-face facial reanimation. We could harvest a nerve pedicle of up to 14.5cm and a vascular pedicle of up to 9.3cm.

Splitting the whole length of the nerve into two halves was possible and the harvested split nerve would be long enough to reach the contralateral posterior parotid margin so that an inconspicuous face-lift incision could be used. A more anterior noticeable facial incision was used by Kumar **[17]** using the gracilis muscle and by Harii et al. **[7]** using the latissimus dorsi muscle for direct nerve anastomosis.

The span between the split muscle segments at the level of neurovascular hilum was sufficient to apply segments to the upper and lower lips without tension on the neurovascular pedicle. The proximal end of the muscle should be cut close to the neurovascular hilum to provide a sufficient nerve length to position the vascular pedicle close to the facial vessels for easy anastomosis.

Hassan et al. **[23]** performed a study similar to the present one using the gracilis muscle from fresh cadavers and observed similar results regarding the constant branching patterns and the possibility of splitting the muscle into independent motor units. One advantage of the latissimus dorsi over the gracilis muscle is the long thoracodorsal nerve that enables performing free muscle transfer for facial reanimation in a single stage without performing conspicuous anterior facial scar used by Kumar et al. **[17]** in their series using the gracilis muscle.

The consistent location of the vascular hilum on the deep surface of the latissimus dorsi muscle makes it possible to thin the muscle in a horizontal plane. This may prevent the excessive facial swelling that can follow the transfer of a full thickness muscle. This is possibly another advantage to the present approach.

Boahene et al. **[24]** designed a functional double paddle gracilis muscle for a multivector facial reanimation. They stated that a multivector gracilis flap design was effective in improving all components of the smile display zone and had the potential for producing the periorbital-wrinkling characteristic of a Duchenne smile. However, they did not address the mobility of the lower lip. They did not split the nerve to gracilis. They applied the split gracilis segments only to the upper lip and angle of the mouth.

Conclusion:

This study suggests that the latissimus dorsi muscle is suitable for segmental splitting into neurologically independent units based on neurovascular branching patterns and has a considerable potential for smile restoration.

Limitations:

This was a cadaveric study that cannot yield information about the dynamic movement of different muscle slips. Given that there is so much axonal orientation change axially along the nerve, we cannot confirm whether there would be fundamentally different anatomical neural pedicles for this approach and an in vivo situation is necessary to prove that the muscle slips would be functional.

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