Anatomic Variance in Common Vascular Pedicle of the Gracilis and Adductor Longus Muscles: Feasibility of Double Functioning Free Muscle Transplantation with Single Pedicle Anastomosis

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ABSTRACT

Fifty thighs from fresh human cadavers were studied to evaluate the feasibility of a double functioning free muscle transfer of the gracilis and adductor longus with single common vascular pedicle anastomosis. Methylene blue intra-arterial injection and loupe-magnified dissection were used to demonstrate three groups of vascular patterns in these two muscles. The common vascular pedicles of 88% of our specimen muscles were long enough for possible anastomosis. Ten percent (type B2) were quite short, making microsurgical procedure difficult. Two percent (type A3) of our specimens were not suitable for single anastomosis. Four percent of our gracilis muscles had two major arterial pedicles that branched from the common pedicle in a Y-shaped configuration. If only one pedicle of this type is harvested during a free gracilis muscle transfer, it may cause inadequate flap perfusion. Four specimens were studied using contrast media angiography to confirm both are Mathes and Nahai type II muscle flaps. In summary, this study typed the common vascular pedicle of our sample of gracilis and adductor longus muscles and confirmed the feasibility of double functioning free muscle transfer of the gracilis and adductor longus with single vascular anastomosis.

KEYWORDS: Adductor longus and gracilis, functioning free muscle transplantation, brachial plexus injury

The gracilis muscle has been the donor muscle preferred by many reconstructive microsurgeons for functioning free muscle transplantation (FFMT) because of its reliable vascular supply, ease of harvesting, multifascicular nerve (enabling separation of muscle functions), and expendability.[1–7] Most studies of the gracilis muscle have focused on blood supply[5,8–11] and surgical approach.[6,12] By comparison, however, the adductor longus has rarely been mentioned in the literature for reconstructive microsurgery. The gracilis and adductor longus muscles are located in the same region of the human thigh, and the two are supplied by the same vascular source and nerve. Both are also long strap muscles with good excursion. Overall, these

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characteristics make the two muscles candidates for the development of surgical procedures for double functioning free muscle transplantation (DFFMT) based on single vascular anastomosis.

FFMT is the only surgical method used to solve the problems related to muscle destruction in a limb where the surgeon cannot find a suitable local donor muscle or tendon to transfer. These conditions include severe Volkmann ischemic contracture, severely traumatic limb, and brachial plexus injury (BPI). In some patients with BPI, more than one FFMT is required to restore function.[3,4] In such cases, each FFMT requires a single recipient vessel for the separate stages of reconstruction. DFFMT with single vascular pedicle anastomosis may be an excellent alternative surgical treatment in this situation. Fewer vascular anastomoses and reduced surgical time are required to restore function in the two muscles, in comparison to the previous technique. Chuang et al introduced the DFFMT concept for treating severe Volkmann ischemic contracture.[13] However, there may be variations in the vascular pattern and nerves in these two muscles, which have not been investigated.

Therefore, the purpose of this study was to determine the types of these variations and, thereby, the possibility and feasibility of performing DFFMT using the gracilis and adductor longus muscles with a single vascular anastomosis.

MATERIALS AND METHODS

A total of 54 fresh cadaveric thighs were dissected and examined during a 6-month period. There were 27 bodies with an equal number of thighs on the right and left sides, and all were free from pathological conditions that might have affected the anatomic features of the regions of interest. Fifty thighs were used for our anatomic dissection study, and four fresh cadaveric thighs were used for contrast media injection study.

Arterial dissection commenced from the femoral artery at the level of the inguinal ligament, under loupe magnification (3.3 ×). After identification of the branches of the femoral artery, it was ligated at its most proximal point and then injected with 15 mL methylene blue, which was manually massaged through the hip and thigh area before further dissection to enhance visualization of the small vessels, especially the minor pedicles of the source artery. The gracilis and adductor longus muscles were identified carefully to preserve all surrounding tissue. The method of measuring common pedicle length and distance from the profunda femoris artery to each muscle is depicted in Fig. 1. The feasibility of DFFMT with single artery anastomosis, which depends on the diameter, length, and muscle supply of the common vascular pedicle, was recorded. Nerve lengths for both muscles were measured from the edge of the obturator foramen to the muscle

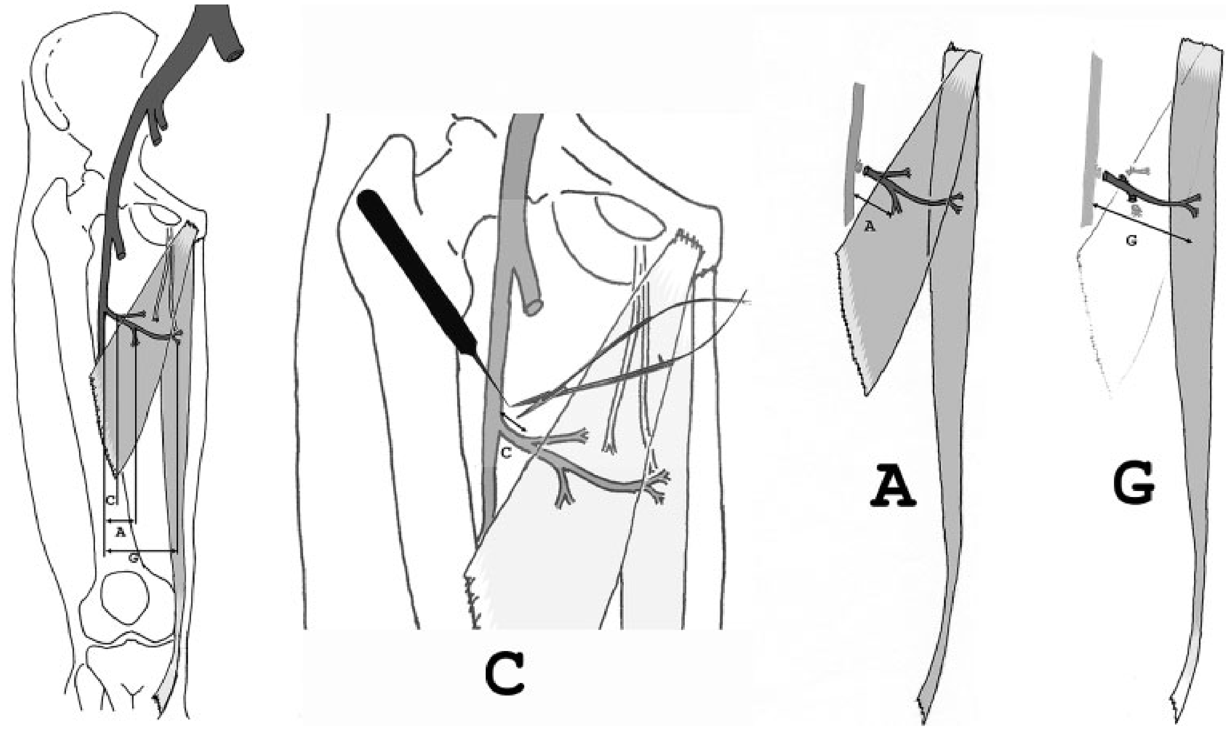

Figure 1 Measurement methods for the parameters in Table 1. The common pedicle length (C) is measured from the profunda femoris artery and the first branch supplying the adductor longus muscle. Adequate length allows the microsurgeon to divide the common pedicle and suture it to the recipient vessel. A and G are the distances between profunda femoris artery and adductor longus and gracilis muscles, respectively. These dimensions are also important in FFMT, because the muscle and vascular anastomosis site should be inset less than this distance.

entry point. The resting (noncontracted) length of both muscles was measured from origin to insertion, with the anatomic position of the cadaver. After completion of all measurements, both muscles were harvested to record weight.

Four double muscles were studied using a radiopaque injection and roentgenogram to identify the type of blood supply after anatomic dissection. The muscles were harvested while preserving all the surrounding fascia and neurovascular attachments, including the superficial and profunda femoral vessels. Warm normal saline was irrigated through the femoral artery before the angiographic study. Other branches of the femoral vessels were ligated to prevent contrast media leakage. Iohexol contrast medium (2 to 5 mL, 300 mg/mL; Omnipaque^{TM}, Amersham Health Limited, Shanghai, China) was sequentially injected into the profunda and superficial femoral arteries, and follow-up with a roentgenogram was performed.

RESULTS

Methylene blue injection enhanced visualization of the major and minor pedicles supplying both muscles (Fig. 2).

Vascular Pattern and Classification

The source of vascular supply for both muscles was the common branch arising from the profunda femoral artery and vein. The repeated variations of the branching pattern were classified into three types (A, B, and C). These types were further subclassified according to common pedicle length (from the profunda femoris artery to the first branch of the common vascular pedicle). This length is an important parameter for DFFMT microsurgery as it determines the facility with which the microsurgeon is able to divide the common pedicle and suture it to the recipient vessel (Fig. 1, Table 1).

Type A (n = 23; 46%) is defined as having a common pedicle with a single major vascular branch to supply each muscle. Type A is further subclassified into three types: A1 (n = 21; 42%), with a long common pedicle 20 mm or more in length (mean length 34.8 mm, mean diameter 2.95 mm); A2 (n = 1; 2%), consisting of a short common pedicle (length 10 mm, diameter 3 mm); and A3 (n = 1; 2%), which has a long common pedicle, with an additional major pedicle supplying the adductor longus muscle that was not within the common pedicle. If surgeons use only the common vascular pedicle for vascular anastomosis during flap transfer, the blood supply for the adductor longus flap may be inadequate. In this case, the procedure should be converted to single FFMT using only the gracilis muscle.

Type B consists of common pedicles with two major vascular branches to the adductor longus muscle. Type B is further subclassified into three subtypes: B1 (n = 19; 38%), consisting of a short common pedicle (mean length 12.6 mm); B2 (n = 5; 10%), with an ultrashort common pedicle (mean length 4.6 mm), utilization of which may prove difficult for microsurgical procedures; and B3 (n = 1; 2%), where there is a short common pedicle with a branch from the major common pedicle to the adductor brevis.

The difference between type A and type B is that the former has only one vascular branch to the adductor longus muscle and the latter has two. During clinical dissection for DFFMT, harvesting of type A variants should prove easier due to the longer pedicle. In type B, sufficient preservation of the two vascular branches during dissection and flap harvest is also important to ensure adequate blood supply to the adductor longus muscle.

Type C (n = 2; 4%) has a Y-shaped common pedicle. The two branches of the common pedicle divide equally and both provide blood to the muscle pair. If only one pedicle of this type is harvested during the free gracilis transfer, inadequate perfusion may result. The subclassifications of C1 and C2 are shown in Fig. 3. One thigh had a branch of the major pedicle to the adductor brevis (subtype C2). During the DFFMT microsurgical procedure, subtypes B3 and C2, which are characterized by an additional vascular branch to the adductor brevis, might not have an ischemic effect on the adductor longus and gracilis muscles when this additional adductor branch is ligated. Because the vascular supply to both adductor and gracilis is through the common major pedicle in types B3 and C2, the microsurgeon may ligate this branch before the flap elevation.

The distance from the profunda femoris artery to each muscle is also important in FFMT microsurgery, because the muscle and vascular anastomosis site should be inset less than this distance (Fig. 1, Table 1). The overall mean value of the distance from the gracilis to the profunda femoris artery is much greater than that from the adductor longus. This greater length greatly facilitates gracilis flap harvest compared with the adductor flap or a combination of the two.

Contrast Media Roentgenographic Study

Four specimens were investigated using an intra-arterial iohexol injection to confirm the characteristics of the common vascular pedicle. Further information was obtained with respect to the characteristics of the minor vascular pedicles. The minor pedicles originated from both the profunda and superficial femoral arteries. It was confirmed that the adductor longus muscle was a Mathes and Nahai type II muscle flap.[7] A Y-shaped common pedicle with two major branches to both the adductor longus and gracilis was evident in one type C specimen (Fig. 4). Our cadaveric study revealed that 4% of the

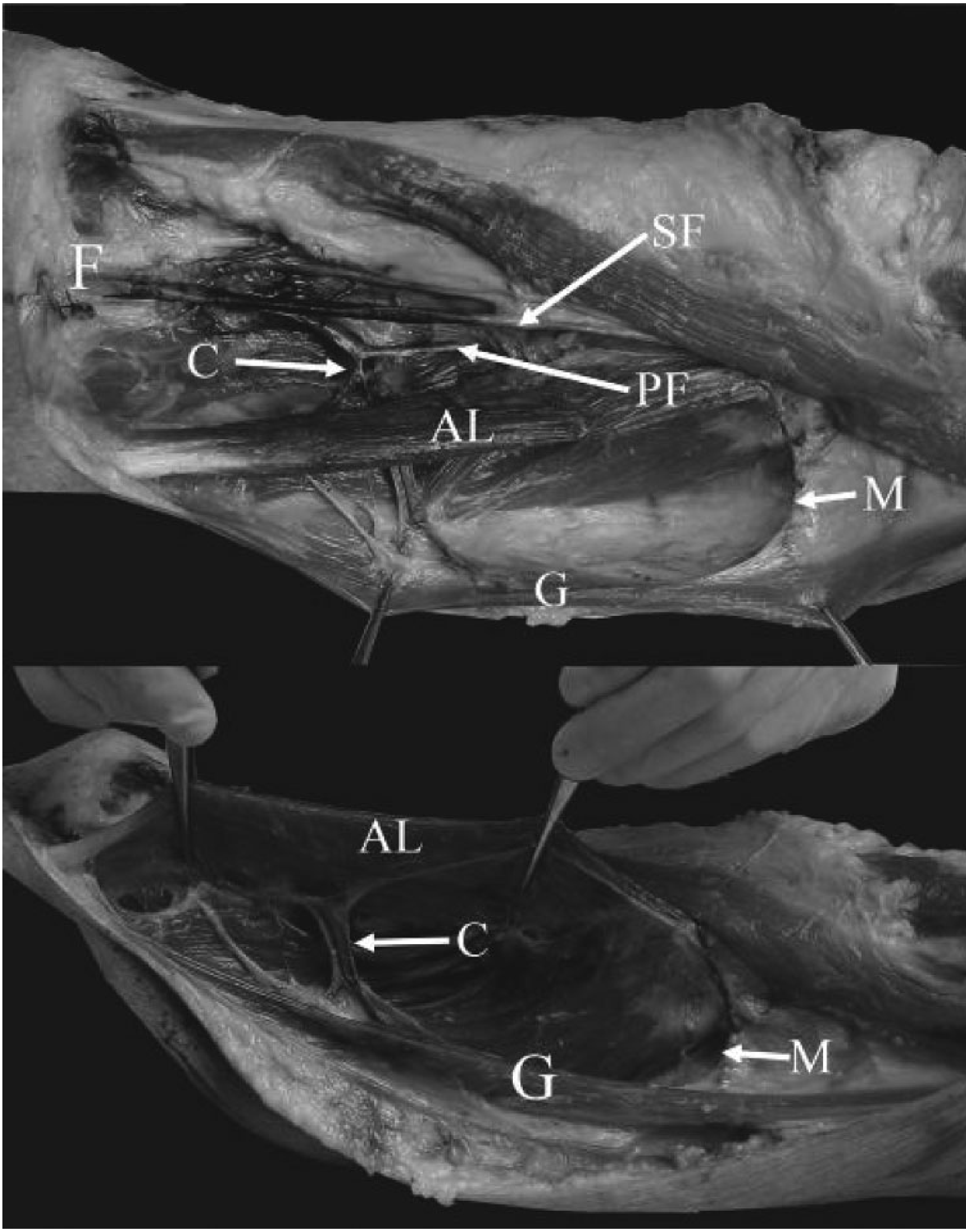

Figure 2 Upper picture is an anterior view of the cadaveric dissection after methylene blue injection into the femoral artery (F). The common vascular pedicle (C) of the adductor longus muscle (AL) and the gracilis (G) originate from the profunda femoris artery (PF). The minor pedicle (M) of the gracilis in this cadaver originate from the superficial femoral artery (SF). The lower picture is the medial view with adductor muscle elevation. The common vascular pedicle (C) travels underneath the adductor longus (AL), and its terminal branch supplies the gracilis muscle (G).

Table 1 Common Vascular Pedicle Types and Salient Parameters for Functioning Free Muscle Transplantation Microsurgery

		Common Pedicle		Distance from Profunda Femoris Artery to Muscle	
Type	**Thighs, n (%)**	**Diameter (mm)**	**Length (mm)**	**Adductor Longus**	**Gracilis**
A	23 (46%)	2.93 + 0.23	33.5 + 11.5	33.5 + 11.5	83.5 + 10.7
A1	21 (42%)	2.95 ± 0.22	34.8 ± 10.8	34.8 ± 10.8	82.9 ± 11.0
A2	1 (2%)	3	10	10	90
A3	1 (2%)	2.5	30	30	90
B	25 (50%)	3.01 ± 0.29	11.1 ± 5.9	27.1 ± 8.3	90.5 ± 12.3
B1	19 (38%)	2.95 ± 0.23	12.6 ± 8.3	26.6 ± 8.5	91.3 ± 11.5
B2	5 (10%)	3.20 ± 0.45	4.6 ± 0.9	28.6 ± 9.2	90.6 ± 15.7
B3	1 (2%)	3.3	15	30	75
C	2 (4%)	3.5 ± 0.7	12.5 ± 3.5	32.5 ± 3.5	72.5 ± 3.5
C1	1 (2%)	3	10	30	70
C2	1 (2%)	4	15	35	75
Overall	50 (100%)	3.00 ± 0.30	21.5 ± 14.2	30.3 ± 10.2	86.6 ± 12.1

gracilis muscles were type C, characterized by two major pedicles in a Y-shaped configuration (Fig. 3). This is important information for clinical microsurgery, even in ordinary single gracilis FFMT because the surgeon needs to realize that both major vascular pedicles in type C should be anastomosed to ensure adequate blood supply.

Muscle Characteristics and Nerve Supply

Both the gracilis and adductor longus are long strap muscles. The adductor longus is heavier than the gracilis muscle; however, the length relationship is the inverse. Information regarding muscle characteristics may lead to clinical selection for excursion and power judgment. Both muscles are supplied by anterior branches of the obturator nerve. The mean weight, length, and nerve length for both muscles are presented in Table 2.

DISCUSSION

DFFMT with single vascular anastomosis is an excellent choice of treatment for severely traumatic limbs. The number of recipient vessels available in mangled limbs is usually limited, and they are difficult to identify. Furthermore, the surgeon will spend less time on single anastomosis using DFFMT based on a single pedicle in comparison with double anastomosis. Our study revealed that DFFMT of the gracilis and adductor longus with single anastomosis is feasible because of the commonality of the vascular pedicle. Various origins of the main vascular pedicle to the adductus longus and gracilis muscles have been described: from the profunda femoral artery[6,7,12,14,15]; from the medial circumflex artery[5,16,17]; and from both arteries.[10,18] In our cadaveric dissection, however, the common vascular pedicle to both muscles originated from the profunda femoral artery. Regarding the clinical microsurgery application, subtype A1 (42%) may be the only option for most microsurgeons because of the ease of anastomosis afforded because of the long vascular pedicle. However, type A2 (2%) and type B1 (38%), which occurred with a short common pedicle in our sample, may also be suitable for DFFMT procedures in experienced hands. Type B2 (10%), with its ultrashort common pedicle (< 5 mm), may be very difficult for most microsurgeons. Subtype A3 (2%) has another major blood supply to the adductor longus outside the common pedicle, which arises from the medial circumflex femoral artery, and may cause inadequate perfusion to the adductor longus with a single anastomosis. Of the 50 studied specimens, 88% (subtypes A1, A2, B1, B3, C1, and C2) were potentially suitable for clinical DFFMT application. However, types B2 and A3 were not suitable for DFFMT harvesting.

Gracilis and adductor longus DFFMT with a single vascular anastomosis was first reported by Chuang et al,[13] who described two cases of severe forearm injury. In the first of these, the surgeons performed gracilis and adductor longus DFFMT in two stages, restoring the extensor muscle before the flexor. In the second case, the reconstruction was similar; however, a single gracilis muscle was used for transfer in each stage. No additional benefit was noted for incorporation of the adductor longus muscle in comparison with the application of the gracilis alone. One explanation for this is that the isolated function of the two muscles does not offer any benefits where there is no intrinsic hand function. Another possible factor is the technical difficulty associated with elevating and covering the bulky muscle with local forearm skin. However, gracilis and adductor longus DFFMTs may be more suitable for functional restoration of BPI where the DFFMT is placed at arm

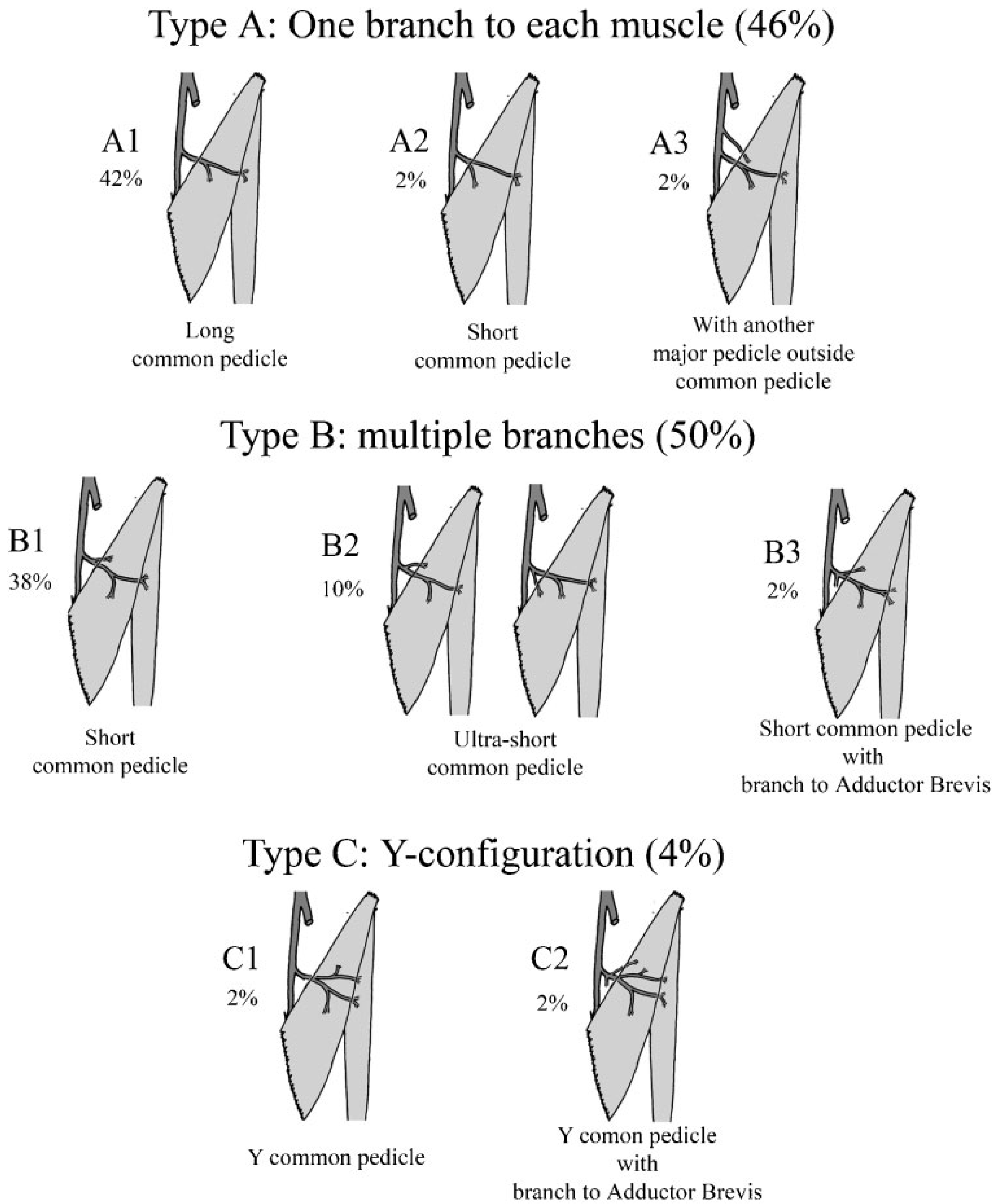

Figure 3 Types of common vascular pedicle of the adductor longus and gracilis. The lengths of the long, short, and ultrashort common pedicles is ≥ 20, 10 to 19, and < 10 mm, respectively.

level, rather than reconstructing the Volkmann contracture by placing the DFFMT at forearm level. This is because the elbow flexion provided by the adductor longus and finger flexion provided by the gracilis require less fine motor movement, but rather rely on gross motor power. Furthermore, more skin area is available for flap coverage at the arm level compared with the forearm level. The gracilis muscle is longer but lighter than the adductor longus. These parameters indicate that the gracilis can create more excursions but less power compared with the adductor longus. Therefore, it appears reasonable to suggest that for BPI reconstruction, the

Figure 4 Angiogram of a type C1 common pedicle. Its Y-shaped configuration with the two equally sized major branches mandates elevation of both branches during flap harvesting.

adductor longus is suitable for restoration of elbow flexion, which requires more power, and the gracilis is preferable for restoration of finger motion, where less power and better excursion are needed.

Table 2 Adductor Longus and Gracilis Muscle: Main Parameters

	Adductor Longus	Gracilis
Resting length (mm)	214.2 ± 17.4	325.4 ± 25.3
Weight (g)	59.2 ± 24.3	40.5 ± 16.3
Nerve length (mm)	89 ± 7.3	123 ± 14.6

In terms of the clinical concerns, the volume of muscles in DFFMT is greater compared with single gracilis transplantation. Modifications of skin elevation may solve the resultant problem of inadequate skin coverage in DFFMT. A larger and wider flap will incorporate more fascia overlying the superficial femoral artery, including the conjoint medial circumflex femoral perforator.[11,18] Careful positional checking of the skin perforator with a preoperative Doppler,[17] meticulous dissection,[2] or a design involving a more transverse orientation may decrease the incidence of skin-coverage problems.[15,16,19]

It appears reasonable to suggest that our sample of 50 cadaveric thighs was too small to yield a classification scheme applicable to every reconstruction case. There may be more relevant variants of the common pedicle, such as the case reported by Lasso et al, involving embedding in the adductor longus muscle.[9] To our knowledge, however, this is the first focused cadaveric study and the largest of its type. Although gracilis and adductor longus DFFMT is anatomically sound, further clinical experience is needed. Even though Chuang et al reported no donor site morbidity when harvesting DFFMT, further investigation of the risk associated with adductor longus and gracilis harvesting is needed.[13] Additionally, more evidence is required to justify clinical application of DFFMT for functional restoration in BPI reconstruction.

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REFERENCES

1. Baliarsing AS, Doi K, Hattori Y. Bilateral elbow flexion reconstruction with functioning free muscle transfer for obstetric brachial plexus palsy. J Hand Surg [Br] 2002;27: 484–486
2. Chuang DC, Mardini S, Lin SH, Chen HC. Free proximal gracilis muscle and its skin paddle compound flap transplantation for complex facial paralysis. Plast Reconstr Surg 2004;113:126–132
3. Doi K, Muramatsu K, Hattori Y, et al. Restoration of prehension with the double free muscle technique following complete avulsion of the brachial plexus. Indications and long-term results. J Bone Joint Surg Am 2000;82:652–666
4. Doi K, Sakai K, Ihara K, Abe Y, Kawai S, Kurafuji Y. Reinnervated free muscle transplantation for extremity reconstruction. Plast Reconstr Surg 1993;91:872–883
5. Giordano PA, Abbes M, Pequignot JP. Gracilis blood supply: anatomical and clinical re-evaluation. Br J Plast Surg 1990;43:266–272
6. Hattori Y, Doi K, Abe Y, Ikeda K, Dhawan V. Surgical approach to the vascular pedicle of the gracilis muscle flap. J Hand Surg [Am] 2002;27:534–536

7. Mathes SJ, Nahai F, Vasconez LO. Myocutaneous free-flap transfer: anatomical and experimental considerations. Plast Reconstr Surg 1978;62:162–166
8. Cavadas PC, Sanz-Gimenez-Rico JR, Landin L, Martinez-Soriano F. Segmental gracilis free flap based on secondary pedicles: anatomical study and clinical series. Plast Reconstr Surg 2004;114:684–691
9. Lasso JM, Rosado J, Perez Luengo E, Jimenez E, Perez Cano R. Gracilis flap: a variation of the main vascular pedicle. Plast Reconstr Surg 2004;114:597–598
10. Taylor GI, Cichowitz A, Ang SG, Seneviratne S, Ashton M. Comparative anatomical study of the gracilis and coracobrachialis muscles: implications for facial reanimation. Plast Reconstr Surg 2003;112:20–30
11. Whetzel TP, Lechtman AN. The gracilis myofasciocutaneous flap: vascular anatomy and clinical application. Plast Reconstr Surg 1997;99:1642–1653
12. Hasen KV, Gallegos ML, Dumanian GA. Extended approach to the vascular pedicle of the gracilis muscle flap: anatomical and clinical study. Plast Reconstr Surg 2003;111:2203–2208
13. Chuang DC, Strauch RJ, Wei FC. Technical considerations in two-stage functioning free muscle transplantation reconstruction of both flexor and extensor functions of the forearm. Microsurgery 1994;15:338–343
14. McCraw JB, Massey FM, Shanklin KD, Horton CE. Vaginal reconstruction with gracilis myocutaneous flaps. Plast Reconstr Surg 1976;58:176–183
15. Wechselberger G, Schoeller T. The transverse myocutaneous gracilis free flap: a valuable tissue source in autologous breast reconstruction. Plast Reconstr Surg 2004;114:69–73
16. Arnez ZM, Pogorelec D, Planinsek F, Ahcan U. Breast reconstruction by the free transverse gracilis (TUG) flap. Br J Plast Surg 2004;57:20–26
17. Kappler UA, Constantinescu MA, Buchler U, Vogelin E. Anatomy of the proximal cutaneous perforator vessels of the gracilis muscle. Br J Plast Surg 2005;58:445–448
18. Hallock GG. The conjoint medial circumflex femoral perforator and gracilis muscle free flap. Plast Reconstr Surg 2004;113:339–346
19. Yousif NJ, Matloub HS, Kolachalam R, Grunert BK, Sanger JR. The transverse gracilis musculocutaneous flap. Ann Plast Surg 1992;29:482–490