

Study of Neurovascular Anatomy of the Split Gracilis Muscle for the Purpose of Facial Reanimation

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ABSTRACT

We carried out an anatomical study on ten gracilis muscle specimens obtained from five fresh cadavers. The study showed the technical possibility of splitting all the muscles specimens into independent neuromuscular units with two separate nerves and one vascular pedicle. We aim at applying this technique in the future on patients with established facial palsy. One muscle segment might be employed to the angle of the mouth and upper lip and the other segment to the lower lip to get the bonus of lower lip mobility and thus producing a near natural smile in those patients. Further clinical evaluation of the technique is required.

INTRODUCTION

The gracilis muscle is a highly reliable flap characterised by a highly predictable and adequate neurovascular pedicle and a longitudinal intramuscular neurovascular pattern [1]. It has been used for the purpose of facial reanimation by many authors [2-12]. The transferred gracilis muscle replaces the function of some of the paralysed muscles (Zygomaticus major muscle in Kumar [9]). The depressors of the lip are not replaced and asymmetry of the mouth persists. If we could split the muscle into two functional units, lip depression could be restored. In the previous studies involved the gracilis muscle for facial reanimation, neither the muscle nor its nerve has been split completely into separate units.

There are 16 pairs of facial muscles involved in the different facial expressions and movements [6]. In facial palsy, majority or all of these muscles may not be functioning. In spite of the recent refinements in reconstructive surgery to the paralyzed face, it is impossible to replace the function of all the paralyzed muscles.

Free micro-neurovascular muscle transfer with cross-face nerve graft connected to the contra-lateral intact facial nerve offers the best prospect in restoring muscle tone and voluntary and emotional ex-

pressions in long established facial palsy [5]. The transferred muscle replaces some of the paralyzed muscles. If the lip depressors are not replaced, asymmetry of the angle of the mouth persists. Smile will be unnatural especially in patients with full denture smile (2% in Rubin [13]). Digastric muscle transfer and other local dynamic transfers to the lower lip have proved unsatisfactory [5]. There have been many trials to split the transferred free muscle to the face. O'Brien et al. [5] separated the distal end of the gracilis muscle in two segments to be attached to lateral aspect and angle of mouth. He insisted that it is necessary to separate the muscle into two motor units if it is going to be used to reanimate the both upper and lower face. In order to do so, he separated the nerve at the muscle hilum into two divisions using intra-fascicular dissection facilitated by nerve stimulator. He identified the corresponding fibers of the muscle and separated them into two units as far as possible. In none of his cases, either the muscle or the nerve was completely split and thus dyskinesia was a problem.

Harii et al. [2] split the distal end of the gracilis muscle longitudinally and sutured the upper portion to upper lip and lower portion to lower lip. Harrison divided the insertion of pectoralis minor muscle into three elements [14]. One muscle element was inserted into alar base and the other two elements were inserted into upper and lower lip. Koshima et al. divided the distal end of the transferred rectus femoris muscle into two segments and sutured it to the lateral aspect of upper and lower lip [15]. Sassoon et al., separated the lower end of gracilis muscle graft into three main slips, two deep ones to go through upper and lower lip tunnels and a more superficial and shorter one to be sutured to the modulus and nasolabial fold [8]. Wei et al. (1999) used the distal part of latissimus dorsi muscle based on its segmental anatomy. This enabled him to get an ultra long vascular pedicle

(13-17.5cm) and consequently to perform the whole procedure in one stage [16]. In the above-mentioned studies, neither the transferred muscle nor its nerve was split completely along their whole length and the resultant movement was one movement (one direction of pull). Dyskinesia and persistent lower lip deformity was noticeable. In the present study, the possibility of splitting of the whole length of the donor muscle (latissimus dorsi, serratus anterior and gracilis) and its nerve supply forming two independent motor units on a single vascular pedicle was investigated. This concept can be applied clinically by attaching one segment to the angle of the mouth and the other to the lower lip to improve symmetry of angles of mouth and avoid dyskinesia. As far as we can determine, MacKinnon et al., was the only one to report splitting the whole length of latissimus dorsi muscle and only part of its nerve. The procedure was performed in two stages with a possible third one [17]. They split up to 8-10cm of nerve and left the remaining part without division. They used the second segment to reanimate the eye. The overlapping of the territories caused some mass movements because of incomplete division of the nerve. In agreement with O'Brien, we can say that splitting of the whole nerve and muscle is the only way to avoid dyskinesia and mass movements [5].

MATERIAL AND METHODS

The study was carried out on muscle specimens obtained from fresh hospital post-mortem cadavers (within 3 day of death and without any injected preservatives). We had access to 10 gracilis. The study was done in the period between June 2006 and April 2008.

This work is a continuation of the research started in Whiston hospital, Liverpool, UK during the scholarship awarded to the first author.

Venue:

Anatomy Department and Plastic Surgery Unit, Faculty of Medicine, Minia University.

Position:

The cadaver was kept during dissection in supine position with the knee flexed and the hip flexed and externally rotated. An assistant was required to perform this task.

Technique of muscle harvest:

An inverted L-shaped incision made along a line joining the adductor tubercle to the medial condyle of the femur. The incision corresponds to

the posterior margin of the adductor longus muscle. The anterior border of the gracilis was postero-medial to the adductor longus. Skin flaps were raised in a plane just superficial to the muscles on either sides of the incision. Anterior border of the muscle was identified and raised with care not to damage the neurovascular pedicle. The vascular pedicle was mobilized to its origin from profunda vessels with division of all branches to the overlying adductor longus muscle. To obtain the maximum possible length the gracilis nerve, which comes off the anterior division of the obturator nerve, we had to trace it up to the obturator foramen. Muscle origin from the pubis was divided. Anterior border of the muscle was traced distally to look for possible other vascular pedicles from the superficial femoral artery or the popliteal. Muscle insertion into the tibia was then divided.

Microsurgical dissection:

Careful dissection using surgical microscope was carried out to remove fatty tissue surrounding the neurovascular pedicle to clearly identify the proximal neurovascular branching pattern. On reaching the neurovascular hilum, intramuscular dissection for the branches of the nerve and blood vessel was performed. Branches were traced until they sank deeply into the muscle. Photographs were then taken.

Injection technique:

We used the injection technique described by Rees and Taylor to inject muscle specimens [18]. It consists of preparing a mixture of lead oxide (PbO), gelatin and warm water in the following proportions:

- 200gm lead oxide.
- 100ml water.
- 3ml gelatin powder.

Gelatin powder was added to warm water at 50°C and stirred until dissolved. An electric frying pan with a thermostat was used to provide a warm water bath (Fig. 1). Instead of water, about 500ml of normal saline was heated in the pan. This saline was used subsequently to perfuse and flush the arterial tree just before injecting 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. Then radiographs were obtained.

Further microsurgical dissection to split the muscle:

Based on the branching pattern of the vessels and nerves seen by dissection and in the radiographs, the muscle was split. Splitting of the muscle

was done parallel to 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 intra-fascicular dissection using surgical microscope along its whole length. Photographs and radiographs were then taken.

Statistical analysis:

All data were tested for normal distribution using Kolmogorov-Smirnov test comparing ideal normal data (generated by computer using Stat-View statistical package) and actual data. An alpha value of 0.1 was used to determine significant variance from normal distribution. Mann-Whitney U test was used to compare data that are normally distributed whereas Wilcoxon signed rank test is used to compare skewed data. Mean and standard deviation were used to describe normally distributed variables while the median value and interquartile range were used to describe skewed data.

RESULTS

The mean age of the cadavers was 60.12 years old (\pm SD 19.15), range (35.52-87 years).

The gracilis muscle dimensions:

The mean length of the muscle was found 26.34cm (\pm SD 0.91). The mean width at level of main vascular pedicle was 4.31cm (\pm SD 0.13). The neurovascular hilum always came out of anterior border of the muscle approximately at the junction of its upper quarter and lower three-quarters.

The proximal (main) vascular pedicle: (Figs. 3,4,5 and Table 1)

The main vascular pedicle to the muscle came off the profunda femoris vessels. It entered the muscle on its deep (lateral) surface after crossing its anterior border and at a mean distance of 9.49cm (\pm SD 0.25) from muscle origin and 1.62cm (\pm SD 0.14) from the anterior border. The vascular pedicle consists of one artery and two venae comitantes. The mean external diameter of the artery at its origin was 1.72mm (\pm SD 0.13) and it was 1.05 mm (\pm SD 0.09) just before its division. The mean external diameter of the venae comitantes at their origin was 1.60mm (\pm SD 0.14). Figs. (3,4,5) shows diagrammatic representation of the gracilis muscle and its neurovascular pedicle.

The middle vascular pedicle: (Fig. 5, Table 2)

This was found in the middle third of the muscle in 8 of the specimens (80 percent). It was found to come off the superficial femoral artery in all

specimens. The mean external diameter of the middle vascular pedicle was 0.80mm (\pm SD 0.12) and it was found at a mean distance of 16.10cm (\pm SD 1.33) from muscle origin. Two venae comitantes of similar diameter were found to join the artery.

The distal vascular pedicle: (Fig. 4, Table 2)

The distal vascular pedicle was found in the distal third of the muscle in 5 of the specimens (50%). It originated from the superficial femoral vessels in 2 cases and from the popliteal artery in 3 cases. The mean external diameter of the distal vascular pedicle was 0.63mm (\pm SD 0.08) and it was found at a mean distance of 19.63cm (\pm SD 0.80) from muscle origin. Two venae comitantes of similar external diameter were found to join the artery.

Nerve to gracilis: (Table 3)

Nerve to gracilis was found to take origin from the anterior division of the obturator nerve. It runs obliquely from anterior to posterior on the deep (lateral) surface of the muscle in a deeper plane to the vascular pedicle. The mean length of the nerve to gracilis was found 10.12cm (\pm SD 0.95). Its mean external diameter was found 1.81mm (\pm SD 0.13). The nerve bifurcation situated at a mean distance of 1.86cm (\pm SD 0.10) proximal to the vascular bifurcation.

Intramuscular neurovascular branching patterns:

The neurovascular branches were traced inside the gracilis muscle. The branching pattern was found identical for the artery, vein and nerve in all specimens except for the site of nerve division. It was found proximal to the site of vessel division as mentioned above. The branching pattern was in the form of bifurcation into superior and inferior branches in all specimens. The superior branch was found to run first transverse then downwards and posteriorly. The inferior branch runs first obliquely then longitudinally downwards. It runs parallel to and at a mean distance of 2cm from anterior muscle border. The superior neurovascular branch was usually the larger and is usually separated from the inferior branch at a mean of 55-degree angle. The superior branch gave one or more segmental branch that went parallel to the inferior branch. The external diameters of the main branches of the main vascular pedicle and number of its segmental branches are shown in Table (1). These neurovascular branching patterns supplied the muscle with long parallel branches that are also parallel to muscle fibers that allows splitting the muscle longitudinally into vascularised and

independently innervated muscle units. Only two segments would serve the purpose of our study to employ them to upper and lower lips. All specimens could be split into two segments using microsurgical dissection. Each segment contained at least one of the main branches of the neurovascular bundle. Intra-fascicular splitting of the whole length of the nerve to gracilis into two branches was performed in all dissections using the surgical microscope with high magnification. We measured the span between the split muscle segments at the level of the neurovascular hilum while the neurovascular branches are under no tension. The mean span was 4.74cm (\pm SD 1.31). This would allow applying segments to upper and lower lips without tension on the neurovascular branches. All data were subjected to normal distribution testing using Kolmogorov-Smirnov test comparing ideal normal data and actual data (Table 1). An alpha value of 0.1 was used to determine significant variance from normal distribution. Most data were normally

distributed. Superior branch external diameter of the artery and nerve as well as the number of the sub-branches of nerve superior branch were not normally distributed. We have looked for correlations between dimensions that do not show a normal distribution (Table 1). This could lead to a significant occurrence of samples where splitting of the muscle would be impossible in a larger study. Wilcoxon signed rank test was used to do so and no convincing evidence for such correlation could be established ($p=0.0022$). Mann-Whitney U test of two groups of data was carried out to find out whether there is any significant difference between the external diameters of the main neurovascular branches of the two segments that might result in significant levels of failures. There was statistically significant difference between external diameters of the main branches of the artery ($p=0.0016$) and the vein ($p=0.0101$). There was no significant difference between nerve branches ($P=0.5033$) (Table 3).



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.

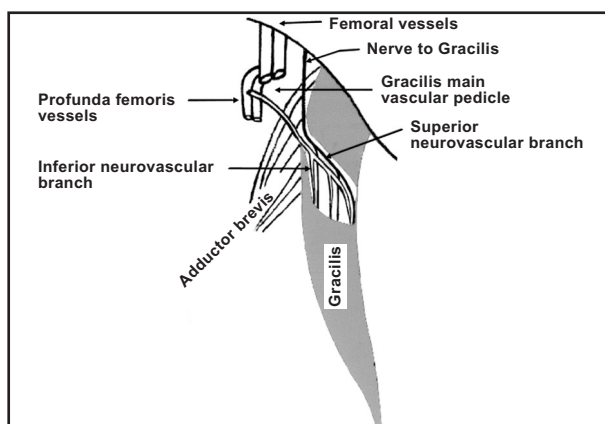
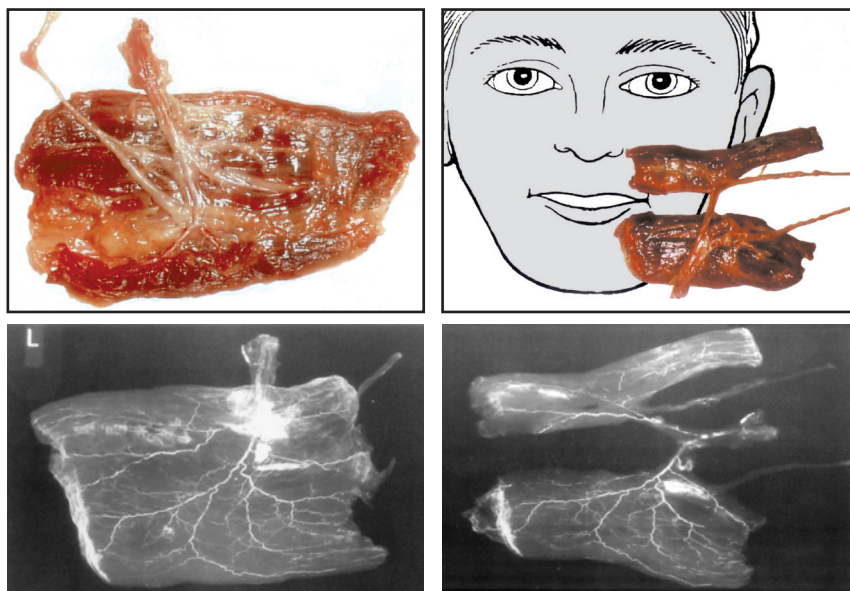


Fig. (2): Diagrammatic representation of gracilis muscle and its neurovascular pedicle.

Fig. (3): Left Gracilis muscle specimen; above left, fresh specimen showing two vascular pedicles and one nerve pedicle. Above right, the split muscle and its nerve is applied on face diagram. 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.



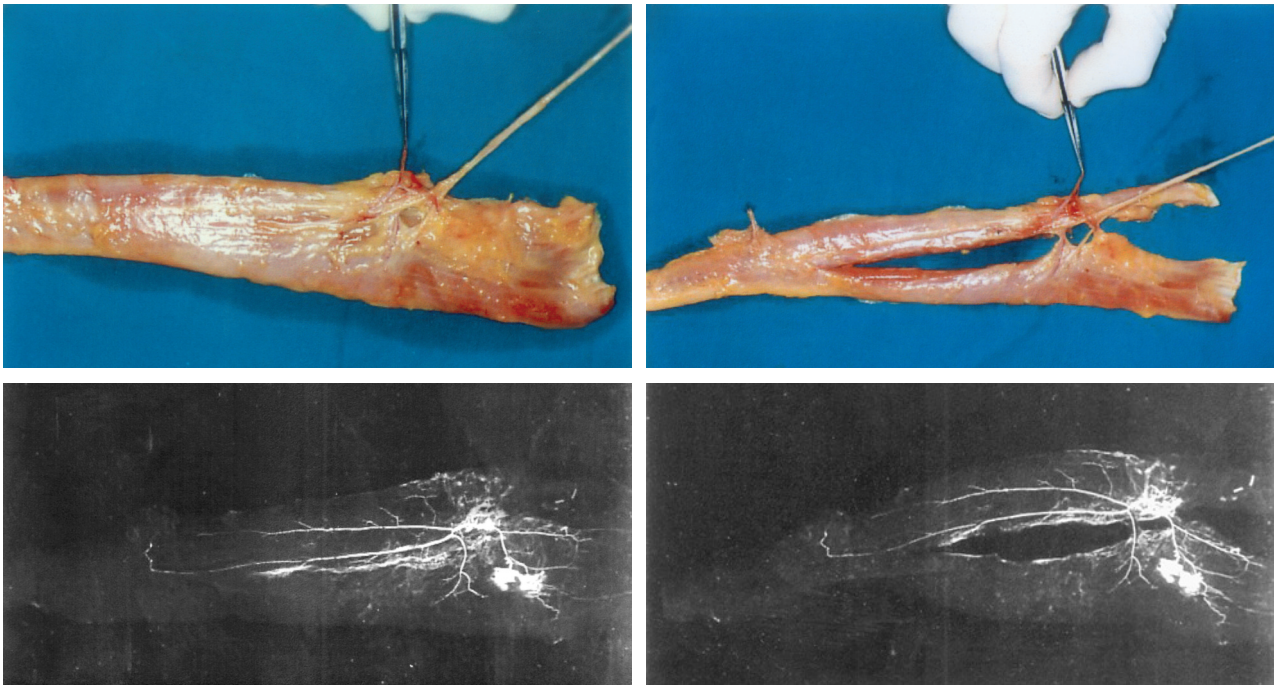


Fig. (4): Left gracilis muscle specimen; above, dissected muscle showing main vascular pedicle and a long nerve pedicle with their main branches before splitting. Below right, muscle is split into two segments with two separate nerve branches and one vascular pedicle. Note a distal vascular pedicle is shown. Below left, X-ray of the same muscle after dye injection. Below right, X-ray of the split muscle after dye injection.

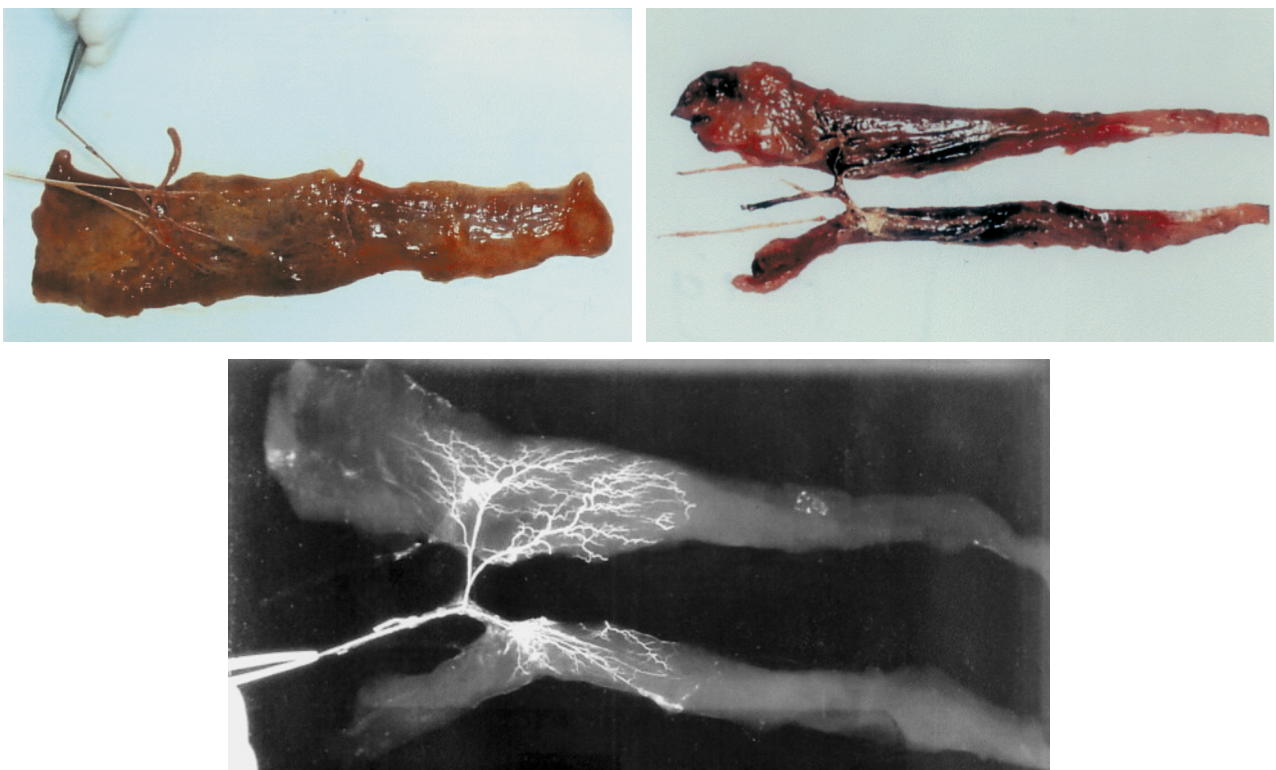


Fig. (5): Right gracilis muscle specimen; above left, dissected muscle showing main vascular pedicle and nerve pedicle with their main branches before splitting. Note a middle vascular pedicle is shown. Above right, muscle is split into two segments with two separate nerve branches and one vascular pedicle. Below, X-ray of the split muscle after dye injection.

Table (1): Main gracilis vascular pedicle data (diameter = external diameter).

Parameter	Mean (SE)	SD	Normally Distributed (p-value)	Range	Median (IQR)
Arterial length (cm)	8.5 0.04	0.13	Yes $p=0.53$	8.3-8.7	
Arterial diameter at origin (mm)	1.72 0.04	0.13	Yes $p=0.55$	1.6-1.9	
Arterial diameter at bifurcation (mm)	1.05 0.22	0.09	Yes $p=0.25$	0.8-1.15	
Arterial bifurcation-muscle origin (cm)	9.49 0.07	0.25	Yes $p>0.99$	8-9.5	
Vein length (cm)	8.5 0.04	0.13	Yes $p=0.53$	8.3-8.7	
Vein diameter at origin (mm)	1.60 0.03	0.14	Yes $p=0.24$	1.3-1.75	
Vein bifurcation-muscle origin (cm)	9.49 0.07	0.25	Yes $p>0.99$	9-10	
Nerve length (cm)	10.12 0.28	0.95	Yes $p>0.99$	9.6-12	
Nerve diameter (mm)	1.81 0.04	0.13	Yes $p=0.36$	1.5-1.9	
Nerve bifurcation-vascular bifurcation (cm)	1.86 0.04	0.10	Yes $p=0.53$	1.6-2.0	
Artery superior branch diameter (mm)	0.75	0.07	No $p=0.03$	0.6-0.8	0.80 0.71-0.80
Artery superior branch number of branches	3.25 0.33	1.14	Yes $p=0.25$	2-5	
Vein superior branch diameter (mm)	0.53 0.03	0.11	Yes $p=0.53$	0.4-0.7	
Vein superior branch number of branches	3.08 0.34	1.16	Yes $p=0.25$	2-5	
Nerve superior branch diameter (mm)	0.57	0.08	No $p=0.05$	0.5-0.7	0.52 0.5-0.61
Nerve superior branch number of branches	3.25	0.62	No $p=0.03$	2-4	3.12 3-3.1
Artery inferior branch diameter (mm)	0.62 0.02	0.8	Yes $p=0.25$	0.5-0.7	
Artery inferior branch number of branches	2.83 0.32	1.11	Yes $p=0.1$	2-5	
Vein inferior branch diameter (mm)	0.41 0.02	0.08	Yes $p=0.25$	0.3-0.5	
Vein inferior branch number of branches	2.83 0.32	1.11	Yes $p=0.1$	2-5	
Nerve inferior branch diameter (mm)	0.54 0.03	0.09	Yes $p=0.4$	0.4-0.7	
Nerve inferior branch number of branches	3 0.3	1.04	Yes $p=0.1$	2-5	

Table (2): Middle and distal gracilis vascular pedicles (diameter = external diameter).

Parameter	Middle vascular Pedicle	Distal vascular Pedicle
Incidence	80%	50%
Diameter at origin (mm)	0.8 (SD 0.12)	0.63 (SD 0.08)
Hilum from muscle origin (cm)	16.10 (SD 1.33)	19.63 (SD 0.80)

Table (3): Mann-Whitney U test for external diameters of the two main neurovascular branches of Gracilis muscle.

Data	<i>p</i> -value (Mann-Whitney U test)
Artery superior branch diameter / Artery inferior branch diameter	<i>p</i> =0.0016
Vein superior branch diameter / vein inferior branch diameter	<i>p</i> =0.0101
Nerve superior branch diameter / nerve inferior branch diameter	<i>p</i> =0.5033

DISCUSSION

The gracilis is the preferred muscle used by many reconstructive surgeons for the purpose of facial reanimation. It has a reliable vascular pedicle, long nerve and can be easily harvested without functional loss [9]. It also allows two teams to work in the same time without the need to change the position of the patient [11]. In all the previous studies, the gracilis muscle was only partially split at its distal end to reanimate different parts of the paralyzed face. Unfortunately, dyskinesia and mass movements were real problems. Studies on gross and detailed anatomy of gracilis showed comparable results to the present study [19,20]. They did not split the muscle. Recently, Terzis et al., reported good results of reanimation of the lower lip using pedicled platysma flap, digastric muscle transfer connected to cross-face nerve graft and end to side cervicofacial-hypoglossal anastomosis [21]. The described platysma flap technique seemed to be lengthy and tedious and required significant incisions in the sub-mandibular area. The harvest of the contra-lateral mandibular nerve to innervate the cross-face nerve graft required for digastric muscle innervation will inevitably result in weakening of the normal depressor muscles on the

opposite side and the balance between both sides would be difficult then. Innervation of the facial muscles with the hypoglossal nerve is expected to result in mass movements and dyskinesia. Depressor muscle myectomy is another technique preferred by Manktelow as quick easy to perform technique that resulted in symmetric smile [22]. Lack of dynamic function of the lip is a disadvantage to this technique. This technique symmetry at rest and on smiling to some extent but can not produce active expressions of the lower lip. In the present study, two (Figs. 3,4,5) completely separate muscle segments with separate nerve pedicles could be obtained. Splitting of the muscle segments was based on its intramuscular neurovascular branching pattern. Each segment contained its own nerve, artery and vein branches. Both upper and lower lips could be reanimated by the use of these muscle segments. The separate nerve pedicles can be connected to separate facial nerve branches to get independent movements. Whether the split muscle segments will be functioning and there is no dyskinesia, this will be answered only by clinical trials or animal experimentation in the future. In the present study, up to 12.2cm of the nerve to gracilis could be harvested by tracing the nerve up to the obturator foramen and by doing intra-fascicular splitting of the nerve to gracilis from other branches of the anterior division of the obturator nerve. Kumar reported harvesting 10-12cm of the nerve to gracilis that helped in the advocacy of his single stage gracilis transfer without cross-face nerve graft. The nerve to gracilis was long enough not to need a cable nerve graft [9]. A longer neurovascular pedicle can be possibly obtained by harvesting a more distal portion of the muscle by intramuscular dissection. This was the concept applied in the study reported by Wang and Wei et al., on latissimus dorsi muscle [16,23]. They harvested an ultra long latissimus dorsi neurovascular pedicle that helped in performing a single stage latissimus dorsi transfer without cross-face nerve graft. If a longer gracilis nerve pedicle can be obtained, we would be able to use the usual non-visible face-lift incision for single stage facial reanimation. The mean external diameter of the proximal pedicle artery at its origin was found 1.75mm (SD 0.14) which is reasonably good size for micro-vascular anastomosis. All gracilis dimensions were subjected to normal distribution testing (Table 1). Most data were normally distributed and we can say that 95% of all dimensions we would expect to encounter are within the range observed. In all cases the dimensions observed did not prevent splitting of the muscle-therefore we would predict that if this factor could be limiting it would not be

observed to be limiting in a significant number of cases. Three of the dimensions were not normally distributed (diameters of superior branch of a gracilis nerve and artery and the number of sub-branches of superior branch of gracilis nerve). In these cases, we can not predict whether a larger study would have identified a significant number of samples where the successful splitting would be impossible on the basis of this factor (if this is the limiting factor). There also may be co-relationships between factors, this could also lead to a significant occurrence of samples where splitting of the muscle would be impossible in a larger study. We have looked for co-relationship in dimensions that do not show a normal distribution and have not established convincing evidence for such interdependence ($p=0.0022$, using Wilcoxon signed rank test). Using Mann-Whitney U-test, the hypothetical aspect of the uneven occurrence of dimensions between diameters of the two main neurovascular branches that might result in significant levels of failure of muscle function was tested (Table 3). There was statistically significant difference between main branches of the artery and vein. We can regrettably say that the split muscle might not be functioning in the future based on these factors (if these are actually limiting factors). There was no significant difference between nerve branches. The measured span between the split muscle segments at the level of neurovascular hilum appeared enough so that the muscle segments could be applied to upper and lower lips without tension on the neurovascular pedicle.

Conclusion:

Facial reanimation is one of the most challenging fields in plastic surgery practice. Numerous muscles are paralyzed and need be replaced. To restore symmetric near natural smile, we need at least two functional muscle units, one for the upper lip and another for the lower lip. The above anatomical study proved the possibility of splitting gracilis muscle into two functional muscle units on a single vascular pedicle and two separate nerves. Clinical application of the technique is required in a near coming study.

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