

Use of the Vertical Profunda Artery Perforator Flap to Capture the Dominant Perforator: A Cadaver Dissection and Imaging Study

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Abstract

Introduction While the originally described transverse profunda artery perforator (tPAP) flap is designed to capture the first profunda perforator, our group hypothesized the dominant perforator may not always be captured in this configuration. This study maps the location of dominant profunda perforators using imaging and cadaveric dissections to determine the probability of capturing dominant perforators with the transverse flap design versus the vertical PAP (vPAP) variant.

Methods Fifty preoperative magnetic resonance angiogram or computed tomographic angiogram scans (100 total extremities) were examined from autologous breast reconstruction patients between 2015 and 2019. Profunda perforator characteristics that were examined included the distance from the pubic tubercle to the infragluteal fold (IGF), the distance of the perforators from the IGF, distance posterior to the gracilis, the diameter of the perforator at fascial exit, and total number of perforators present. Profunda perforator dissection was performed in 18 cadaveric extremities. Analysis included mean distance from pubic tubercle, distance posterior to the gracilis, diameter at fascial exit, and total number of perforators.

Results In imaging analysis, the mean distance from the IGF to the fascial exit of all dominant perforators was 7.04 cm. The mean diameter of the dominant perforator at the fascial exit was 2.61 mm. Twenty-six thighs (26%) demonstrated dominant perforators that exited the fascia greater than 8 cm below the IGF. In cadaver dissections, the mean distance from the pubic tubercle to the fascial exit of all the dominant perforators was 10.17 cm. Nine cadaver specimens (50%) demonstrated perforators that exited the fascia greater than 8 cm below the estimated IGF.

Conclusion The dominant perforator can often be missed in the traditional tPAP design. The vPAP incorporates multiple perforators with a long pedicle, excellent vessel diameter, and favorable donor-site.

Keywords

- microsurgery
- perforator flap
- profunda artery perforator flap

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With continuing advancements in microsurgery and flap design, plastic surgery has seen an evolution of autologous breast reconstruction to utilize donor tissues from multiple different regions of the body. Use of the lower abdomen has long been considered the first choice for donor site but is not always available. Prior abdominal surgery, unfavorable body habitus, or unfavorable perforator anatomy are among the reasons to seek donor sites outside of the territory of the traditional deep inferior epigastric perforator (DIEP) or superficial inferior epigastric artery (SIEA) flap for autologous breast reconstruction.^{1–3}

Use of posteromedial thigh tissue has become an important secondary option for autologous breast reconstruction and may be ideal for patients who harbor excess subcutaneous fat in these areas. The profunda artery perforator (PAP) flap evolved from descriptions of the transverse upper gracilis (TUG) flap, which uses tissue based on the medial circumflex femoral artery but requires muscle sacrifice.^{1,2,4} Originally described by Agrigiani et al in 2001, it was later applied to breast reconstruction in 2010.¹

The profunda femoris is the first deep branch off the common femoral artery and arises at the level of the ischial tuberosity. The vessel courses posterior to the adductor longus muscle and gives off three branches. The medial branch supplies the perforators of interest, which form the anatomic vascular basis of the PAP flap. The perforator anatomy of the PAP flap has been described in previous cadaveric and radiologic studies.^{5–9} Haddock et al reported finding the perforators in relatively consistent locations medially in the vicinity of the adductor magnus and laterally in the vicinity of the biceps femoris and vastus lateralis.⁶ Saad et al described the average distance of the target perforator for the transverse PAP (tPAP) pedicle as 3.5 cm inferior to the gluteal fold on dissection and 4.4 cm on computed tomography angiograms (CTA),⁵ and the perforator has been shown to extend beyond the previously accepted 7-cm width of the flap.⁴

For autologous breast reconstruction, the originally described tPAP flap is most commonly designed with the superior border of the flap just inferior to the gluteal fold and the inferior border 7 to 8 cm below the superior border of the flap. The medial and lateral borders of the elliptical design typically do not extend beyond the visible lateral and medial thigh.^{10,11} The tPAP is designed to capture the first profunda perforator, which lies in the above-described anatomic location; however, our group has found that the first profunda perforator is not always dominant. Additionally, our experience has been that there is a significant incidence of wound healing complications associated with the often tight closure and awkward location of the transverse donor site. Thus, our flap designs have evolved to include vertical, oblique, and fleur-de-lis variations in an attempt to both increase the probability of capturing the dominant vascular pedicle, and also to reduce tissue tension with closure and mitigate donor site complications.^{10,12–14} This study was designed to map the location of dominant profunda perforators using imaging (CTA and MRA) and cadaveric dissections to determine the probability of capturing

dominant perforators with the transverse flap design versus the vertical PAP (vPAP) variant, which we propose may increase the rate at which the dominant perforator is captured for this flap.

Methods

Imaging Analysis

Following Institutional Review Board approval at the respective participating institutions, radiographic studies were retrospectively reviewed and analyzed as the basis of our imaging data. Fifty preoperative magnetic resonance angiogram (MRA) or CTA scans (100 total extremities) were examined from autologous breast reconstruction patients between January 2015 and December 2019. For the patients included in our radiographic analysis, CTA or MRA studies were used depending on the surgeon's preference of imaging technique. At our institutions, the standard preoperative imaging protocols for evaluating the PAP flap vascular anatomy begin at the pelvic inlet and stop 10 cm proximal to the knee. Patients who did not have extremity imaging ordered as part of their workup were excluded. Measurements were recorded regardless of the reconstructive procedure that was ultimately performed. Profunda perforator characteristics that were examined included the distance from the pubic tubercle to the infragluteal fold (IGF), the distance of the perforators from the IGF, distance posterior to the gracilis, the diameter of the perforator at fascial exit, and the total number of perforators present (►Fig. 1). These measurements were collected for all perforators noted to be >2 cm inferior to the gluteal fold, to account for the fact that perforators within the first 2 cm are not typically captured with any flap design. The perforator with the largest diameter at fascial exit was designated as the dominant perforator.

Cadaver Studies

Cadaver dissections (►Fig. 2) were also performed to record the anatomic location of the profunda perforators. Profunda perforator dissection was performed in 18 cadaveric extremities for correlation with our radiographic findings (►Fig. 3). Due to the condition of the cadavers, the IGF was distorted; and so, the pubic tubercle was used as the reference point for perforator dissections. Analysis included mean distance from pubic tubercle, distance posterior to the gracilis, diameter at fascial exit, and total number of perforators. The perforator with the largest diameter at fascial exit was designated as the dominant perforator. Dissections and measurements were undertaken by three surgical staff using a standardized technique and overseen by the lead surgeon (JZ).

Results

Imaging Analysis

The median age of the patients included in this study was 53 years (mean: 51.8; range: 28–74) and the average body mass index was 27.5 (range: 19–36). Thirty-nine patients (78%) were evaluated by CTA and 11 patients (22%) were evaluated by MRA. The average distance from the pubic

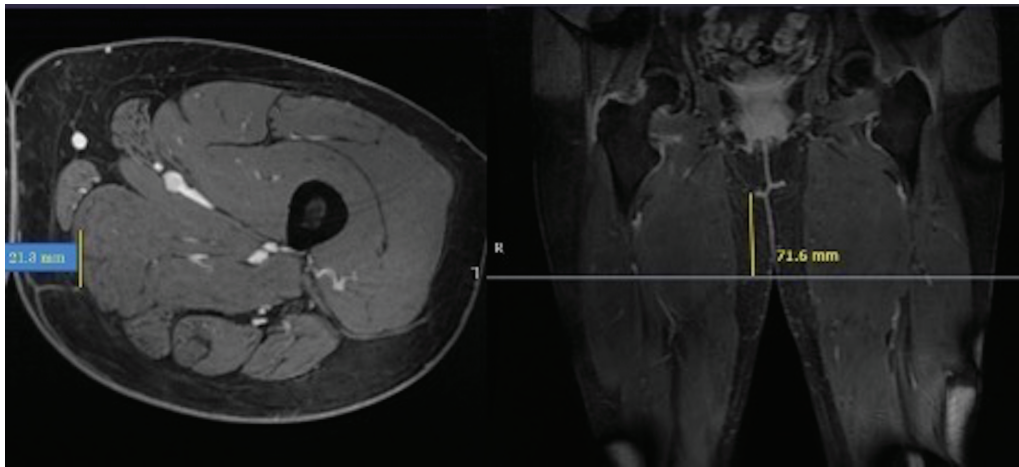


Fig. 1 (A) Displays distance from posterior border of gracilis to perforator at fascial exit. (B) Illustrates distance from infragluteal fold (arrow) to perforator at the fascial exit. Place an arrow pointing to the gluteal fold on B.

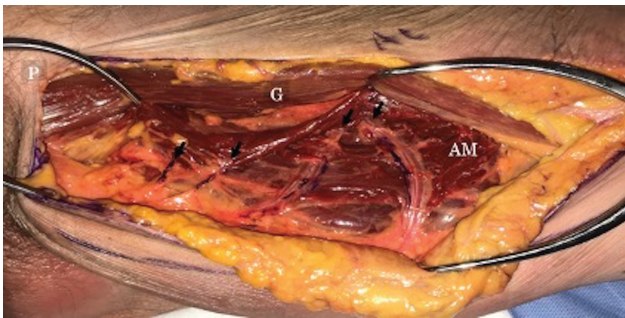


Fig. 2 Four cadaveric profunda perforators (black arrows) exiting from the adductor magnus (AM), posterior to the posterior border of the gracilis (G) muscle and inferior to the pubic tubercle (P).

tubercle to the IGF was 3.76 cm (range: 2.81–4.96 cm). The average number of perforators per thigh was 3.6 (range: 3–6). The mean distance from the IGF to the fascial exit of each of the perforators (designated 1 through 6, 1 being closest to the gluteal fold and 6 being furthest inferior to the fold) was 3.8 cm ($n=100$), 6.6 cm ($n=100$), 9.5 cm ($n=95$), 10.6 cm ($n=43$), 13.5 cm ($n=14$), and 11.6 cm ($n=2$), respectively (► **Fig. 4**). The mean distance from the IGF to the fascial exit of all perforators was 7.16 cm (range: 2.20–19.20 cm). In contrast, the mean distance from the IGF to the fascial exit of all dominant perforators was 7.04 cm (range: 3–17.03 cm). There was no statistical difference in the number of perforators, the distance of each perforator from the IGF to the fascial exit, or the diameter of perforators at fascial exit based on laterality.

The mean distances from the posterior border of the gracilis muscle to each of the perforators at fascial exit were 2.49 cm ($n=100$), 2.23 cm ($n=100$), 1.75 cm ($n=95$), 1.33 cm ($n=43$), 0.93 cm ($n=14$), and 0.35 cm ($n=2$), respectively. Meanwhile, the mean distance from the posterior border of the gracilis to the dominant perforator was 1.98 cm (► **Fig. 5**). Mean diameter of each perforator 1 through 6 at the fascial exit were 2.21 mm ($n=100$), 2.20 mm ($n=100$), 2.20 mm ($n=95$), 2.34 mm ($n=43$), 2.32 mm ($n=14$), and 2.5 mm ($n=2$), respectively. The mean diameter of the

dominant perforator at the fascial exit was 2.61 mm (range: 1.5–3.6 mm).

Further analysis of the perforator dominance above and below 8 cm inferior to the gluteal fold was performed, this designation was chosen as 8 cm would typically be the most inferior border of tPAP flap design. There was no statistical difference between the average diameter of perforators exiting within 8 cm from the IGF and the perforators exiting distal to 8 cm. However, 26 thighs (26%) demonstrated dominant perforators that exited the fascia greater than 8 cm below the IGF, and 15 thighs (15%) displayed codominance, defined as more than one perforator of the same diameter.

Cadaver Studies

In cadaver dissections, the perforators were measured from the pubic tubercle because of distortion in the cadaveric IGF. The mean and median distances between the pubic symphysis and the IGF were calculated in our imaging analysis to account for the difference in reference points. The mean and median distances were 3.76 and 3.72 cm, respectively. The mean number of perforators per thigh was 2.5 (range: 2–4). The mean distance from the pubic tubercle to the fascial exit of each perforator designated as perforators 1 through 4 (1 being most proximal to the pubic tubercle and 4 being most distal to the pubic tubercle) was 7.3 cm ($n=18$), 11.1 cm ($n=18$), 13.4 cm ($n=7$), and 14.7 cm ($n=3$), respectively. The mean distance from the pubic tubercle to the fascial exit of all perforators was 10.15 cm (range: 3.50–15.0 cm). In contrast, the mean distance from the pubic tubercle to the fascial exit of all the dominant perforators was 10.17 cm (range: 3–17.03 cm) (► **Fig. 6**).

After subtracting the mean distance from the pubic tubercle to the IGF (3.72 cm), the mean distance from the estimated IGF to the fascial exit of each perforator designated as perforators 1 through 4 (1 being most proximal to the pubic tubercle and 4 being most distal to the pubic tubercle) was 3.61 cm ($n=18$), 7.36 cm ($n=18$), 9.66 cm ($n=7$), and 10.97 cm ($n=3$), respectively. The mean distance from the

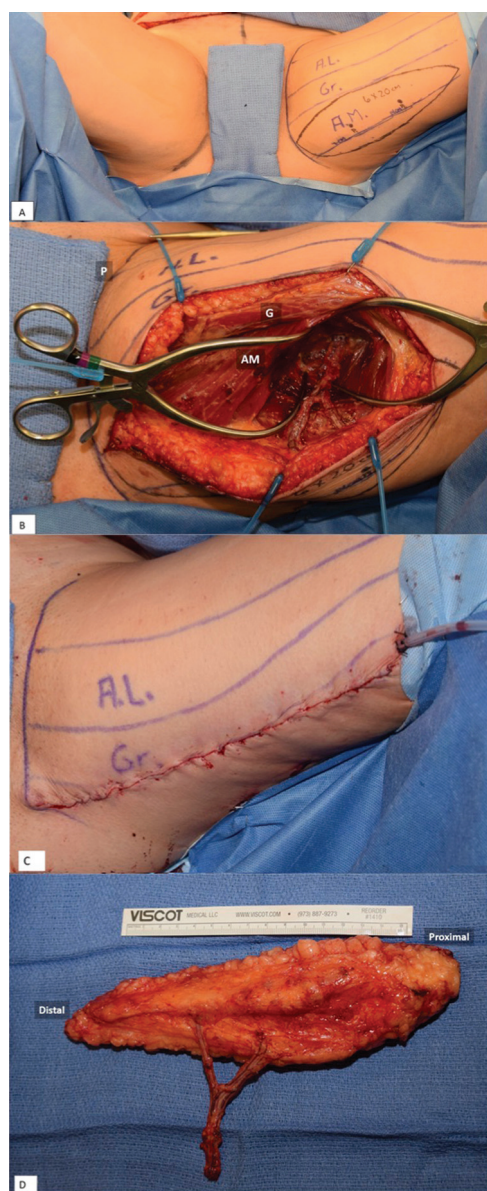


Fig. 3 Vertical profunda artery perforator flap design. (A) The pubic tubercle (P), adductor longus (AL), and gracilis (G) muscle borders are marked. (B) Incision is made along the posterior border of gracilis (G) and carried down to the deep fascia (A). The gracilis muscle is elevated and adductor magnus (AM) identified. Dissection is performed in the subfascial plane over adductor magnus and perforating vessels identified. Intramuscular dissection is performed back to the take-off of the perforator from the profunda femoris (B). The thigh is closed in layers over a closed suction drain (C). (D) Harvested flap.

pubic tubercle to the fascial exit of all perforators was 6.46 cm (range: 1–16.3 cm). In contrast, the mean distance from the pubic tubercle to the fascial exit of all the dominant perforators was 7.02 cm (range: 3–17.03 cm) (►Fig. 7).

The mean distance from the fascial exit of perforators 1 through 4 to the posterior gracilis was 1.96 cm ($n=18$), 1.51 cm ($n=18$), 1.10 cm ($n=7$), and 0.50 cm ($n=3$), respectively. Meanwhile, the mean distance from the posterior border of the gracilis to the dominant perforator at the fascial exit was 1.26 cm (►Fig. 8).

Finally, mean diameters of perforators 1 through 4 at the fascial exit were 2.5 mm ($n=18$), 2.6 mm ($n=18$), 2.5 mm ($n=7$), and 2.5 mm ($n=3$), respectively. The mean diameter of the dominant perforator at the fascial exit was 2.5 mm (range: 1.5–3.0 mm). There was no statistical difference between the diameter of perforators exiting within 8 cm from the pubic tubercle and the perforators exiting distal to 8 cm. After correcting for the distance between the IGF and pubic tubercle, 9 cadaver specimens (50%) demonstrated perforators that exited the fascia greater than 8 cm below the estimated IGF.

Discussion

The PAP flap, initially described for breast reconstruction by Allen et al in 2012, is a versatile, reliable, and anatomically robust flap.^{1,5,15} Since then, many studies have shown multiple benefits of the PAP flap, including consistent perforator location, wide area of perfusion, reasonable volume, long pedicle, and favorable donor site morbidity, which can be seen in ►Fig. 9.^{1,4–6,8,14,16} For the purposes of breast reconstruction, a transverse and crescentic flap is harvested from the posterior–medial thigh to form the traditional tPAP flap. While the use of the tPAP has become quite popular, discussion of the vPAP flap has been limited in the literature.

Our study assessed the PAP anatomy using two different methods of evaluation, radiographic imaging and cadaver dissection. On imaging, the mean distance of all profunda perforators from the IGF was 7.16 cm. An anatomic study of the posterior thigh blood supply by DeLong et al similarly demonstrated the average perforator distance at 6.2 cm below the IGF. However, the most distal perforator seen was 10 cm from the IGF that may have skewed their data.⁷ Similar to our findings, cadaveric perfusion studies of 29 posterior thigh flaps demonstrated hotspots for dominant perforator location with 5 to 10 cm of the IGF.¹⁰ Satake et al and Karakawa et al also demonstrated similar results of the distance of the perforators from the groin crease and size of perforators.^{9,17}

Our findings demonstrate the mean dominant profunda perforator location is 7.04 cm distal to the IGF. With traditional tPAP flap design, this would result in an eccentrically located perforator since the inferior border of the tPAP flap is generally 6 to 8 cm inferior to the gluteal fold.^{10,11,17} Satake et al had similar findings regarding the mean distance of musculocutaneous perforators of the adductor magnus muscle from the proximal thigh crease was 7.49 cm, which further supports the perforators eccentricity in their flap design.¹⁷ Additionally, our findings on imaging showed that 26% of dominant perforators exited the fascia greater than 8 cm below the IGF, suggesting that the ideal perforator may not be captured in the transverse design a quarter of the time. In our cadaver studies, the mean perforator distances were similar to the findings described by Largo et al. We found the average distance of the dominant perforator from the pubic tubercle to be 10.72 cm. When we adjust for the difference in reference points by subtracting the mean distance between the pubic symphysis and IGF from the average distance of the

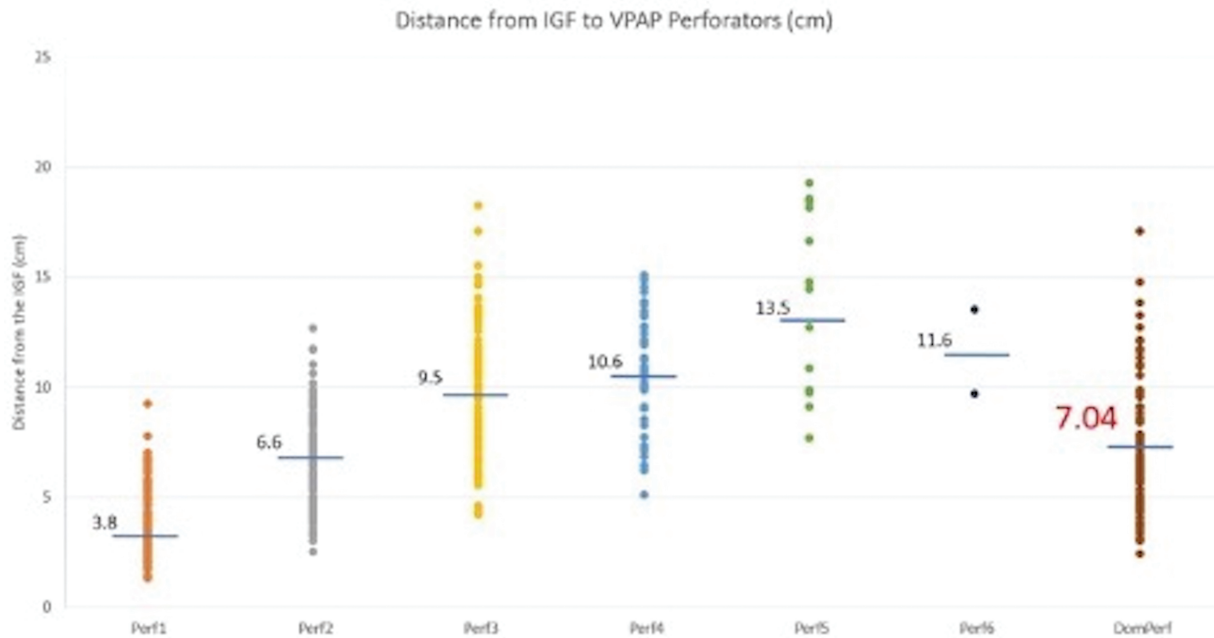


Fig. 4 The distance of all perforators from the infraglutal fold (IGF) in imaging studies. vPAP, vertical profunda artery perforator.

dominant perforators, the distance to the dominant perforator (7.02 cm) is more similar to our imaging analysis. Furthermore, 50% of dominant perforators exited the fascia greater than 8 cm below the estimated IGF.

Adoption of a vPAP flap design has been recently described for applications including breast reconstruction, head and neck, and lower extremity reconstruction.¹³ Given the segmental nature of the posterior thigh blood supply, vertically oriented flaps offer the advantage of capturing more than one perforator for maximal perfusion if a large flap is needed. Hammond et al describe the use of a potential

chimeric flap consisting of the gracilis and PAP flap for increased volume and contour, but the prevalence of a single arterial pedicle supplying both the gracilis and PAP flap was not 100%.^{18,19}

Attention must also be paid to potential donor site morbidity. The transverse design was originally employed to hide the scar in the gluteal fold; however, in our experience, we have found this can result in wound healing problems, painful scars or contour deformities while sitting, or unsightly distortion of the buttock fold. The vertical scar, on the other hand, can be hidden along the inner thigh in a

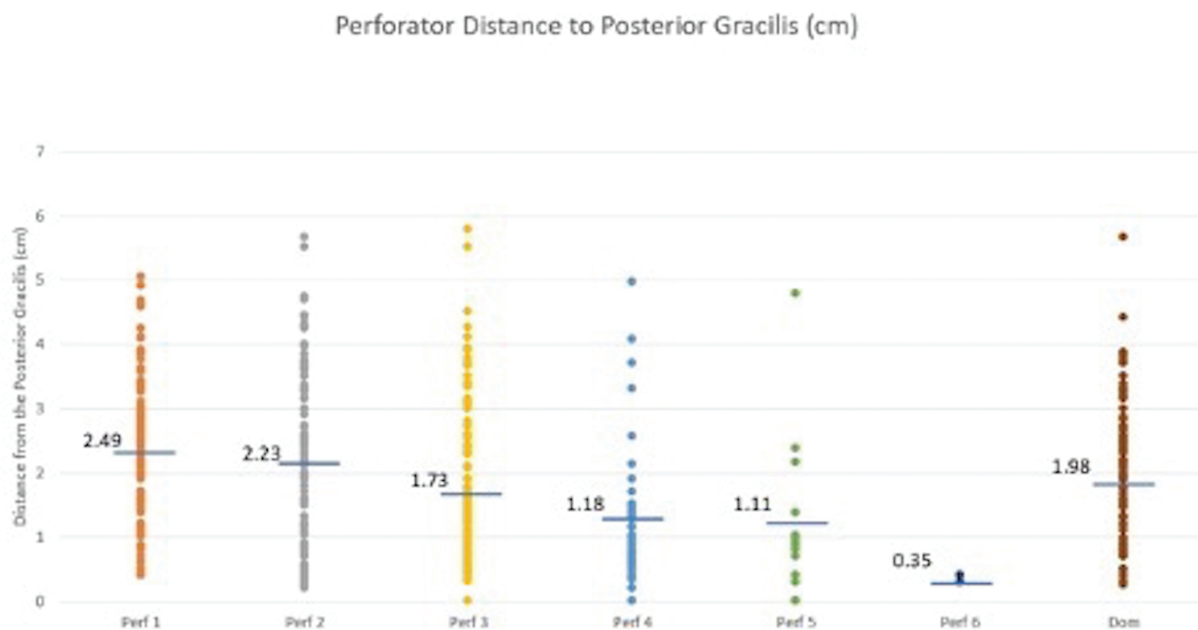


Fig. 5 The distance of each perforator from the posterior gracilis. As the perforator becomes more distal, it also becomes more anterior.

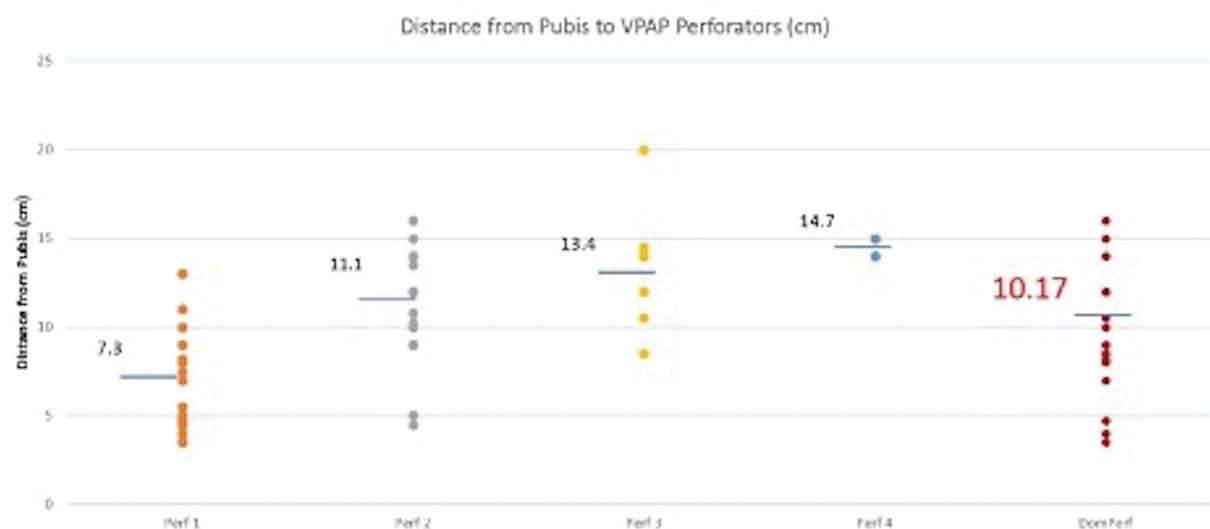


Fig. 6 The distance of all perforators from the pubic tubercle in cadaver dissections. vPAP, vertical profunda artery perforator.

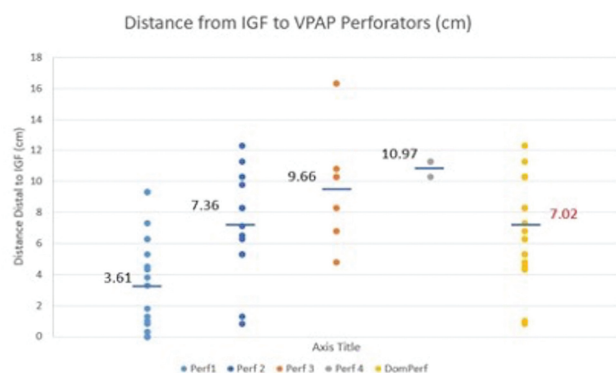


Fig. 7 The distance of all perforators from the estimated infragluteal fold (IGF) in cadaver dissections. vPAP, vertical profunda artery perforator.

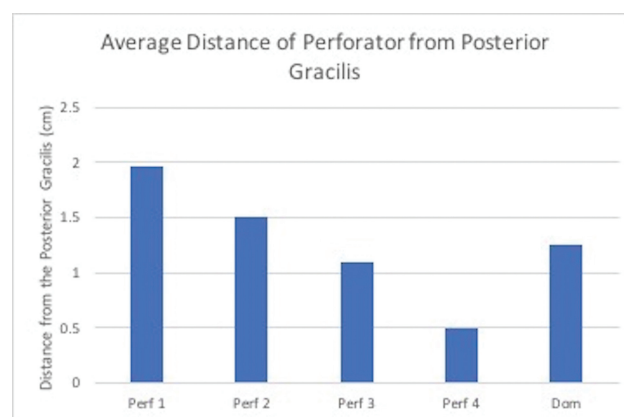


Fig. 8 The average distance of each perforator from the posterior gracilis in cadaver dissections.

fashion similar to an aesthetic vertical thigh lift, and can potentially reduce tension on closure and with flexion of the extremity. However, it is important to note that perforators located more posteriorly will result in a more posterior flap design, and scars may be visible posteriorly. In our experience, we have not had any complaints regarding the donor site scar. Another advantage of the vertical design of the PAP flap is that it may decrease the chances of patients developing postoperative lymphedema. Although Saint-Cyr et al discuss one of the disadvantages of the TUG flap, the tPAP flap has a similar dissection in which the anterior aspect of the flap can extend into the femoral triangle and possibly damage the lymphatic drainage of the lower extremity. The dissection of the vPAP will not be as anterior and has a higher chance of sparing the lymphatic drainage.^{20,21}

We found that the dominant perforator is located at a mean distance of 1.98 and 1.26 cm (on imaging and cadaveric dissection, respectively) from the posterior border of the gracilis. Furthermore, distal perforators were found in a slightly more anterior location, suggesting that vertical flap design may be shifted slightly anteriorly when centered

on these vessels. Regardless, patients with thigh tissue laxity and fat excess in the transverse axis may find aesthetic benefit from this approach to improve the contour and fullness of the inner thigh. Liposuction can later be performed as an adjunctive procedure to improve final thigh contour.

We acknowledge several limitations in our study, most notably that the CTA and MRA scans were reviewed by the authors but not independently reviewed by a third party. Each imaging study's official interpretation by a radiologist was compared with the authors' findings, but selection and reader bias are possible since neither the same radiologist nor author reviewed each scan individually. Interpretation bias may also exist due to nonuniform imaging modalities. Furthermore, the imaging protocol for preoperative evaluation the PAP flap vasculature stops 10 cm proximal to the knee. If any perforators extended distal to the 10 cm cutoff, they would not have been evaluated. In comparison, the cadaver dissections were performed by the same author but the IGF could not be used as a reliable reference point. This led us to use the pubic tubercle instead of the IGF as a



Fig. 9 Here is an example of a patient with left breast cancer, who was treated with mastectomy and bilateral stacked deep inferior epigastric perforator-vertical profunda artery perforator (vPAP) flap reconstruction: (A, C) Preoperative and (B, D) postoperative. The vPAP donor site is well hidden in the posterior thigh. There is no distortion of the gluteal fold and it is similar to a vertical thigh lift scar (D).

reference point because of the distortion of the IGF. We attempted to account for the difference in distance from the reference points by averaging the distance between the pubic tubercle and the IGF and subtracting that from our cadaveric profunda perforator distance. However, the average pubic tubercle to IGF distance calculated in the imaging study may be different than the pubic tubercle to IGF distance in the cadavers.

Future studies should address the aesthetic results of the vPAP scar compared with the tPAP scar, as well as patient preference and pain levels, and may be useful to demonstrate the potential advantages regarding donor site morbidity. Additionally, comparing the average weight of tissue harvested with each flap design could provide useful guidance as to whether the vPAP is able to potentially capture additional volume.

Conclusion

Both radiographic and cadaveric anatomic studies have displayed the presence of clinically viable profunda perforators distally in the posterior-medial thigh.^{8,9,15–19,22,23} Based on these findings—as well as our previously reported clinical experience—we believe the vPAP presents an excellent flap configuration to consider in appropriate patients.^{3,13,24} Our data suggests that although the dominant perforator exits within 8 cm most of the time, over 25% of the time in our imaging studies and up to 50% of the time in our cadaver dissections the dominant perforator can be missed in the traditional tPAP design. Additionally, the vPAP has the potential to incorporate multiple perforators with a reliably

long pedicle and excellent vessel diameter. This flap design also provides for a well-hidden donor site scar, and the potential for reduced donor site complications relative to the transverse design.^{22,25,26} These findings lend further anatomic support for the clinical application of the vPAP flap in autologous breast reconstruction, as well as for the use of preoperative imaging for surgical planning.^{1,8,15,17–19}

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