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ORIGINAL PAPER

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Anatomic analysis of the vascular network and vascular pedicle of the tensor fascia lata flap (angiographic and cadaver study)

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Abstract Knowing the vascular network and properties of the vascular pedicle is of crucial importance for elevation of the tensor fascia lata (TFL) transpositional or free flap; therefore, the origin of the lateral circumflex femoral artery (LCFA), its diameter at the site of origin, the length of the vascular pedicle, the number of lateral branches, the number of terminal branches and the anastomosis of the LCFA ascending branch are of utmost importance for successful elevation and clinical application of this flap. The study was conducted on clinical (100 angiographic images of the femoral artery) and autopsy (48 preparations) material. The first part of the study comprised analysis of the angiographic images that were used to obtain the information on LCFA. The diameter of LCFA at its origin was measured to be 0.44 cm, while it was 0.33 cm at the origin of ascending branch. The mean value of the diameter at the bifurcation of the terminal branches of ascending branch (inside tensor fascia lata muscle) was 0.24 cm. It has been established that the vascular pedicle of the tensor fascia lata flap (ascending branch of LCFA) is anastomosed with the superior gluteal artery in all cases. Measurement of the tensor fascia lata muscle revealed an average length of 15.91 cm, width of 3.55 cm and thickness of 1.98 cm. Injection of colour-ink into the ascending branch LCFA that enters directly into the TFL muscle was used to measure the extent of the TFL flap vascularization and on the average, the TFL flap was 20.32 cm long and 16.57 cm wide while the surface was 17.52 cm^3.

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Introduction

The tensor fascia lata flap may be a musculocutaneous, musculofascial or muscle flap. The tensor fasciae lata (TFL) flap vascularization originates from the lateral circumflex femoral artery (LCFA), i.e. from its ascending branch (ramus ascendens) that enters through the medial side of the TFL muscle as a single dominant branch. The LCFA blood vessel reaches the rectus femoris muscle and provides a branch for the lateral vastus muscle, while the branch supplying the tensor fascia lata muscle (TFLM) is divided into two or three wide terminal branches.

Materials and methods

Our study was conducted on clinical material i.e. 100 angiographic images of the femoral arteries of adult patients (both sexes, aged 25–68 years) and 48 preparations of LCFA on fresh cadavers (both sexes, aged 25–55 years). Two experimental groups were formed, clinical and autopsy. The angiographic images were used for analysis of LCFA and its ascending branch, that is the vascular pedicle of the TFL flap.

The material obtained from cadavers was subjected to dissection. After that, colour-ink was injected into the LCFA and the extent of vascularization was monitored, particularly of its ascending branch. Dissection was selected as the method most frequently used for the study of anatomical systems and structures, since it enables direct exposure and visual monitoring of anatomic and topographic relations of the LCFA, course of its trunk and both terminal and lateral branches.

The stained structures delineated the vascularised area of the TFL flap vascular pedicle. The vascularised territory was measured by transparent graph paper. The following statistical measures were used for the analysis: mean value (X), Student's *t*-test, correlation test, standard deviation (SD) and variation coefficient (VC).

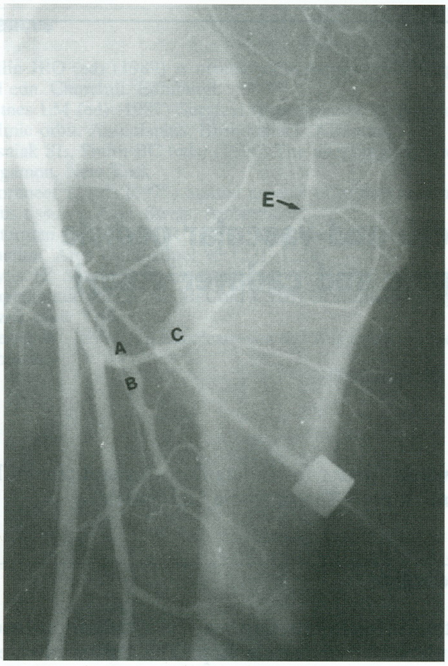

Fig. 1 Angiographic imaging of LCFA: *A* LCFA origin, *B* origin of descending branch, *C* origin of ascending branch, *E* origin of terminal branches of ascending branch

Results

The first part of the study comprised angiographic studies to obtain data on the LCFA. The results were classified according to the following features of observation (Fig. 1):

1. Origin of LCFA

Analysis of 100 angiographic images showed that the LCFA originated from the femoral artery in 26% of cases, proximal to the source of deep femoral artery, mean value X=2.68 cm (SD=1.62, VC=62.70%). In 74% of the cases the LCFA originated from the deep femoral artery, distal to its source, mean value X=2.03, (SD=1.16, VC=5.40%).

2. Diameter at the origin of LCFA and its ascending branch

Measurements at the origin of the LCFA revealed its diameter of X=0.44 cm (SD=0.09, VC=21.84%). Diameter at the origin of ascending branch was X=0.33 cm (SD=0.07, VC=21.75%) with a variation of max.=0.48 cm to min.=0.16 mm. The mean value of the diameter at the bifurcation of terminal branches of the ascending branch were X=0.24 cm (SD=0.03, VC=13.75%) this varied from max.=0.34 cm to min.=0.14 mm. (Table 1).

3. Length of the vascular pedicle of the LCFA and its ascending branch

Measurements of the ACFL vascular pedicle length revealed the mean value X=2.4 cm (SD=1.47, VC=61.04%). The mean value of the ascending branch was X=6.88 cm (SD=1.64, VC=23.83%) with a variation of max.=11.8 cm to min.=4.5 mm. (Table 2). The significant male to female difference in the length of the ascending branch trunk was confirmed by Student *t*-test ($t=2.02$, $p<0.05$). Similarly, male to female significant difference in the length of greater and lesser trochanter was also confirmed ($t=3.25$, $p<0.01$).

4. Number of lateral branches of the LCFA ascending branch (vascular pedicle of the TFL flap)

The ascending branch gave off four lateral branches on average, X=4 (SD=0.31, VC=30.85%) ranging from max.=12 to min.=0 of lateral branches. The ascending branch was particularly important for our studies since this is the vascular pedicle of the TFL flap, so it was there where we also counted the terminal branches situated directly in the tensor fascia lata muscle (Table 3). The number of terminal branches was three (SD=0.88, VC=31.09%) this varied from max.=5 to min.=1 of lateral branches. After that we counted lateral branches given off by each of the terminal branches of the ascending branch. The first terminal branch gave off approximately four lateral branches (SD=1.26, VC=35.49%), the second gave off three lateral branches (SD=1.45, VC=43.28%), the third gave off four lateral branches (SD=1.31, VC=38.30%), the fourth terminal gave off X=1 lateral branch

Table 1 Tabular representation of source diameters LCFA

	Diameter of LCFA at its source	Diameter at ascending ramus source	Diameter at descending ramus source	Diameter at transversal ramus source	Diameter at branching site of ascending ramus terminal branches
Total number of cases	100	99	91	33	99
Arithmetic mean	0.44 cm	0.33 cm	0.33 cm	0.25 cm	0.24 cm
Standard deviation	0.97	0.72	0.76	0.65	0.33
Coefficient of variation	21.84%	21.75%	22.55%	25.89%	13.75%

Table 2 Tabular representation of the vascular trunk length of LCFA and its branches

	CFL trunk length	Ascending ramus trunk length	Descending ramus trunk length	Transversal ramus trunk length	Distance between trochanter minor and trochanter major
Total number of cases	80	86	55	26	86
Arithmetic mean	24.08 mm	68.88 mm	107.46 mm	60.69 mm	94.18 mm
Standard deviation	14.70	16.42	39.37	24.46	10.15
Coefficient of variation	61.04	23.83	36.63	40.30	10.77
Correlation coefficient	$p>0.05$	$r=0.46$; $p\leq 0.05$	$p>0.05$	$p>0.05$	$r=0.46$; $p\leq 0.05$

Table 3 Tabular representation of terminal ascending ramus branches number as well as number of lateral ramuli of terminal branches

	Number of terminal ascending ramus branches	First terminal branch (no. of lateral branches)	Second terminal branch (no. of lateral branches)	Third terminal branch (no. of lateral branches)	Fourth terminal branch (no. of lateral branches)	Fifth terminal branch (no. of lateral branches)
Total number branches	99	88	888	52	17	2
Arithmetic mean	3	4	3	4	3	3
Standard deviation	0.88	1.26	1.45	1.31	1.04	1.00
Coefficient of variation	31.09%	35.49%	43.28%	38.30%	32.80%	33.33%

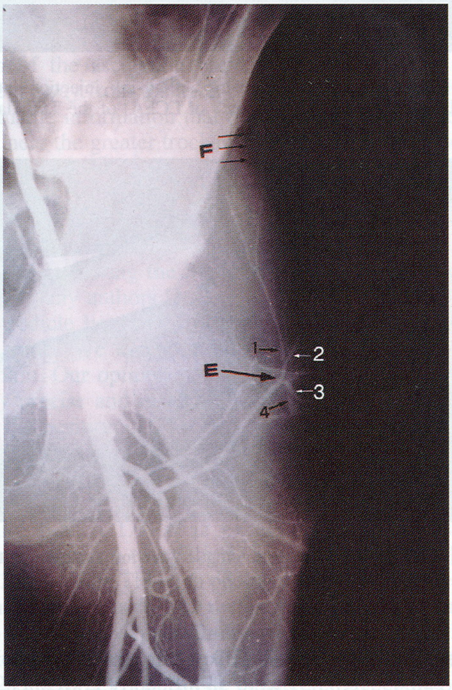

Fig. 2 Terminal branches of ascending branch LCFA are marked by numerals *1–4* (anastomoses with gluteal artery marked by *F*)

(SD=1.04, VC=32.80%) and the fifth also gave off one lateral branch (SD=1.00, VC=33.33%) (Fig. 2) (Table 4).

5. The number of anastomosis of the LCFA ascending branch

Analysis of angiographic images has revealed that the ascending branch anastomosis with the medial circumflex femoral medial artery in 80% of cases on average with three branches (SD=0.75, VC=43.35%), with perforating arteries in 5% of cases on average with two branches (SD=0.74, VC=35.71%), with the circumflex iliac superficial artery in 49% of cases on average with three branches (SD=1.75, VC=62.27%), and with the superior gluteal artery in 100% of cases on average with four branches (SD=1.64, VC=45.68%) (Fig. 3).

The second part of the study comprised autopsy material, and the results were classified according to the following features of observation:

1. Topography of the ascending branch LCFA trunk

(a) Anterior: (1) femoral nerve with its branches (overlying only 1/3 of medial trunk); (2) sartorius muscle; (3) rectus femoris muscle; (4) tensor fascia lata muscle. (b) Posterior: (1) ascending branch LCFV; (2) iliopsoas muscle; (3) vastus intermediate muscle; (4) lateral vastus muscle. (c) Medial: (1) bifurcation at the ascending and descending branches. (d) Lateral: (1) tensor fascia lata muscle.

2. Tensor fascia lata muscle (TFLM) proportions

Measurements of tensor fascia lata muscle revealed a length of X=15.91 cm (SD=3.03; VC=26.47%), and a

Table 4 Tabular representation of the average number of anastomoses and number of anastomosing branches of the ascendant ramus

Anastomoses of ascendant ramus with:	Medial circumflex femoral artery	Perforant artery	Circumflex iliac superficial artery	Superior gluteal artery
Average number of anastomoses in percent	80%	5%	49%	100%
Mean value of anastomosing branches	2	2	3	4
Standard deviation	0.75	0.74	1.75	1.64
Coefficient of variation	43.35%	35.71%	62.27%	45.68%

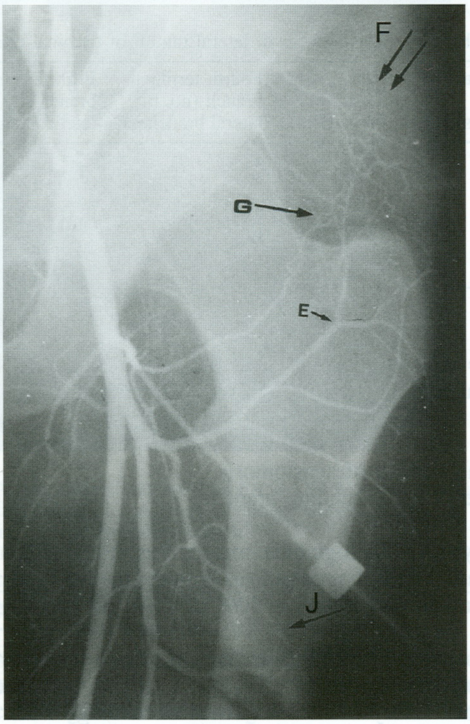

Fig. 3 A number of anastomoses with the ascending branch: *G* anastomoses with medial circumflex femoral artery, *J* anastomoses with perforating artery, *F* anastomoses with superior gluteal artery

width of X=3.55 cm (SD=1.59; VC=20.75 mm). The mean muscle thickness was X=19.88 mm (SD=0.98; VC=27.04%).

3. The area supplied by the original vascular pedicle

The injection of colour-ink into ascending branches of LCFA entering directly into TFL muscle was used to measure the extent of TFL flap vascularized, and on average, the TFL flap was 20.32 cm long (SD=1.57; VC=7.75%), 16.57 cm wide (SD=1.15; VC=6.98%), while the surface was 175.20 cm^3 (SD=9.09; VC=5.18). An average distance between anterior superior iliac spine and lateral epicondyle was X=49.5 cm (SD=2.3; VC= 4.63%) (Fig. 4).

A correlation test showed that the flap length and surface ratio (r=0.96; $p \leq 0.01$) as well as the distance between anterior superior iliac spine and lateral epicondyle (r=0.43; $p<0.05$) were significantly correlated. The flap width and surface (r=0.91; $p \leq 0.1$) ratio was also confirmed to be significantly correlated.

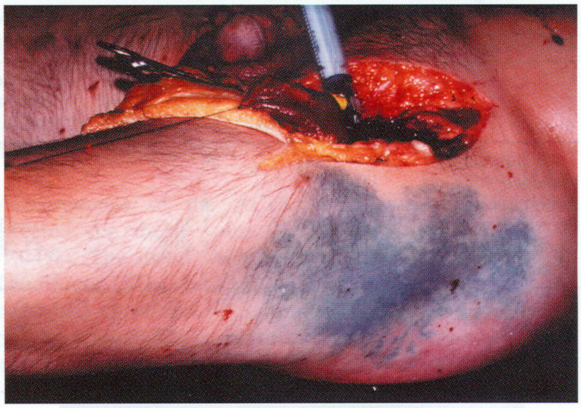

Fig. 4 Vascular territory following colour-ink injection into the vascular pedicle (ascending branch of LCFA) of the TFL flap

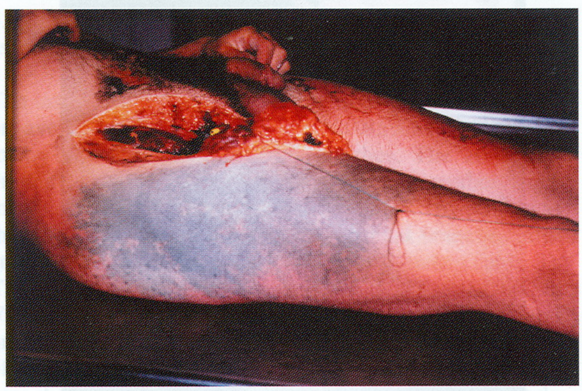

Fig. 5 Vascular territory following colour-ink injection into the whole trunk of the LCFA

The injection of gel ink into the whole LCFA (ascending branch and descending branch) trunk was used in two cases to measure the vascularied territory of stained skin, and on average, it was 31.0 cm long (SD=2.0; VC=6.45%), 22.25 cm wide (SD=1.75; VC=7.86) and the surface was 3220.75 cm^3 (SD=20.25; VC=6.31%) (Fig. 5).

4. Characteristics and the site of the vascular pedicle entry into tensor fascia lata muscle

Analysis of the site of the vascular pedicle entry showed that it entered directly into the middle of the muscle at the greater trochanter level. The vein always ran in front of the artery, and in 38 cases, the artery was accompanied by a single vein while in 10 cases the artery was accompanied by two veins.

5. Characteristics and relationship of the LCF artery and vein as well as their spatial orientation

In all cases, in the area where the LCFA branched into an ascending branch and a descending branch, the LCF vein joined the artery running below and behind it all the way up to 2 cm from TFL muscle and that was where it began running completely in front of the LCF artery.

Discussion

Analysis of the results obtained revealed that the bifurcation of the ascending branch terminal branches was 2.17 cm away from the apex of greater trochanter. Owing to valuable information that the ascending branch terminated near the greater trochanter in all cases, the vascular pedicle of TFL flap could be readily detected, since the greater trochanter can be palpated directly. Our knowledge was applied to TFL flap elevation on cadavers and appeared to be accurate in all cases.

While reviewing the literature related to TFL flap elevation many authors [1, 2, 3, 4, 5, 6] state that the vascular pedicle lies 8 to 10 cm from the anterior superior iliac spine. We consider this somewhat incorrect and uncertain. Our opinion is that the greater trochanter is a highly precise and reliable point of orientation to determine the position of TFL flap vascular pedicle.

The mean value of TFL flap vascular pedicle diameter at the entry into the muscle was 0.24 cm (max.=0.34 cm to min.=0.14 cm). This diameter indicates that the ascending branch LCFA is excellent for microvascular anastomosis when using the TFL unit as a free flap [2, 7, 8, 9, 10, 11]. The TFL flap pedicle is situated between the lateral vastus muscle and rectus femoris muscle, and in some cases may extend almost to the bifurcation, therefore, while elevating a free TFL flap an average diameter of 0.24 cm to 0.33 cm can be counted on depending upon the length of vascular pedicle.

Measurements of the vascular pedicle by angiographic imaging revealed its length to be 6.88 cm. However, dissection of material obtained from cadavers showed that such length cannot be relied upon due to the structures surrounding the pedicle causing a more difficult surgical approach. The femoral nerve is the structure that makes the obtaining of a longer vascular pedicle very difficult, since it lies directly on the artery anteriorly about 5 cm from the entry of the vascular pedicle into the TFL muscle. Sometimes, there are individual variations in the course of these nerve fibres. Nevertheless, thorough preparation of the vascular pedicle and deliberate elevation of rectus femoris muscle as well as detachment of the vascular pedicle from the lateral vastus muscle may result in the vascular pedicle being lengthened by about 2.5 cm to 3.5 cm, so that its length of 6.00 cm may be counted on (Fig. 6), although the ascending branch of LCFA cannot be taken into account as a whole due to the very difficult surgical approach. Femoral nerve branches should not be sacrificed to obtain a longer vascular pedicle; but, if this happens, their reconstruction is imperative.

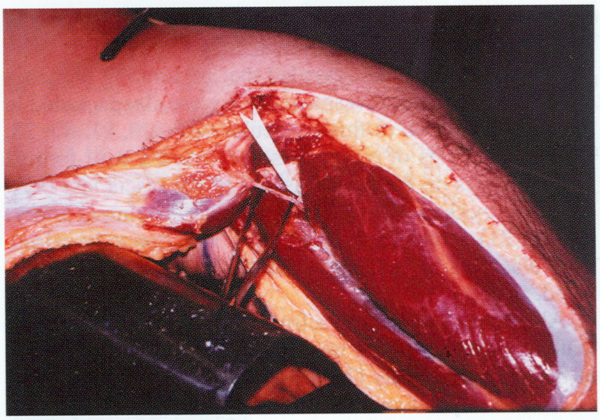

Fig. 6 The length of the vascular pedicle (it is evident that the TFL muscle is supplied only by the ascending branch of the LCFA, the only one useful for microvascular anastomosis)

Following the complete dissection and finding that only the ascending branch of the LCFA is the vascular pedicle of TFL flap [15], the injections of black gel ink into the ascending branch LCFA were used to stain the surface vascularized by this vascular pedicle. This surface was different from the territory raised during the transpositional flap elevation. The fact that the transpositional TFL flap surface was larger than that of the free flap was due to the vascularization of the TFL muscle being supplied both by the LCF artery and the superior gluteal artery [16, 17, 18]. The superior gluteal artery is an accessory vascular branch to the TFL muscle, but it is highly significant in elevation of the transpositional TFL flap because it enters the TFL muscle proximally and therefore is not compromised; conversely, in elevation of the free TFL flap, it is divided and ligated. Moreover, the transpositional flap carries lateral fascia lata having a remarkably developed fascial plexus [16, 19, 20, 21, 22, 23] which enables the elevation of a flap with a considerably larger surface than that of the TFL muscle [24]. The fascial plexus of fascia lata is very well developed and it is one of the most important factors for elevation (harvesting) of flaps in this region.

In cases when colour-ink was injected into the entire trunk of the LCF artery and that of the superior gluteal artery, a considerably larger vascular territory was outlined [25, 26, 27, 28, 29, 30, 31], which was significantly different from the vascular area obtained by injection of colour-ink into ascending branch LCFA only.

Dissection in layers revealed that perforating branches emerging from lateral vastus muscle were also included in the vascularization in this particular case [20, 21, 27, 28, 29, 30]. Analysis of our results confirmed a well-formed fascial plexus on the lateral aspect of the fascia lata (vascularized by the whole LCFA and superior gluteal artery) [19, 20, 21], which enabled a longer TFL flap to be raised. This was clearly evident when the fascia lata was elevated.

All attempts to transfer a free TFL flap, with its surface matching the size of the transpositional TFL flap, resulted in distal flap necrosis [32, 33, 34, 35, 36, 37, 38].

A free myocutaneous TFL flap was used by Hill, Nahai and Vasconez in 1978 [39], who reported that there were partial failures in the distal ends of the flaps. Hollis Caffe reported that in his series of 12 free TFL flaps distal necrosis developed in four of them following the transpositioned TFL flap technique. Another eight free flaps with no necrosis had considerably smaller surfaces [33]. Likewise, Haw-Yen Chiu reported distal necrosis of the TFL flap in his review on abdominal wall reconstruction [34]. In their review "Experiences with tensor fascia lata flap" discussing the complications of using the free TFL flap, Nahai and associates stated: "In three partial losses of several centimetres of distal ends of free flaps, all of them were long flaps" [6].

A free TFL flap is based strictly on the ascending branch of the LCFA, its area of vascularization delineated by earlier colour-ink injection demarcates the tissue that may be raised safely as a free TFL flap. The surface marked by colour-ink injection into an ascending branch is of utmost significance in elevation of the microvascular TFL flap. Raising a larger surface of a free TFL flap would result in partial flap necrosis [6, 33, 34, 36, 40]. Analysis of flap staining methods revealed that if perforating blood vessels were present, the whole flap was evenly stained [28, 22].

In the TFL flap elevation technique, the greater trochanter should be considered a point of orientation to determine the position of the TFL flap vascular pedicle. The fact that a pedicled TFL flap surface is larger than a free flap surface, has been explained by the fact that the TFL muscle has dual vascularization (supplied by LCFA and superior gluteal artery). The superior gluteal artery is an accessory vascular branch of TFL muscle, however, it is highly important in pedicled flap elevation, because it enters the TFL muscle proximally and is not compromised as compared to free TFL flap elevation where it is cut and ligated. Moreover, a pedicled flap includes the lateral fascia lata having well-formed fascial plexus this enables the elevation of a flap significantly larger than the TFL muscle surface.

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