A Description of the Vascular Anatomy of the Tensor Fascia Lata Perforator Flap Using Computed Tomography Angiography

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Background: The perforator anatomy of the tensor fascia lata (TFL) flap has been studied using cadaver dissection; however, exact descriptions of location, size, and origin of perforator vessels using preoperative imaging modalities remain limited. The aims of this study are to describe TFL perforator anatomy using high-resolution computed tomography angiography (CTA) and to correlate these findings with landmarks for the anterolateral thigh flap to facilitate flap planning.
Methods: We identified 33 patients who previously underwent bilateral lower extremity CTAs for preoperative planning of free-flap reconstruction. The images were retrospectively reviewed, and the TFL perforator number, size, type, location, and overall pedicle origin and length were recorded.
Results: Thirty-three patients and 59 thighs were included in the study. There was an average of 2.5 perforators per TFL. All perforators arose from the ascending branch of the lateral circumflex femoral artery with an average pedicle length of 8.3 cm (range, 6.0–11.2 cm). Sixty-six percent of perforators were septocutaneous and 34% were musculocutaneous. The average perforator size as measured on CTA was 3 mm. The average perforator location was 10.1 cm inferior and 8.5 cm lateral to the line drawn from the anterior superior iliac spine to the superolateral patella.
Conclusions: To our knowledge, this is the first study to characterize the vascular anatomy of the TFL perforator flap using high-resolution CTA and correlate this with well-established landmarks used in the planning for other thigh-based flaps. We believe data will facilitate flap design and dissection; potentially shortening operating room times, limiting exploratory incisions used to confirm the presence of thigh based perforators, and improving overall outcomes for patients.

Key Words: tensor fascia lata (TFL) flap, anterolateral thigh (ALT) flap, computed tomography angiography (CTA), perforator flap, free tissue transfer, microvascular surgery

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Wangensteen first described the utilization of the tensor fascial lata (TFL) for reconstructive purposes in 1934.[1] Since that time, our understanding of the TFL flap has grown significantly, and it has been used in a wide variety of reconstructive surgeries.[2] Its widespread adoption as a free flap, however, has been limited due the disadvantages related to sacrificing the TFL TFL muscle; including flap bulkiness, depressed donor site, and destabilization of the knee.[3] The TFL perforator flap, which avoids these downsides, was described by Koshima et al[4] in 2001. Although the TFL perforator flap has not achieved the same workhorse status as the anterolateral thigh (ALT) flap, it serves as a viable alternative when ALT perforator anatomy is unfavorable, which has been documented to occur between 0.7% and 11.2% of the time.[5] Several published reports describe converting to a TFL flap if the dissection of an ALT flap reveals absent perforators.[6–8] Although this is a viable approach, it invariably results in a flap that has an eccentrically located perforator and additional skin incisions as the perforators for an ALT flap are typically distal and medial in relation to TFL perforators. When large flaps are needed, such flap designs can result in necrosis at the most distally perfused areas. Computed tomography angiography (CTA) can facilitate surgical planning and operative efficiency by allowing the surgeon to visualize perforator anatomy and select the appropriate perforator flap (right vs left, ALT vs TFL vs AMT) before surgical incision.[9–13]

Given its increasing adoption in preoperative flap planning, our goal was to characterize the perforator anatomy of the TFL flap using CTA. Specifically, we sought to compare the number of TFL and ALT perforators, document the location of TFL perforators in reference to the familiar ALT flap planning landmarks of the anterior superior iliac spine (ASIS) and superolateral patella, and measure the overall TFL pedicle size and length. We report our clinical experience with a patient in whom the TFL perforator flap was selected over an ALT flap based on preoperative imaging characteristics.

METHODS

This study was conducted at Virginia Commonwealth University Medical Center, and institutional review board approval was obtained. Adult patients who had CTAs performed in the work-up before free-flap reconstruction from January 2013 to December of 2016 were included. Each thigh was assessed individually, and thighs were excluded from evaluation if measurements were obscured by soft tissue stranding or orthopedic hardware, or if anatomic landmarks (ASIS and superolateral patella) were not included in the sagittal reconstructions.

The scans were performed using SOMATOM Definition Flash 128-slice CT scanners (Siemens AG, Munich, Germany). A bolus of nonionic radiopaque contrast media (Isovue; Bracco Diagnostics Inc, Monroe Township, NJ) was given according to weight-based dosing protocols. Two-millimeter axial cuts were obtained from just below the diaphragm to the toes, with coronal and sagittal reconstructions performed to fully assess perforator location and make measurements of vertical distance from the ASIS (y-coordinate) and horizontal distance from the line connecting the ASIS to the superior lateral aspect of the patella (x-coordinate; Fig. 1).

The CTA images were retrospectively reviewed and measurements regarding TFL perforator number, size, type (septocutaneous vs musculocutaneous), location (in reference to the line drawn from the ASIS to the superolateral patella), and overall pedicle origin and length were recorded. The number of ALT perforators was also recorded for comparison. Tensor fascia lata perforators were defined as blood vessels highlighted by contrast that were found to pierce the TFL fascia and supply the subcutaneous tissue in the region of the TFL muscle and the surrounding fascia lata. Anterolateral thigh perforators were identified in the subcutaneous tissue overlying the rectus femoris and vastus lateralis, and by tracing down from the descending branch of the lateral circumflex femoral artery. Descriptive statistics were calculated, with 2-tailed Student t tests used to compare means when appropriate. Illustrative figures were created.

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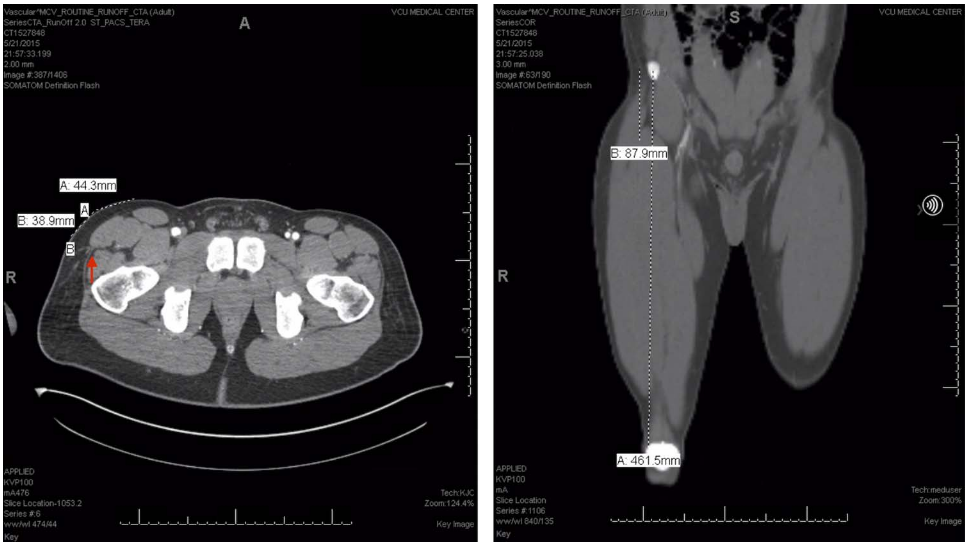

FIGURE 1. Measurement of the perforator's vertical distance below the ASIS (*y*-coordinate) and its horizontal distance lateral to the ASIS–lateral patella line (*x*-coordinate). The arrow marks a septocutaneous TFL perforator. To measure the vertical distance, the axial and coronal images are placed side-by-side and localizer mode is used to transpose the level of the axial slice onto the coronal cut with the ASIS–superolateral patella line marked. To measure horizontal distance, localizer mode is used to transpose the location of the ASIS–superolateral patella line onto the axial slice. Then several lines are measured out laterally from the ASIS–superolateral patella line to the perforator to account for the curvature of the thigh.

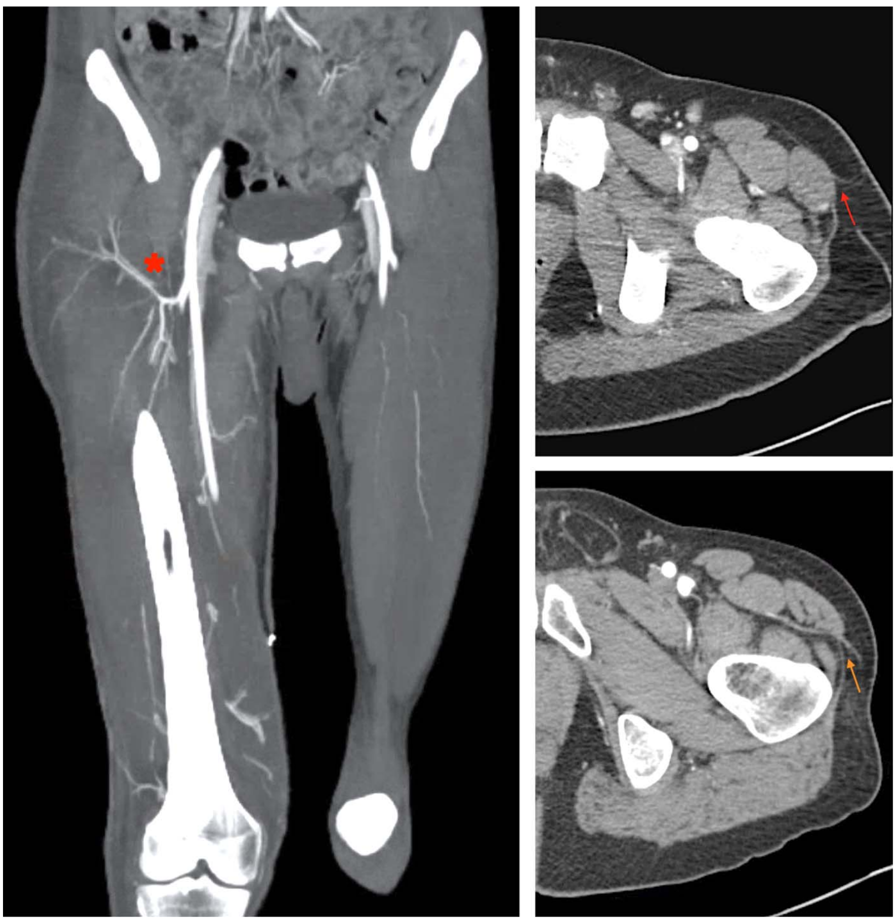

FIGURE 2. Branching pattern of ascending branch of the lateral circumflex artery (left image). In the upper right image, the arrow marks a TFL musculocutaneous perforator. In the lower right image, the arrow marks a TFL septocutaneous perforator.

RESULTS

A total of 33 patients underwent preoperative CTA for flap planning purposes. On analysis, 7 thighs were excluded due to inadequate imaging, leaving 59 thighs for evaluation. Examples of coronal and axial cuts indicating TFL perforators are in Figure 2.

The average number of TFL perforators was 2.5, and this ranged from 1 to 5. The average number of ALT perforators was 2 (range, 1–5), and this was found to be significantly lower than the number of TFL perforators ($P = 0.01$). Seventeen (29%) of 59 thighs had only 1 ALT perforator, whereas 11 (18%) of 59 thighs had only 1 TFL perforator. The average TFL pedicle length was 8.3 cm, with a minimum of 6 cm and a maximum of 11 cm. Average TFL perforator size was 3 mm, with septocutaneous perforators being larger than musculocutaneous perforators on average (2.9 mm vs 2.4 mm, $P < 0.001$; Table 1).

Most perforators (141/149; 95%) were able to be traced back to the ascending branch of the lateral circumflex femoral artery; the remaining 8 were clearly found to pierce the TFL fascia as a perforator, but their entire course was unable to be traced back to a source vessel. Sixty-six percent of perforators were septocutaneous, and the average number of septocutaneous perforators per leg was significantly greater than the average number of musculocutaneous perforators per leg (1.7 vs 0.9, $P < 0.001$). Despite having on average a greater number of septocutaneous perforators, 3 (5%) of 59 thighs did not have a septocutaneous perforator present at all, whereas all thighs studied had at least 1 musculocutaneous perforator (Table 1).

Measurements of the perforator location relative to flap planning landmarks found that they were an average of 10.1 cm below the ASIS and 8.5 cm lateral to the line connecting the ASIS to the superolateral patella. Septocutaneous perforators were on average 9.7 cm inferior and 9.1 cm lateral to that line, whereas musculocutaneous perforators were on average 10.9 cm inferior and 7.5 cm lateral. Coordinates of perforator location were superimposed onto a schematic of the thigh, illustrating the clustering of perforators over the lateral superior thigh (Fig. 3).

TABLE 1. TFL Perforator Measurements

TFL perforator no.			
Total no.			149
Average per thigh			2.5
Range			1–5
Septocutaneous			98 (66%), 1.7 per thigh*
Musculocutaneous			51 (34%), 0.9 per thigh*
Absence of SC perforator			3 (5%)
TFL perforator size, mm			
Overall			3.0
Septocutaneous			2.9*
Musculocutaneous			2.4*
	Overall	**SC**	**MC**
TFL perforator location, cm			
Distance below ASIS	10.1	9.7	10.9
Distance lateral to ASIS-patella line	8.5	9.1	7.5
TFL pedicle length, cm			
Average			8.3
Minimum			6
Maximum			11.2

MC, musculocutaneous; SC, septocutaneous.

Clinical Experience

The patient was a 24-year-old man with a left grade IIIB tibia-fibula fracture after a motorcycle accident. He underwent external fixator placement and was then transferred to our hospital for management of the soft tissue defect. He underwent serial debridement and wound vacuum placement until a stable tissue bed was achieved. The final defect measured 18 × 9 cm with exposed tibia, stripped periosteum, and exposed tibialis anterior muscle/tendon. A preoperative CTA was performed to evaluate perforator anatomy from potential flap donor sites. The perforators to bilateral ALT flap territories were found to be diminutive, whereas the right TFL flap had 2 dominant perforators. Both the ALT and TFL perforators and flap territories were marked out, and the TFL perforator flap was ultimately chosen (Fig. 4). Given the size of the flap required and the difference in skin markings, it was quite useful to know that the ALT flap had unfavorable anatomy before incision. The patient experienced uneventful postoperative flap healing.

DISCUSSION

The TFL perforator flap is a versatile flap with many possible uses. Despite not having the same "workhorse" status as the ALT flap, it is important to understand the vascular anatomy of the TFL flap, because situations may arise when the perforator anatomy of the ALT is unfavorable and one may use the TFL flap as a preferred alternative from a similar regional donor site.[6–8] Since the TFL perforator flap was first described in 2001 by Koshima and others,[4] there have been relatively few reports describing its vascular anatomy and characteristics.[3,14] Therefore, the purpose of this study is to describe the vascular anatomy of the TFL perforator flap through the use of preoperative CT angiography.

Among lower extremity perforator flaps, the ALT perforator flap has been extensively studied due to its numerous indications in reconstructive flap surgery. Although it is a robust and dependable flap, several reports have demonstrated the significant variability of the descending branch of the lateral circumflex femoral artery and its perforators to the ALT flap.[5,15–18] In a report of 74 ALT flap transfers, 4 patients (5.4%) had a complete absence of perforators.[15] In another case series of 32 patients, 5 patients (16%) were found not to have adequate perforators for flap harvest, and required exploration and harvest from different flap territories.[18] A systematic review of ALT vascular anatomy in 2012 found 10 prior studies that documented the rate of ALT perforator absence, and this ranged from 0.7% to 11.2% of cases.[5] Another comprehensive analysis of 110 ALT flaps demonstrated 16 different vascular branching patterns, with a single distal or "C" perforator present in 9.1% of the patients.[17] If a large flap is required and a single "C" perforator supplies the ALT flap territory, the authors recommended seeking an alternative flap due to difficulties anticipated with designing a large skin paddle around such a distal perforator.[17] It is clear that there are situations in which perforators are completely absent from the typical ALT flap territory, as well as situations in which the perforator origin and distribution may be inadequate for the requirements of the reconstruction. The combined incidence of these scenarios is unknown, but estimates based on the summarized prior research may place this between 5% and 15%.

In contrast to the ALT flap, which has been found to have a wide spectrum of perforator size and location, the TFL flap generally is thought to have more consistent and reliable perforator anatomy.[3,5,8,14] A cadaver study performed by Hubmer and others[3] in 2009 showed that all perforators originate from the ascending branch of lateral circumflex artery with an average pedicle length of 8.1 cm. In a clinical case series by Contedini and others[8] from 2013, they report an average pedicle length of 8 cm from TFL flap surgeries performed in 11 patients. Similar to prior analyses, our results show that all perforators whose path was able to be traced on CTA were found to arise from the ascending branch of lateral circumflex artery, with an average pedicle

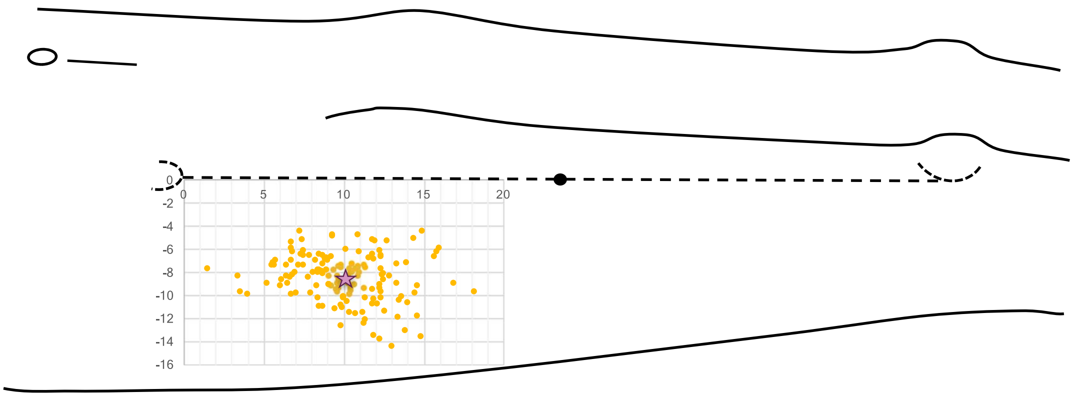

FIGURE 3. Mapping of TFL perforators in relation to the line connecting the ASIS to the lateral aspect of the patella. The black dot marks the midpoint of that line, and the star marks the average location of TFL perforators, at 10.1 cm inferior to the ASIS and 8.5 cm lateral to the ASIS–patella line.

length of 8.3 cm. The average vertical distance from the ASIS was also similar between studies, at 10.9 cm from Hubmer et al[3] in 2009, 11 cm from Hubmer et al in 2011,[14] and 10.1 cm in our study.

Prior TFL anatomical studies have established that septocutaneous perforators are consistently larger in diameter than musculocutaneous perforators. This correlation was also reflected on our findings; however, the specific average size showed some variability. We found that septocutaneous and musculocutaneous perforators averaged 2.9 and 2.4 mm in diameter, respectively, whereas Hubmer and others[3] documented 1.5 and 0.9 mm from their cadaver dissections. We suspect that the slightly larger sizes measured in our study may be due to imaging artifact, as the "blush" from intra-arterial contrast and the resolution available seems to create a representation of the vessel that may be slightly larger than in situ. Although it is unlikely that the absolute size findings from our study are accurate, it is interesting that the relative size differences between septocutaneous and musculocutaneous perforators discovered in prior anatomic studies are reflected in CTA imaging.

Another difference in our findings compared with prior studies is with the relative proportion of septocutaneous and musculocutaneous perforators. We found that 66% of perforators are septocutaneous, whereas the cadaveric study by Hubmer et al[3] documented that 44% of perforators were septocutaneous. This difference may be due to inherent limitations of imaging studies of anatomy. Because musculocutaneous perforators may be more difficult to visualize on CT imaging, it is possible that there were simply fewer musculocutaneous perforators discovered using CTA. Also, in some instances when the perforator runs deep to a thin layer of muscle, it may appear to be septocutaneous on CTA but be identified as musculocutaneous during anatomic dissection. On the other hand, the overall average number of perforators was similar between studies and the differences may simply reflect more variability in TFL perforator anatomy than previously

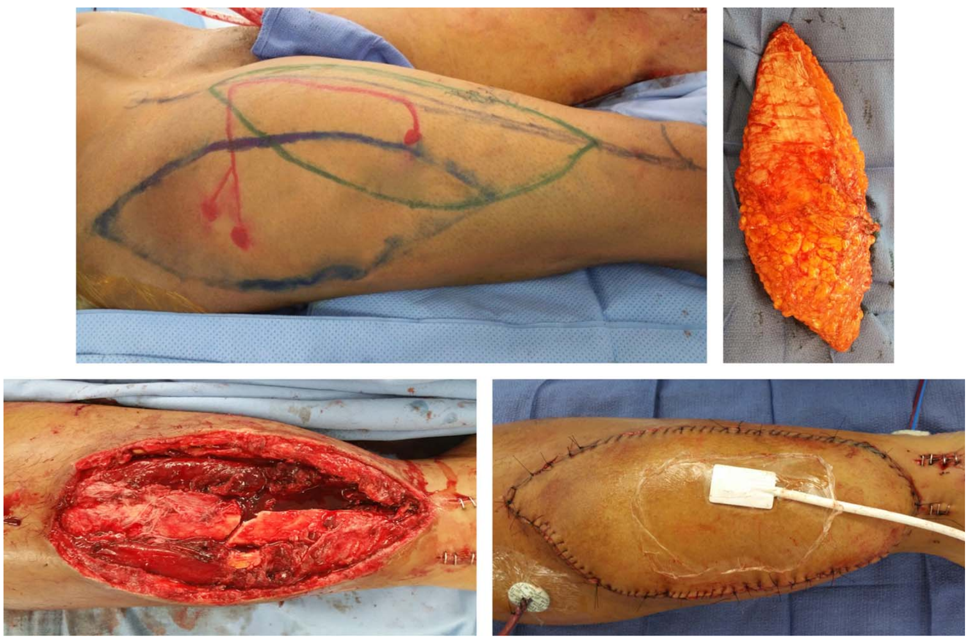

FIGURE 4. Clinical example of the use of a TFL perforator flap as an alternative to the ALT flap in lower extremity reconstruction. ALT (more medial and inferior markings) and TFL (more superior and lateral markings) flap territories drawn out around perforators discovered on preoperative CTA (upper left). TFL perforator flap was chosen due to the single diminutive ALT perforator (upper right). Left lower-extremity grade IIIB open-fracture defect (lower left). TFL perforator flap after inset (lower right).

appreciated. To adequately investigate this further, there is a need for larger sample sizes and correlation with intraoperative findings in future more comprehensive studies.

Hubmer et al[3] also found that at least one septocutaneous perforator was present in all of the cadaver thighs that were dissected, but the absence of musculocutaneous perforators in 4 (8%) of 45 specimens. Hubmer and others have touted the anatomic consistency and reliability of the TFL perforator flap,[3,6,8,14] and indeed, we found that the overall perforator density of the TFL flap was significantly higher than the ALT flap. However, in contrast to the data in the study by Hubmer et al, additional results from our CTA study found that at least one TFL septocutaneous perforator was present in only 56 (95%) of 59 thighs and that TFL musculocutaneous perforators were present in the CTAs of all thighs studied. It is important to note our contrasting findings and how they may affect surgical planning and decision making. If our results are taken together with prior research, they suggest a previously unappreciated anatomic variability of the TFL perforator flap and emphasize the need for careful preoperative planning before flap choice and dissection. Although a full review of the use of CTA in flap planning is beyond the scope of this article, it is being increasingly adopted as the preferred method to preoperatively assess variations in perforator anatomy. Several studies suggest that the potential benefits of using CTA include reliable flap design, faster operative times, improved success rates, and decreased hospital costs.[9–13] We additionally propose that CTA for preoperative flap planning may be useful to evaluate ALT and TFL flap perforator anatomy, identify situations in which perforator origin, location, and distribution of the preferred flap may be inadequate for the planned reconstruction, and thereby guide the selection of alternative and more ideal perforator flaps.

This study was limited by its retrospective nature with a relatively small sample size and the inability to correlate imaging findings with intraoperative measurements. Computed tomographic imaging is inherently inadequate in its ability to fully account for 3-dimensional vessel path and surface contour, and this may have affected the accuracy of some of our measurements. Future directions may include prospective studies with preoperative imaging data correlated with intraoperative findings and postoperative outcomes.

CONCLUSIONS

Over the past century, understanding of flap design has evolved from axially based flaps reliant on a dominant-named vessel to custom flaps designed around perforating vessels. The development of perforator flaps created a revolution in microsurgery, as new tools were now available to select ideal donor tissue, minimize donor-site morbidity, and achieve a functional and esthetic reconstruction.[19] Despite these advances, anatomic variability remains the inherent difficulty with perforator flaps. Preoperative CTA may be useful in preoperative flap planning, and we believe that this study provides valuable information about TFL perforator anatomy as evaluated by CTA, highlights the differences in location between TFL and ALT perforator flap territories, and demonstrates how to reliably design a TFL perforator flap with reference to standard landmarks.

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