The Superficial Femoral Artery Flap: A 3-Dimensional Anatomical Study

Le lambeau de l'artère fémorale superficielle : une étude anatomique tridimensionnelle

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Abstract

Background: The superficial femoral artery perforator (SFAP) flap offers advantages for pedicled transfer including consistent perforators and vascular territory, well-hidden donor site scar, and hairless flap skin. This article provides a historical overview of the SFAP flap and describes the vascular anatomy of the SFAP by 3-dimensional analysis and angiography. **Methods:** Ten fresh cadavers were injected using the lead oxide technique through the femoral artery. Spiral computed tomographic scanning and 3-dimensional evaluation were used to describe the SFAP number, diameter, length, type, and location. **Results:** A total of 288 perforators in 15 cadaver limbs were identified; 19 ± 8 perforators per thigh ≥ 0.5 mm in diameter, with an average diameter of 0.8 ± 0.3 mm and a range of 0.5 to 2.1 mm; the mean length of each perforator was 68 ± 31 mm; 45% were septocutaneous and 55% were musculocutaneous. The medial thigh region was divided into 6 areas (anterior and posterior halves, then the proximal third, middle third, and distal third of each). The majority of the perforators were located in the middle and distal thirds of the anteromedial thigh (33% each). **Conclusions:** Using 3-dimensional vascular anatomical analysis, the number, location, length, type, and diameter of the SFAP were documented. In the literature, relatively few reports of the use of the SFAP flap are available, however, this is a valid donor site with consistent cutaneous perforators suitable for harvest as a local or regional flap transfer. This is the first 3-dimensional vascular anatomical study to comprehensively document the vascular anatomy of the SFAP flap.

Résumé

Historique : Le lambeau des perforateurs de l'artère fémorale superficielle (PAFS) comporte des avantages lors d'un transfert de lambeau pédiculé, y compris un territoire perforateur et vasculaire uniforme, une cicatrice bien cachée au site du prélèvement et un lambeau glabre. Le présent article fournit un aperçu historique du lambeau PAFS et en décrit l'anatomie vasculaire par analyse et angiographie tridimensionnelles. **Méthodologie :** Les chercheurs ont fait une injection dans l'artère fémorale de dix cadavres frais à l'aide de la technique d'oxyde de plomb. Ils ont utilisé la tomographie spiralée et l'évaluation tridimensionnelle pour décrire le nombre, le diamètre, la longueur, le type et l'emplacement des PAFS. **Résultats :** Les chercheurs ont repéré 288 perforateurs dans les membres de 15 cadavres : 19 ± 8 perforateurs par cuisse, d'au moins 0,5 mm de diamètre, d'un diamètre moyen de $0,8 \pm 0,3$ mm et d'une plage de 0,5 mm à 2,1 mm. Chaque perforateur avait une longueur moyenne de 68 ± 31 mm, 45 % étaient septocutanés et 55 %, musculocutanés. Les chercheurs ont séparé la région médiale de la jambe en six sections (moitiés antérieure et postérieure, et tiers proximal, moyen et distal de chaque moitié). La majorité des perforateurs se trouvaient dans le tiers moyen ou distal de la cuisse antéromédiale (33 % chacun). **Conclusions :** À l'aide d'une analyse anatomique vasculaire tridimensionnelle, les chercheurs ont consigné le nombre, l'emplacement, la longueur, le type et le diamètre des PAFS. Relativement peu de publications traitent de l'utilisation du lambeau PAFS, mais c'est un site de prélèvement valable doté de perforateurs cutanés constants, qui convient pour exciser un lambeau en vue d'un transfert

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local ou régional. Il s'agit de la première étude anatomique vasculaire tridimensionnelle à détailler l'anatomie vasculaire du lambeau PAFS.

Keywords

microsurgery, superficial femoral artery perforator flap, superficial femoral artery, perforator flap, femoral artery, flap, 3-dimensional anatomy

Introduction

Perforator flaps have become increasingly popular in plastic and reconstructive surgery due to a wide variety of flap options, improved anatomical understanding, and preservation of muscle function. Perforator flap use has become more widespread in reconstructive surgery due to minimum donor site morbidity and improved functional and aesthetic results compared to many standard flap options.¹ With the development of microvascular surgery, and the advancement of anatomical techniques that allow for the further understanding of the anatomic vasculature of the superficial femoral artery perforators (SFAPs), its utilization as a donor site likely appears to advance.

Musculocutaneous perforators from the medial circumflex femoral artery supply the proximal third of the anteromedial thigh and the superficial femoral artery (SFA) supplies the distal two thirds of the medial thigh as well as portions of the proximal third of the anteromedial thigh.² The distal two-thirds of the medial thigh are supplied by both the medial branch of the lateral circumflex femoral artery and the SFA. The anteromedial thigh has not been studied extensively as a donor site for pedicled transfer and has therefore not been used frequently in surgical reconstruction. However, there has not been much in the literature that describes the anteromedial thigh, supplied by the SFA, as a potential donor site in reconstructive surgeries, nor has there been a 3-dimensional (3D) detailed study of the SFA vasculature.

In 1983, Baek³ described a fasciocutaneous medial thigh flap based on SFA perforators; and in 1984, Song et al⁴ described the first SFAP flap. However, due to the anatomical irregularity and the small size of the pedicled perforators, the flaps described by Baek and Song have not been commonly used. With the introduction of "supermicrosurgery," which allows the anastomosis of smaller caliber vessels, perforator-to-perforator flap transfer has become more accepted.⁵ In 1984, Cormack and Lamberty classified the SFAP flap as a fasciocutaneous one and identified a dominant septocutaneous perforator supplying it.⁶ Based on their classification, the SFAP flap is further described as being of moderate size and fairly consistent because it has a single fasciocutaneous perforator and may be isolated as an island flap or used as a free flap.⁶ Also in 1984, Song et al described the first anteromedial thigh flap that could be supplied by a musculocutaneous perforator that arises from the SFA at the junction of the middle and lower third of the thigh.⁴

In 2014, Mojallal et al further described this perforator of the SFAP flap.⁷ Their study showed a pedicle is located at an

average distance of 22.79 ± 1.55 cm below the pubic tubercle with a mean diameter of 2.82 ± 0.69 mm and mean length of 4.79 ± 0.52 cm. In 1996, Koshima et al published that the anteromedial thigh flap was supplied by either septocutaneous or musculocutaneous perforators of the SFA.⁸ They also noted that the SFA gives off a muscular branch that supplies the sartorius and gracilis muscles and often has large cutaneous arteries.⁸ These studies utilized perforators from the SFA that share territories with other source vessels. However, our study demonstrates that there are many reliable perforators located in the distal two-thirds of the anteromedial thigh that are supplied by the SFA. Our study was done to further understand and describe the SFAP by analyzing the number, type, length, and diameter in each thigh using 3D vascular anatomical analysis. The purpose of our study was to provide a historical overview of the SFAP flap and analyze the SFAP.

Materials and Methods

Experimental Protocol

Ten fresh human cadavers were obtained through the Dalhousie University Donor Programme. The health sciences human ethics board of the institution approved the project. Cadavers exclusion criteria included scars over area of interest, prostheses, degradation, pressure sores, or extensive atrophy. All the cadavers underwent 3D computerized tomography (CT) prior to injection. Following the initial CT scan, a lead oxide and gelatin preparation was injected systemically through the femoral vessels using the technique described by Salmon,⁹ refined by Rees and Taylor,¹⁰ and modified by Tang and Bergeron et al.^{11,12} After injection, the cadaver was cooled to 4°C for 24 hours to allow the injectate to solidify and then another CT scan was performed. The pre-injection scan aids in the reconstruction of soft tissue and the post-injection scan provides accurate and complete vascular data of the small perforating vessels. The scanning process produces slices at 0.6 mm intervals, generating hundreds of individual images of each specimen in three different planes (transverse, sagittal, and coronal).

The 3-Dimensional Reconstruction

The combination of angiography and Materialise's Interactive Medical Image Control System (MIMICS; Materialise, Leuven, Belgium) was used to create a 3D model of the anatomical basis of the cadaver. The pre- and post-injection CT scans were uploaded onto MIMICS, which interactively reads and analyzes CT and magnetic resonance imaging data in the Digital

Imaging and Communications in Medicine format, and collates the images.¹³ This allows MIMICS software to reconstruct 3D images of the arterial models. The MIMICS program also allows segmentation and editing tools to manipulate the data and to select for the specific tissue type that is desired (bone, soft tissue, skin, and vessels).

A manipulation of the threshold unit was made to clearly display the origin of the source vessel of each perforator. A high-threshold unit of 2700 to 3071 HU was first used to clearly reconstruct the main source arteries. The threshold unit was then lowered to 1062 to 2976 to obtain images of the smaller arteries and other matching vessels. Since the lower threshold correlates with bony structures, further editing and manipulation to remove unnecessary structures was done to obtain the images required to fully examine the anatomical vasculature. These thresholds were chosen based on standard techniques of the MIMICS. Using both a coarse and a fine editing technique, the editing process involved highlighting desired structures and removing unrelated structures via thresholding, highlighting, and deleting. The edited images were then generated into 3D models and further editing was applied via surface smoothing and further modifications. At all times, during the 3D editing process, the accuracy of the anatomical renderings was preserved.

Data Collection and Analysis

After the 3D models were rendered, measurement tools available within MIMICS were applied to collect and analyze the desired information. The data that were collected included the location at which the perforator artery emerges through the fascia (via a coordinate system), the overall length of each perforator (in mm), the diameter of each perforator (in mm), the type (septocutaneous/musculocutaneous), and the number of SFA perforators in designated regions of the thigh. Arteries with a diameter of <0.5 mm were excluded from our study, since 0.5 mm has been the clinically accepted limit for surgical anastomosis.¹⁴

The location of the perforator is described using a coordinate system: X-axis is the line between the right anterior superior iliac spine (ASIS) and the left ASIS; Y-axis is the line from the ASIS to the superior middle patella (Figure 1). To compare measurements between thighs and the variability among cadaver specimens, all measured absolute distances were expressed as a percentage, with the right ASIS as the origin for the right leg and the left ASIS as the origin for the left leg.

The length of the perforator was measured from the source vessel to the point where the perforator emerges from the superficial fascia using the “measure distance” tool on MIMICS. The diameter of the perforator was measured at the point where the perforator emerges from the superficial fascia by using the “measure diameter” tool on MIMICS. Once measured, the perforators detected below a 400 HU threshold were multiplied by a correction factor of 0.4 since a threshold range below 400 HU may cause more pixels to be added to the reconstruction, resulting in larger than actual diameters.¹⁵ The

Figure 1. Landmarks employed for the localization of perforating arteries and schematic of the 5 zones utilized to correlate with anatomical areas. All measurements are converted into percentage position data for standardization among patients. ASIS indicates anterior superior iliac spine.

Figure 2. Location of the superficial femoral artery perforators as measured by percentage position.

correction factor of 0.4 is the standard used on MIMICS images. The type of each perforator was identified using the axial view of the CT scan in MIMICS and manipulating the threshold of the vessel and the soft tissue to extrapolate whether a perforator was musculocutaneous or septocutaneous.

For the purposes of our study, the thigh was divided into a medial half and a lateral half by a line that bisects the thigh from the ASIS to the superior middle patella (y-axis). The anterior half and posterior half were divided by a line that starts at the greater trochanter of the femur and ends at the lateral epicondyle of the tibia. The medial thigh was also divided into thirds, a proximal third, a middle third, and a distal third on the

Figure 3. Percentage of perforators by area.

Table 1. Average Measurements of the Superficial Femoral Artery Perforators.^a

Superficial Femoral Artery	Number of Perforators	Overall Percentage	Mean Length (SD), mm	Mean Length (SD), mm
Anterior				
Proximal third	3	1	39 (13)	0.7 (0.1)
Middle third	94	33	60 (31)	0.8 (0.3)
Distal third	96	33	69 (33)	0.8 (0.3)
Posterior				
Proximal third	0	0	0	0
Middle third	13	5	61 (35)	0.9 (0.2)
Distal third	82	28	78 (27)	0.8 (0.3)
Overall	288	100	68 (31)	.8 (0.3)

^aThe table shows the number, overall percentage, mean diameter, and length per area.

basis of the y-axis (Figure 2). Using these regions, the locations of the perforators were designated into a specific area. Fifteen thighs (10 male and 5 female) from 10 cadavers (5 male and 5 female) were used in this study. Five thighs were excluded due to unsuitable technical maneuvers (primarily overinjection) or unobserved internal cadaveric conditions, making analysis of those particular thighs impossible.

Results

A total of 288 perforators were identified and measured using 3D analysis from 15 thighs. There was a mean of 19 ± 8 perforators per thigh with diameters ≥ 0.5 mm, with an average diameter of 0.8 ± 0.3 mm and a range of 0.5 to 2.1 mm diameter; mean length was 68 ± 31 mm from source vessel to the point of emergence through the fascia. Of the 288 perforators analyzed, 45% were septocutaneous perforators and 55% were musculocutaneous perforators. The percentage position of the perforators to the x-axis and y-axis are summarized in Figure 3, and the documented average measurements of the perforators are summarized in Table 1.

For further analysis, the perforators of the SFA were further subdivided into 6 areas of the medial thigh. The thighs were divided into thirds on the basis of the y-axis (ASIS to superior middle patella) and divided into an anterior half and posterior half using the line between the greater trochanter of the femur and lateral epicondyle of the tibia. The majority of

Figure 4. Type of perforators of medial thigh by region.

Figure 5. Average length of perforators by area.

the perforating arteries are located in the anterior middle and distal thirds of the medial thigh, each having 33% of the perforators (Figure 4). The longest perforators were found in the posterior distal third of the medial thigh (Figure 5). The anterior half of the medial thigh had mostly musculocutaneous perforators, whereas the posterior half of the medial thigh had mostly septocutaneous perforators (Figure 4).

Discussion

Our study demonstrated that the majority of the SFAP are located in the anterior middle and distal thirds of the medial thigh (33% each) and are mostly musculocutaneous (55%). The SFAPs supply a large part of the anteromedial thigh with an average of 19 ± 8 perforators per thigh and an average diameter of 0.8 ± 0.3 mm. This means that there are a large number of viable perforators from the SFA that can be used to supply a flap. With the average length of the perforators being 68 ± 31 mm, the perforators are short but plentiful. The posterior distal third of the medial thigh has the longest perforators with an average of 78 ± 27 mm and they are mostly septocutaneous (45%).

The SFAPs supply a large part of the anteromedial thigh, and the flap itself has been underutilized in favour of the anterolateral thigh (ALT) flap. The vascular anatomy and supply of the ALT flap have been described in the past¹⁶⁻²⁰ and has therefore been the popular choice of skin flaps for defect reconstruction by surgeons.¹⁷ However, the SFAP flap shares many things in common with the ALT flap, with the addition of significant advantages. Since the SFAP flap lies in the anteromedial region of the thigh, the skin is more pliable, less hair dense, has less scar visibility, and less contour deformity than the ALT flap.²¹ As well, the anteromedial region carries both the greater saphenous vein and the anterior cutaneous branch of the femoral nerve, and therefore both can be used in the flap for venous drainage²² and neurosensory supply.⁸ Due to the position of the flap, it can be joined to other flaps in the anterior or medial thigh so that wide defects can be closed in one maneuver. In contrast to fasciocutaneous flaps from other regions, it provides a large skin territory.²¹ There are several pedicle perforators coming from the SFA, making it possible to create reliable circulation in the elevated flap by use of anastomoses. Another advantage is that in case of any problem with the perforating vasculature of the SFAP flap, an ALT flap can be used as a backup without any additional incisions, or even a gracilis muscle flap can be harvested through the same incision as a last resort.²¹

The SFAP flap can be used to cover wounds of up to 15 cm wide and 20 cm long or larger if the donor site is grafted. The patient is placed supine and the leg is prepped entirely. The thigh is abducted and the knee is flexed at 45°. A line is drawn between the pubic tubercle and the middle of the medial femoral condyle.⁷ The line is then marked 23 cm from the pubic tubercle.⁷ Doppler-assisted localization of the vascular pedicle should then follow.

The benefits of the SFAP flap are extensive; however, there are a few drawbacks. The anteromedial thigh flap is thicker than the ALT thigh flap and in some situations, the fatty tissue of the area is welcomed, but in other situations the bulkiness of the flap may require thinning. Therefore, if a thin flap is necessary for certain reconstruction, the effectiveness of this flap is decreased. As well, the SFA has small, short pedicles usually limited to 7 cm in length, making it unsuitable for some microsurgical applications.²³ The SFAP flap is also limited by the donor site skin grafting if the flap width exceeds 7 to 8 cm, giving a non-aesthetic result, especially for women.²³ With this in mind, it is easy to see that reconstruction done with the SFAP flap can be used for an extensively wide range of defects but with certain limitations.

Conclusion

In the literature, there have been relatively few reports of the use of the SFAP flap, specifically those that supply the anteromedial thigh. However, this is a valid donor site with consistent cutaneous perforators suitable for harvest as a local or regional flap transfer. This is the first 3D vascular anatomical

study to comprehensively document the vascular anatomy of the SFAP flap.

Declaration of Conflicting Interests

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