Defining Vascular Supply and Territory of Thinned Perforator Flaps: Part II. Superior Gluteal Artery Perforator Flap

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Background: Superior gluteal artery perforator flaps are surgical options in breast and pressure sore reconstructions. Based on the recipient site, primary thinning of these flaps may be necessary for final optimal contour. As the thinning of a superior gluteal artery perforator flap should be based on the knowledge of perforator vascular territories to prevent vascular compromise, the authors performed an anatomical study to determine the number, location, and diameter of the perforators present in the superior gluteal artery perforator flap. Accompanying veins and acceptable locations for surgical incisions were also determined.

Methods: Fourteen superior gluteal artery perforator flaps were harvested from seven cadavers. Perforator flaps were thinned to 8 to 15 mm, except for a 2.5-cm radius around the dissected perforator. Vascular territory areas were quantified before and after thinning by photographic and radiographic methods, and respective vascular territory maps were constructed. Surgical incision "danger zones" of vertical and horizontal axes were determined at specific depths (relative to the skin surface) for each flap. Danger zone measurements were determined with an automatic three-dimensional vascular tree construction using computed tomographic images and several modeling algorithms.

Results: Mean perforator artery diameter and number at the fascia level were 0.91 ± 0.07 mm and 2.86 ± 0.77 (mean $\pm$ SD), respectively. Perforator pedicles were located midway between the posterior superior iliac spine and the greater trochanter. After thinning, skin surface and whole flap vascular territories were reduced 80.9 percent (photographic) and 76.9 percent (radiographic), respectively, compared with unthinned vascular territory areas. From the skin at 4-, 6-, and 8-mm thicknesses, elliptical danger zones (two vertical segments and two horizontal segments) had overall vertical segment axis length ranges from the pedicles of 59 to 66 mm, 51 to 57 mm, and 49 to 51 mm, respectively. Horizontal axis segment length ranges were 61 to 76 mm, 61 to 66 mm, and 60 to 57 mm for 4-, 6-, and 8-mm skin thicknesses, respectively.

Conclusions: The superior gluteal artery perforator flap provides an excellent blood supply to adipose tissue but may be compromised when aggressively thinned. Surgeons may design and harvest partially thinned superior gluteal artery perforator flaps based on the anatomical vascular territory maps provided by this study. (*Plast. Reconstr. Surg.* 118: 1338, 2006.)

Perforator flaps are increasingly being used for reconstruction, with minimal donor-site morbidity.[1–4] Improved instrumentation and greater experience are enabling surgeons to achieve higher success rates using flaps that involve smaller vessels. An increasing number of very skilled microsurgeons have pioneered the use of smaller pedicles in what has been described as supermicrosurgery.[5] Perforator flaps can exhibit a wide range of anatomical variability, which results in technical challenges during surgery. The ability to optimally contour the flap to the recipient site is critically important, as the vascular territories fed by their respective perforators may be compromised, thus decreasing the survivability of the thinned flap.

The superior gluteal artery perforator flap, in particular, has been reported for the reconstruction of breast and sacral tissue defects by preserving underlying gluteal muscle function and hiding the donor-site incision well under conventional wardrobes.[6–9] However, reconstruction using a thinned superior gluteal artery perforator flap has not been reported in the literature, to the best of our knowledge.

The purpose of this anatomical study was to determine the extent of thinning that was possi-

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ble for the superior gluteal artery perforator flap using anatomical data on multiple aspects of the respective vasculature. Variations of perforator artery location and size, and variations of their associated angiosomes (before and after thinning), were determined both grossly and radiographically. The superior gluteal artery perforator flap was thinned to a thickness of 8 to 15 mm while retaining the native thickness for a 2.5-cm radius around the pedicle. Using four methods to identify different aspects in the vascular territories of superior gluteal artery perforator flaps, predictive maps were prepared to provide surgeons presurgical plots or maps of superior gluteal artery perforator flap perforator locations and resultant vascular territories. "Danger zones," defined as areas where excessive thinning may result in vascular compromise and potential flap loss, varied as a function of skin thickness and proximity to the perforator vessel. Three-dimensional computed tomographic reconstructions of the vascular skeletal tree and modeling algorithms were generated to determine danger zone distances from the perforator vessel. On the basis of these data, surgeons can decide whether the superior gluteal artery perforator flap can be effectively thinned or not for contouring recipient surgical soft-tissue reconstructions.

MATERIALS AND METHODS

Cadavers

An anatomical study was performed on seven fresh Caucasian adult cadavers; four were male and three were female cadavers with a mean age of 78.3 years (range, 64 to 87 years). Fourteen superior gluteal artery perforator flaps were harvested and studied within 5 posthumous days.

Harvesting and Cannulation

While in prone position, the key anatomical landmarks of the posterior superior iliac spine, apex of the greater trochanter, coccyx, and the center between the left posterior superior iliac spine and the right posterior superior iliac spine were identified. A line was drawn from the posterior superior iliac spine to the greater trochanter as the vertical axis and all anatomical landmarks were marked with surgical wires that facilitated subsequent radiographic identification. The superior boundary of the flap was 5 cm above the posterior superior iliac spine and the inferior boundary was 3 cm below the coccyx. The lateral border was 3 cm lateral to the greater trochanter. The superior gluteal artery perforator flap was undermined below the gluteal maximus fascia and dissected from the lateral side to the medial side. All perforator vessels were identified and dissected approximately 2 to 3 cm into the muscle and then cut. The superior gluteal artery perforator was identified and distinguished from the inferior gluteal artery perforator by dissection to the vessel source (Fig. 1). All other perforator vessels were ligated (i.e., parasacral perforator artery).

The number of superior gluteal artery perforator vessels that were able to be cannulated using polyethylene tubing (Clay Adams PE-50; outside diameter, 0.975 mm; Becton Dickinson, Franklin Lakes, N.J.) was recorded. The largest perforator

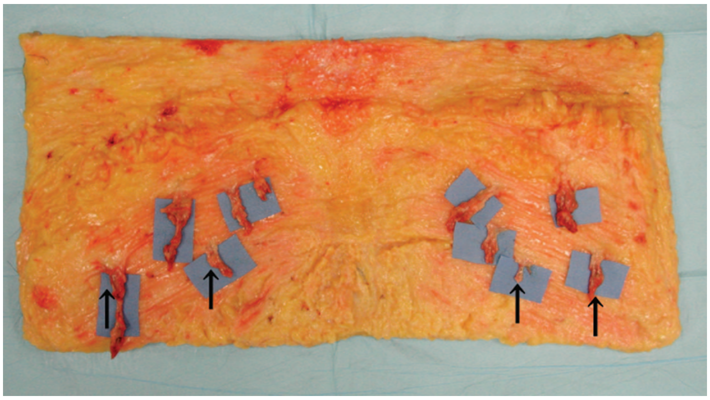

Fig. 1. Perforator number identification in gluteal artery perforator flaps. The number of pedicles was counted for each gluteal artery perforator flap. The pedicle source from the inferior gluteal artery (*arrows*) was confirmed by dissection from proximal to the pedicle. These perforators were not counted.

artery was cannulated and irrigated gently with 300 ml of warmed saline (40°C) containing heparin (10 units/ml) until the effluent was colorless from the flap and accompanying veins.

Vascular Territory Determinations (before Thinning)

In each superior gluteal artery perforator flap, two solutions were sequentially injected to determine either the skin surface–associated or whole flap vascular territories. Before thinning, a bolus of 7 ml of EosinY solution (3 mg/ml) was injected into the largest perforator artery. (Fig. 2, *above, left*) The subsequent red-colored skin area, flap borders, and anatomical landmarks were immediately traced onto a transparent cellophane sheet and were defined as skin surface vascular territory. After a washout solution of warmed saline solution, 7 ml of Omnipaque (Amersham Health, Princeton, N.J.) was injected as a contrast medium into the same artery. Each flap was placed directly onto a computed radiographic image plate cassette and radiographed using a 80-kVp, 1-mAs technique at a 40-inch source-to-image distance. Digital radiographs were generated for each superior gluteal artery perforator flap using a computed radiography imaging system, and the resulting contrasted arterial areas were defined as the whole flap vascular territory (Fig. 2, *above, right*).

Thinning Superior Gluteal Artery Perforator Flaps

Each flap was then copiously irrigated with heparinized saline and a circle (2.5-cm radius) was drawn around the pedicle. All flaps were thinned to 8- to 15-mm thickness using a no. 10 scalpel, except for the area inside the circle (Fig. 3, *left*). Multiple small arteries were encountered during the thinning procedure (Fig. 3, *right*).

Vascular Territory Determinations (after Thinning)

Two solutions were sequentially injected to determine either the skin surface–associated or

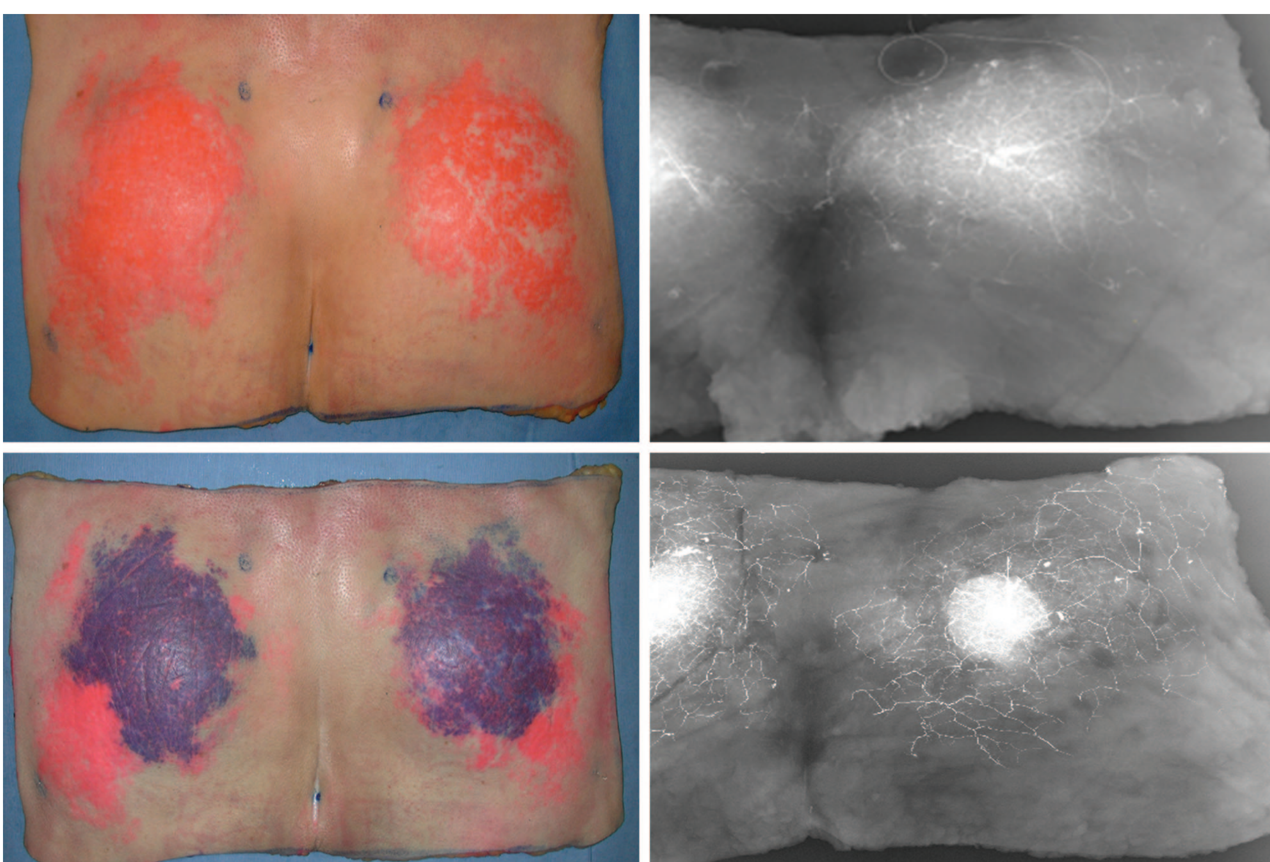

Fig. 2. Red dye (EosinY) was injected into the largest perforator arteries before thinning (*above*, *left*). Digital radiographs were produced before thinning (*above*, *right*). After thinning, blue dye (Evans blue) was administered (*below*, *left*), with subsequent digital radiographs (*below*, *right*).

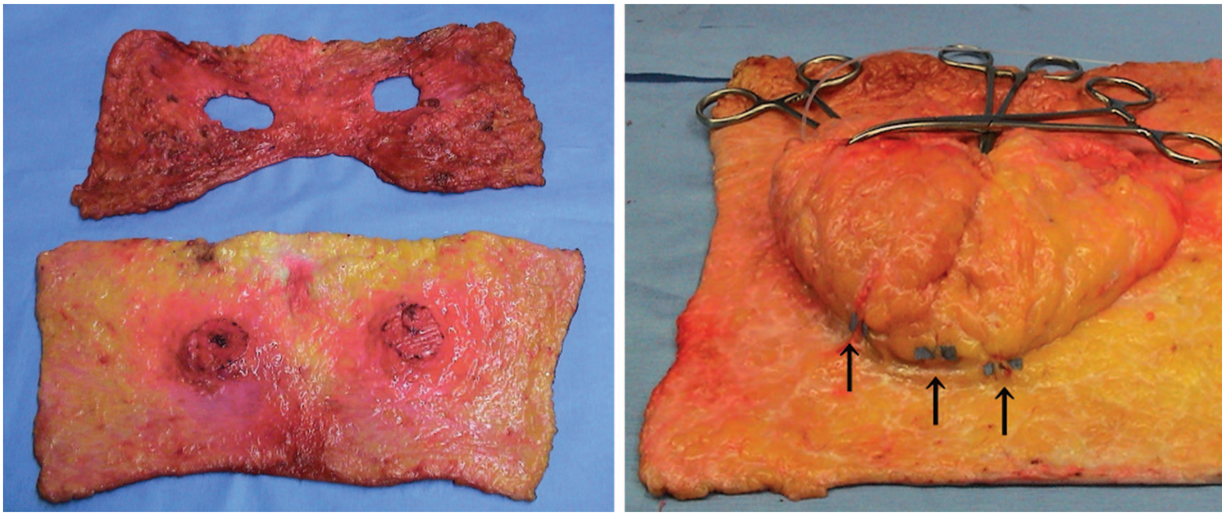

Fig. 3. Fat and deep fascia were retained around the perforator with a 2.5-cm radius and the flap was then reduced to 8- to 15-mm thickness (*left*). Many tiny vessels (*arrows*) were encountered during the thinning procedure (*right*).

whole flap vascular territories of each thinned superior gluteal artery perforator flap. After an additional warm heparinized saline wash through the main perforator artery, an injection of 7 ml of Evans blue solution (1 mg/ml) was administered (Fig. 2, *below, left*). The blue-colored skin areas and landmarks were immediately traced. For direct comparison, the previously used transparent cellophane sheet with the red landmarks and flap borders was aligned over the newly prepared blue-colored skin flap and defined as skin surface vascular territory thinned. From the underside of the flap, a needle was inserted from the pedicle through to the skin to indicate the exact pedicle location. The external needle location was then marked on the same transparent cellophane sheet. A second injection of 7 ml of lead oxide (Aldrich Chemical Co., Milwaukee, Wis.) with gelatin solution was administered using the previously described method.[10] Digital radiographs were produced for each of the thinned superior gluteal artery perforator flaps as described for unthinned superior gluteal artery perforator flaps, and calculated areas were defined as whole flap vascular territory thinned (Fig. 2, *below, right*).

Measurements and Data Analyses

Vascular Pedicle Location and Pedicle Diameter

The vascular pedicle location in each flap was measured in the vertical (posterior superior iliac spine to greater trochanter) and horizontal (perpendicular axis of vertical axis) axes from the above-stated landmarks as defined by visualization of the embedded wire sutures on radiographic images. To compare vascular pedicle locations among patients with various heights, the pedicle location in each subject was expressed as a percentage of the distance along both the horizontal and the vertical axes. Individual ratios were generated using the horizontal lengths (numerators) and the vertical lengths (denominators) as the posterior superior iliac spine to the greater trochanter. Right gluteal data were converted to mirror images and combined with left gluteal data for analysis. Each pedicle diameter was measured directly from radiographic images under microscopic examination and then calculated to actual size.

Vascular Territory Areas

Skin surface vascular territory and skin surface vascular territory thinned tracings were transferred from individual cellophane sheets to lined graph paper. The vertical axis of the graph paper was aligned with the vertical axis of the flap (posterior superior iliac spine to greater trochanter). Within the outlined vascular territory for both red- and blue-colored data sets, 36 separate radii were drawn from the pedicle to the marked margins in 10-degree increments for each flap. Each radius length was measured and recorded.

Whole flap vascular territory and whole flap vascular territory thinned were determined from computed radiographic images using an analysis software package (IDL; Research Systems, Inc., Boulder, Colo.). Vasculature territory contour margins were outlined on the computed radiographic images, and radial lines from the pedicle to the margins at 10-degree increments were automatically generated and measured for each flap. To determine the total vascular territory areas of skin surface vascular territory, skin surface vascular territory thinned, whole flap vascular territory, and whole flap vascular territory thinned data sets, the following formula was used:

$$\sum_{i=1}^{36} \frac{\pi Ri^2}{36}$$

where *Ri* is the measured radius length from the pedicle to the vascular margin. The ratio of normalized thinned vascular territory to unthinned vascular territory was used for comparison among all superior gluteal artery perforator flaps. The mean total vascular territory area *before thinning* was normalized to 100 percent and assigned as the denominator, whereas the mean total vascular territory area *after thinning* was assigned as the numerator. The effect of thinning on vascular territory was expressed as a fraction for each flap. Overall percentage change means were calculated.

Four vascular territory maps were drawn: skin surface vascular territory, skin surface vascular territory thinned, whole flap vascular territory, and whole flap vascular territory thinned. Using all data from each flap, the mean, SD, ranges, and confidence intervals were calculated. Each plotted segment length on a vascular territory map represented the mean value from 14 individual superior gluteal artery perforator flap determinations. All vascular territory contour maps were drawn from 36 segment lengths (radii) at 10-degree intervals. Right gluteal data were converted to mirror images and combined with left gluteal data to produce one total data set. No significant differences were observed between right and left gluteal data sets.

Superior gluteal artery perforator flap total area sizes were calculated by using vertical axis lengths (0- and 180-degree segment radii) and horizontal axis lengths (90- and 270-degree segment radii). Mean, minimum, maximal, and confidence interval lengths were calculated.

Danger Zone of Thinning

All superior gluteal artery perforator flaps were scanned using serial computed tomographic sections (0.625 mm) through the entire flap. From the computed tomographic images, a computer-modeled program produced a three-dimensional vascular skeletal tree of each superior gluteal artery perforator flap[11] (Fig. 4). Flap thicknesses were measured around the pedicle area and the

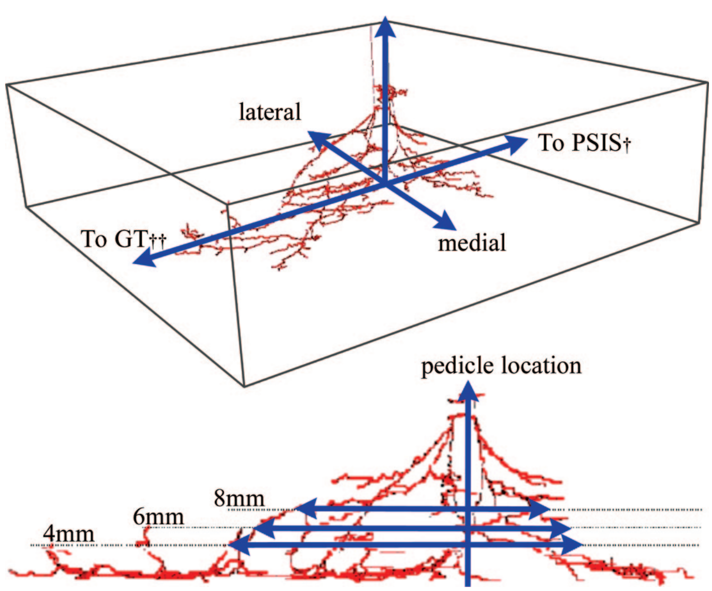

Fig. 4. The three-dimensional vascular skeletal trees of superior gluteal artery perforator flaps were produced from computed tomographic images. Danger zone distances were measured from the pedicle to four (posterior superior iliac spine, greater trochanter, lateral, and medial) directions at 4-, 6-, and 8-mm distances from the skin surface. †Posterior superior iliac spine; ††greater trochanter.

thinned tissue areas using a single computed tomographic image. Danger zones were calculated at the 98th percentile at three different skin thicknesses relative to skin surface (4, 6, and 8 mm). Three-dimensional computed tomographic data were validated by visual examinations and measurements at the vertical (posterior superior iliac spine to greater trochanter) and horizontal (perpendicular axis of vertical axis) axes. In addition, all vascular territory segment lengths were verified using individual radiographic images at each reported skin thickness depth. Four respective segment lengths were recorded based on the pedicle location as the center of the above-stated axes. Danger zone calculations were performed on approximately 80 percent of the computed tomographic images. Tiny vessels ligated during the dissection protocol interfered with direct measurements of vascular territory borders in the remaining digital images.

Statistical Analyses

Mean, SD, and confidence intervals (two-sided) were determined with a statistical software package (Excel; Microsoft Corp., Redmond, Wash.). Superior gluteal artery perforator flap sizes were expressed as mean minus respective confidence interval values, as plus confidence interval would not be meaningful in surgical flap design. Likewise, in the determination of danger zone area, calculations used mean plus confidence interval values to conservatively represent safer surgical operational thinning plots. The Wilcoxon signed rank test was performed to determine the statistical difference among various axes segment lengths and direction preference for subcutaneous arborization of vascular territories. Statistical significance was defined as $p < 0.05$ for all analyses.

RESULTS

Vascular Pedicle Diameter and Number

Mean perforator artery diameter located at the deep fascia level was 0.9 ± 0.1 mm (mean ± SD), with a range of 0.8 to 1.1 mm (Table 1). The number of superior gluteal perforator arteries per flap was 2.9 ± 0.8 (range, 1 to 4), and all perforator arteries had two accompanying veins (Table 1).

Vascular Pedicle Location

Superior gluteal perforator artery locations at the fascia level are shown in Figure 5. On the horizontal axis, all pedicles but one were located on the medial side of the vertical axis (posterior superior iliac spine to greater trochanter) line described above; the majority of perforators are within 10 percent of medial side. On the vertical axis, perforators were widely distributed from 16 to 58 percent, with a majority of arteries located at the junction of the medial portion of the horizontal axis and –10 to 26 percent of the vertical axis.

To compare pedicle locations among subjects, the lengths of measured horizontal and vertical

Table 1. Anatomical Parameters of the S-GAP Flap (*n* = 14)*

	Mean ± SD	Range
Diameter and no. of the perforating arteries		
Diameter, mm	0.9 ± 0.07	0.82–1.05
No. of arteries	2.9 ± 0.77	1–4
No. of accompanying veins	2.0 ± 0	2–2
Pedicle location		
Length (PSIS to GT), cm	20.4 ± 1.7	17.8–22.9
Vertical axis (PSIS to distal, %	40.5 ± 11.9	16.3–58.3
Horizontal axis (drawn line to lateral, %	5.6 ± 9.1	–10.0–25.9
Vascular territory		
SSVT area, unthinned, cm^2	164.3 ± 39.8	94.7–243.5
SSVT area, thinned, cm^2	130.4 ± 35.8	83.2–196.5
FXVT area, unthinned, cm^2	346.2 ± 63.0	237.7–430.4
FXVT area, thinned, cm^2	263.9 ± 74.0	192.0–424.6
Percent SSVT thinned	80.9 ± 20.7	54.6–125.8
Percent FXVT thinned	76.9 ± 17.1	54.8–105.9
Thinning thickness		
Around pedicle, mm	32.4 ± 12.9	25.3–43.5
Thinned area, mm	11.9 ± 4.7	8.4–15.6
Thinned percent†	37.5 ± 6.0	26.1–45.5

S-GAP, superior gluteal artery perforator; PSIS, posterior superior iliac spine; GT, greater trochanter; SSVT, skin surface vascular territory; FXVT, whole flap vascular territory.
*The mean ratio for each flap in thinned vascular territory divided by unthinned vascular territory.
†The mean ratio for each flap in thinned area thickness divided by pedicle thickness.

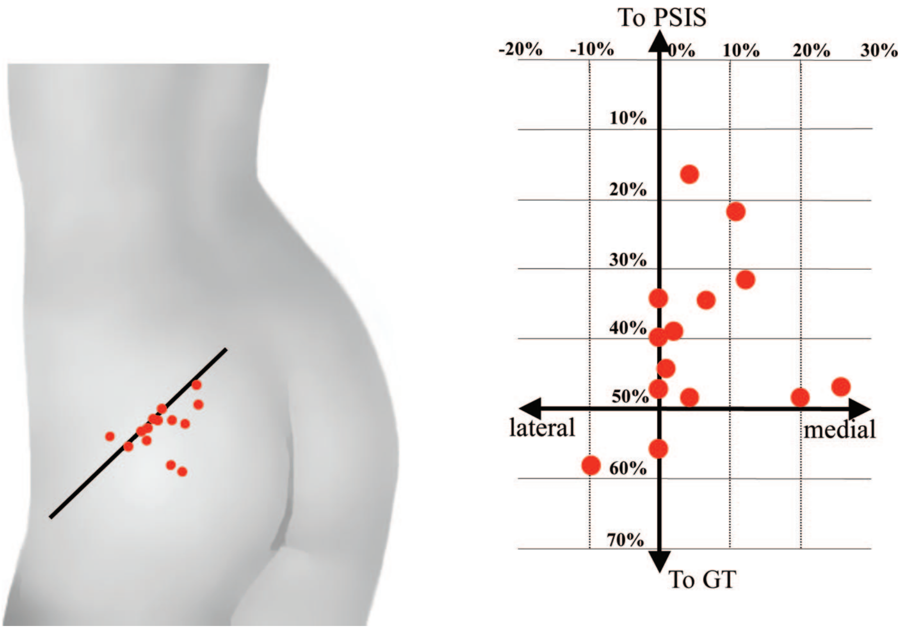

Fig. 5. Perforator location in superior gluteal perforator artery flaps. A line was drawn from the posterior superior iliac spine (*PSIS*) to the greater trochanter (*GT*) in each individual. Pedicle locations at the fascial level were identified, and measurements in each direction were recorded. To compare pedicle locations among all donors, the results from each flap were expressed as a percentage of the total axis length of that respective donor (100 percent). (*Right*) The mean length of the pedicle location for all flaps on the vertical axis was 40.5 ± 11.9 percent from the posterior superior iliac spine; on the horizontal axis, it was 5.6 ± 9.1 percent medial to the drawn line. An anatomical figure shows all pedicle perforator locations (*left*).

lines were assigned a value (100 percent). Relative to that adjustment, the mean pedicle location on the vertical axis was 40.5 ± 11.9 percent from the posterior superior iliac spine; on the horizontal axis, it was 5.6 ± 9.1 percent medial to the drawn line (Table 1).

Vascular Territory of Superior Gluteal Artery Perforator Flaps

Mean vascular territory for skin surface and whole flap areas in unthinned and thinned flaps were determined. In unthinned superior gluteal artery perforator flaps, the mean skin surface vascular territory was 164 ± 39.8 cm^2 and whole flap vascular territory was 346 ± 63.0 cm^2; whereas in thinned superior gluteal artery perforator flaps, the mean skin surface vascular territory thinned was 130 ± 35.8 cm^2 and whole flap vascular territory thinned was 264 ± 74.0 cm^2 (Table 1). Thinning superior gluteal artery perforator flaps decreased both vascular territory measurements (skin surface vascular territory thinned and whole flap vascular territory thinned) compared with unthinned vascular territory ($p < 0.01$). In skin surface vascular territory, 81 percent vascular territory was retained, and in whole flap vascular territory, 77 percent remained after the thinning procedure (Table 1).

Four representative vascular territory maps demonstrate relative geometric shapes in Figure 6. The symmetry of the vascular territory geometric shapes was determined in unthinned and thinned superior gluteal artery perforator flaps by examining relative proportions of the vertical versus horizontal margin length dimensions. In unthinned skin surface vascular territory and whole flap vascular territory groups, the vertical lengths were significantly different from horizontal lengths using the Wilcoxon signed rank test ($p < 0.05$), which denotes an elliptical configuration before thinning. In the thinned superior gluteal artery perforator flaps, the vertical and horizontal line segment lengths of the vascular territory were not significantly different between proximal and distal margins from the pedicle. Therefore, a circular vascular territory shape resulted from the thinning of the superior gluteal artery perforator flap.

The vascular territory (unthinned and thinned) data sets were combined to generate anatomically

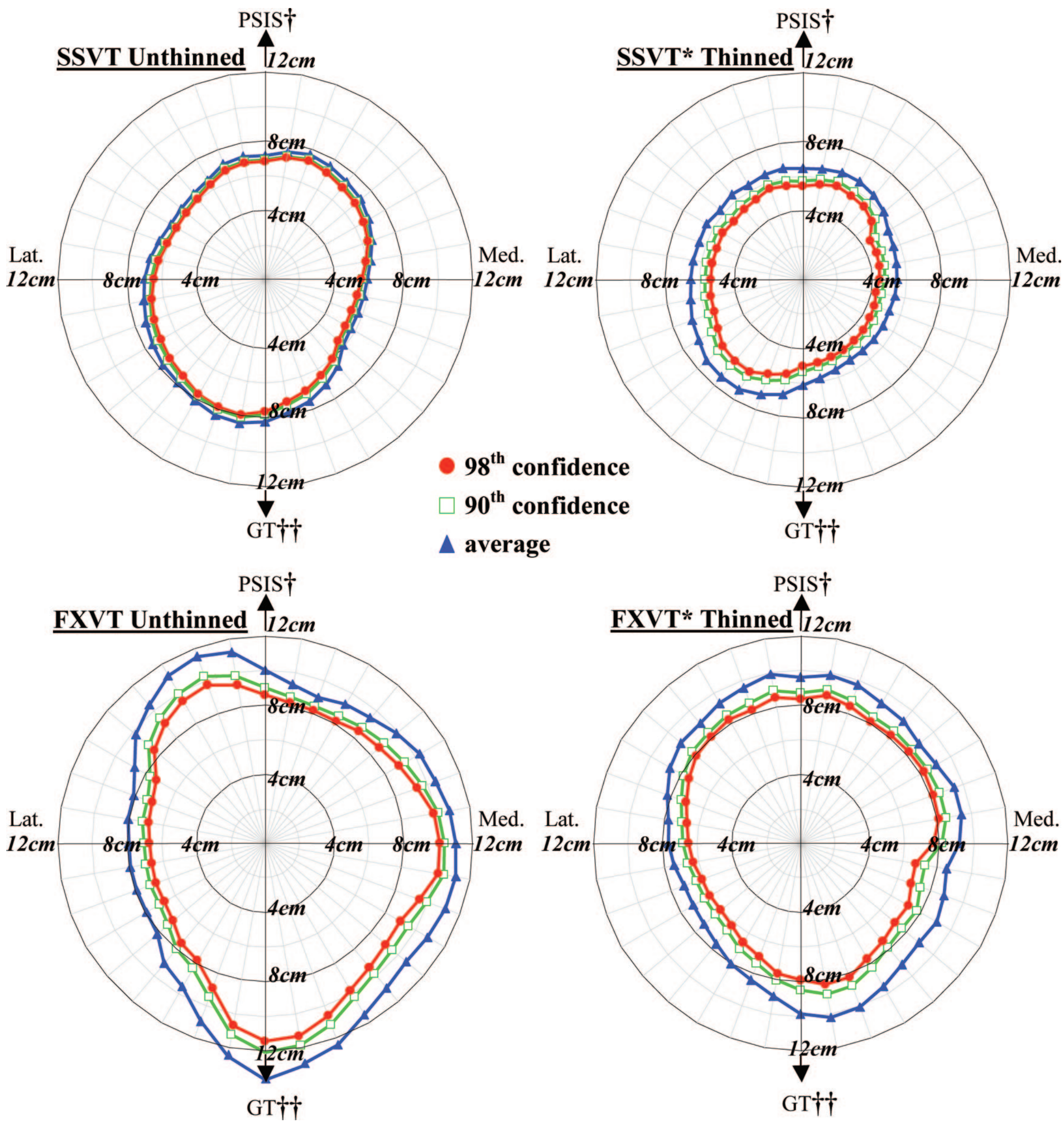

Fig. 6. Vascular territory maps were drawn from respective data sets (thinned versus unthinned). Margin lengths are represented at the 98th (*filled circles*) and 90th (*open squares*) confidence limits. In addition, average (*filled triangles*) lengths are presented. In summary, no statistical differences among the 90th and 98th confidence limit vascular territory margin lengths were observed. †Posterior superior iliac spine; ††greater trochanter. *SSVT*, skin surface vascular territory; *SSVT**, skin surface vascular territory thinned; *FXVT*, whole flap vascular territory; *FXVT**, whole flap vascular territory thinned.

oriented maps to avoid surgically cutting tissue areas that may compromise the vascular supply to the skin, danger zones, for superior gluteal artery perforator flap design (Table 2). With a single 0.8- to 1.1-mm diameter perforator arterial supply, the vascular territory was 14 × 11 cm in an unthinned skin surface vascular territory (98th confidence limit flap size) and 20 × 16 cm in an unthinned whole flap vascular territory (98th confidence limit flap size). A significant decrease in flap size was observed after thinning in skin surface vascular territory (14 × 11 cm to 10 × 9 cm) and whole flap vascular territory (20 × 16 cm to 16 × 14 cm).

Danger Zone

Mean flap thickness within the 2.5-cm radius circle around the perforator pedicle was 32 ± 12.9 mm (range, 25.3 to 43.5 mm), and the remainder of the thinned flap averaged 12 ± 4.7 mm (range,

Table 2. S-GAP Flap Sizes*

S-GAP Flap Size	Minimum (cm)	Maximum (cm)	Mean (cm)	90th CL (cm)	98th CL (cm)
SSVT, unthinned	9 × 7	21 × 19	15 × 12	14 × 12	14 × 11
SSVT, thinned	7 × 6	20 × 18	12 × 11	11 ×10	10 × 9
FXVT, unthinned	16 × 12	35 × 24	23 × 18	21 × 17	20 × 16
FXVT, thinned	13 × 9	33 × 23	19 × 16	17 × 14	16 × 14

S-GAP, superior gluteal artery perforator; CL, confidence limit; SSVT, skin surface vascular territory; FXVT, whole flap vascular territory.
*Using vertical and horizontal lengths from all ALTP flaps, a guide for surgical flap design is presented.

8.4 to 15.6 mm). Vertical and horizontal axes were drawn for the danger zones; each axis was then divided into two segments by the perforator location. As four directions on a map, the respective segment lengths for skin thicknesses of 4, 6, and 8 mm are listed in Table 3. Overall, the range of individual vertical segment lengths from the perforator was 59 to 66 mm, 51 to 57 mm, and 49 to 51 mm for 4-, 6-, and 8-mm skin thicknesses, respectively. Likewise, on the horizontal axis, the range of individual horizontal segment lengths was 61 to 76 mm, 61 to 66 mm, and 60 to 57 mm for 4-, 6-, and 8-mm thicknesses, respectively. All distances were expressed as the 98th confidence limit.

Statistical analysis was performed to test whether minor arteries branch off of the main perforator in one preferential direction in the deep adipose layer. For each thickness, distal danger zone values were not significantly different from proximal danger zone values using the Wilcoxon signed rank test ($p > 0.05$). In addition, medial danger zone values were not significantly different from the lateral danger zone values. Therefore, the subcutaneous arborization of branches off the perforator artery was random.

DISCUSSION

The key to the surgical success of perforator flaps was the discovery of the angiosomes serving the main perforating branches of the named arteries. Advancement in the application of perforator flaps requires a knowledge of the location and variation of perforator arteries and the reliability of the vascular territories served by each respective vessel after thinning.

Many authors have described the arterial blood supply in superior gluteal artery perforator flaps as adequate in length and diameter for successful anastomosis using microsurgery. By using short-pedicle perforators instead of long-pedicle perforators, these surgeons saved valuable time in dissecting and performing perforator-to-perforator anastomosis.[5] However, dealing with short, small vessels requires very skilled procedures. The results from this study design provide specific anatomical data at the fascia level for anastomosis using short-pedicle perforators in the superior gluteal artery perforator flap. In addition, pedicle location, vascular supply, and vascular territory were also delineated. This new information may serve as a surgical guide for safely harvesting, thin-

Table 3. S-GAP Flap Danger Zone Distances*

S-GAP Flap Danger Zone	Mean ± SD (mm)	Range (mm)	90th CL (mm)	98th CL (mm)
Vertical axis (proximal)				
8-mm thickness	34 ± 19	24–55	45	49
6-mm thickness	36 ± 20	22–64	46	51
4-mm thickness	41 ± 23	28–68	54	59
Vertical axis (distal)				
8-mm thickness	35 ± 21	20–59	46	51
6-mm thickness	40 ± 22	20–55	52	57
4-mm thickness	46 ± 26	25–76	60	66
Horizontal axis (medial)				
8-mm thickness	39 ± 24	10–67	54	60
6-mm thickness	40 ± 24	11–69	55	61
4-mm thickness	39 ± 26	14–77	54	61
Horizontal axis (lateral)				
8-mm thickness	36 ± 26	18–92	51	57
6-mm thickness	43 ± 28	23–96	59	66
4-mm thickness	50 ± 31	20–99	68	76

S-GAP, superior gluteal artery perforator; CL, confidence limit.
*Danger zone distances were examined and calculated at 4-, 6-, and 8-mm distances from the skin surface in each direction. These measurements will serve as a surgical guide to avoid vascular disruption by as a result of the thinning procedure.

ning, and contouring the superior gluteal artery perforator flap.

Our data addressed several key questions regarding the reliability of using unthinned, partially thinned, or completely thinned superior gluteal artery perforator flaps. One of the critical issues was to determine the pedicle characteristics at the fascia level for the superior gluteal artery perforator flap. The mean arterial vessel sizes in the superior gluteal artery perforator flap have been reported to be 2.91 mm (artery) and 3.28 mm (vein) as measured before anastomosis using the standard background grid.[12] Our data show that the mean inner diameter of the superior gluteal artery perforator artery at the fascia level was 0.9 mm. Blondeel reported that, as the pedicle was dissected proximally, the vessel diameter increased.[8] We did not determine pedicle length in this study, but a range of lengths (8.5 to 10 cm) has been reported.[9]

Pedicle location in the superior gluteal artery perforator flap has been previously described,[9,13] and our data in superior gluteal artery perforator flaps were confirmatory. Our data extend these results by using a large number of flaps to perform a statistical analysis of variation along both the vertical and horizontal axes that were based on known anatomical landmarks. Furthermore, this study has introduced the concept of normalizing raw data from anatomical landmarks to predict pedicle locations on any size of clinical patient. This may prove of great clinical value, not only in the operating room but also as an educational aid for instructing future surgeons.

The size of the superior gluteal artery perforator flap is dependent on the reliability of the vascular territory supplied by the perforator(s). Our results showed a great degree of variability in superior gluteal artery perforator flap vascular territory, thinned or unthinned. The maximal dimensions of an unthinned superior gluteal artery perforator flap in a living patient has been reported to be 32 × 12 cm.[7] In our cadaver study, the maximum whole flap vascular territory in the unthinned superior gluteal artery perforator flap was 18 × 17 cm. Several confounding factors may explain the differences in our data versus the clinical reports. As these superior gluteal artery perforator flaps were thick, some microthrombosis may have occurred in our anatomical study compared with living subjects.

In this study, the vascular territories of superior gluteal artery perforator flaps were decreased compared with the reported clinical cases. Several confounding factors may explain the differences in our data versus the clinical reports. First, this study used fresh human cadavers that were relatively old compared with clinical cases using perforator flaps. All subjects were not healthy at the time of death and had died as a result of many different causes. Although there are no data suggesting that skin blood supply in cadavers is significantly different from clinical cases, it is reasonable to assume that some decrease in skin surface vascular territory may occur in cadavers. A second point is that during the washout of the flap from the cannulated artery, the effluent from the veins included tiny blood clots. The clots may have had a profound effect on the vascular territory, as microthrombosis occurred in our anatomical study compared with living subjects, especially in the skin surface vascular territory determinations. Third, the syringe pressures used in the dyes and wash procedures were not mechanically applied, so that a standard pressure was not applied for all solutions before and after thinning. A range of viscosities from saline to lead oxide solutions presented a challenge, and a slow, steady pressure was applied by one operator for all solutions. Fourth, a potential limitation of this study may be that during repeated injections, the multiple injections may have gradually opened the choke vessels in the flap. The resulting opened choke vessels would be included as part of the vascular territory; thus, some thinned flaps would appear to have a greater vascular territory than the unthinned vascular territory. Through this study, as flap sizes had to be decreased for fine lateral radiographs, the danger zone could not be evaluated before thinning because of our vascular territory comparison study design. More detailed anatomical information is required of the vascular pathways for surgical flaps. Finally, the photographic and radiographic images were captured at one time point in this study design. This did not allow for temporal analysis of arterial versus venous filling.

Common surgical practice is to harvest the superior gluteal artery perforator flap as an ellipse, as this geometry lends itself more easily to primary closure. Our data demonstrate that the superior gluteal artery perforator vascular territory was elliptical in shape before thinning but that the vascular territory was circular in shape after thinning. This change in shape may result as the artery in the vertical axis runs deeper in the layer of adipose tissue. In addition, our data may differ from other reports, as these subjects were cadavers that were relatively old (chronologic age) and bed-ridden or supine for a long period before death. Nevertheless, we are confident that our whole flap vascular territory areas in the superior gluteal artery perforator flaps were either similar to or an underestimate of the whole flap vascular territory that would be observed in living patients. Therefore, we have provided superior gluteal artery perforator flap characteristics in both total surface area and as maximum, minimum, or average axes lengths that surgeons may find useful in operative planning.

We considered the results published by Angrigiani and Grilli,[14] who used the scapular flap, and the possibility of thinning the superior gluteal artery perforator flap for a total face reconstruction with one free flap. This would require that an anastomosis (perforator-to-perforator anastomosis) between the sacral artery perforator and the facial artery perforator be performed using the superior gluteal artery perforator flap. Because in our study we observed little or no contribution by the superior gluteal perforators to the vascularization at the center of the recision, our results would therefore suggest that superior gluteal artery perforator thinning for total face reconstruction with one free flap would be difficult for flap survival. Clinically, the vascularization of the sacral area is supplied from the perforator(s) of the sacral artery. It is interesting to note how tightly regulated the blood supplies in this cadaver study are restricted to specific anatomical areas.

The thinning procedure was difficult, as many tiny vessels were encountered in the adipose tissue (Fig. 3, *right*). These vessels were cut during thinning, and the resulting disruption of the vascular supply resulted in a 20 to 24 percent decrease in vascular territory (Table 1). Many small vessels were observed to have branched within the adipose tissue layer from the main perforator artery in all superior gluteal artery perforator flaps.

Therefore, we now report quantitative data that may prove useful in the design, harvest, thinning, and contouring of the superior gluteal artery perforator flap. The review of these data will guide the microsurgeon in the clinical application of the superior gluteal artery perforator flap and in the surgical application of safely raising the superior gluteal artery perforator flap.

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DISCLOSURES

None of the authors has a financial interest in any of the products, devices, or drugs mentioned in this article.

REFERENCES

1. Blondeel, P. N., Van Landuyt, K. H., Monstrey, S. J., et al. The "Gent" consensus on perforator flap terminology: Preliminary definitions. *Plast. Reconstr. Surg.* 112: 1378, 2003.
2. Hallock, G. G. Direct and indirect perforator flaps: The history and the controversy. *Plast. Reconstr. Surg.* 111: 855, 2003.
3. Wei, F. C., Jain, V., Suominen, S., et al. Confusion among perforator flaps: What is a true perforator flap? *Plast. Reconstr. Surg.* 107: 874, 2001.
4. Geddes, C. R., Morris, S. F., and Neligan, P. C. Perforator flaps: Evolution, classification, and applications. *Ann. Plast. Surg.* 50: 90, 2003.
5. Koshima, I., Tsutsui, T., Takahashi, Y., et al. Free gluteal artery perforator flap with a short, small perforator. *Ann. Plast. Surg.* 51: 200, 2003.
6. Koshima, I., Kawada, S., Moriguchi, T., et al. Connected deep femoral and gluteal perforator-based flap for repair of an extensive defect on the posterior thigh. *Plast. Reconstr. Surg.* 96: 201, 1995.
7. Allen, R. J., and Tucker, C., Jr. Superior gluteal artery perforator free flap for breast reconstruction. *Plast. Reconstr. Surg.* 95: 1207, 1995.
8. Blondeel, P. N. The sensate free superior gluteal artery perforator (S-GAP) flap: A valuable alternative in autologous breast reconstruction. *Br. J. Plast. Surg.* 52: 185, 1999.
9. Verpaele, A. M., Blondeel, P. N., Van Landuyt, K., et al. The superior gluteal artery perforator flap: An additional tool in the treatment of sacral pressure sores. *Br. J. Plast. Surg.* 52: 385, 1999.
10. Peden, E. K., Robinson, J. B., Jr., and Rohrich, R. J. An improved injection system for vascular anatomical studies having dual radiopacity and visualization capabilities. *Ann. Plast. Surg.* 32: 407, 1994.
11. Gao, J., Kosaka, A., and Kak, A. A deformable model for human organ extraction. *Proceedings of IEEE International Conference on Image Processing (ICIP)* 3: 323, 1998.
12. Dupin, C. L., Allen, R. J., Glass, C. A., et al. The internal mammary artery and vein as a recipient site for free-flap breast reconstruction: A report of 110 consecutive cases. *Plast. Reconstr. Surg.* 98: 685, 1996.
13. Blondeel, P. N., Beyens, G., Verhaeghe, R., et al. Doppler flowmetry in the planning of perforator flaps. *Br. J. Plast. Surg.* 51: 202, 1998.
14. Angrigiani, C., and Grilli, D. Total face reconstruction with one free flap. *Plast. Reconstr. Surg.* 99: 1566, 1997.