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Usefulness of Color Doppler Ultrasonography for the Preoperative Evaluation of Thin Anterolateral Thigh Flap Perforators

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Purpose: The anterolateral thigh flap is commonly applied to various body sites for reconstruction. However, surgeons often struggle against unexpected locations and the nature of perforator vessels during surgery. Thus, this study aimed to assess the accuracy and usefulness of color Doppler ultrasonography as a preoperative tool for the perforator position and course of anterolateral thigh flaps.

Methods: A prospective study involving 77 anterolateral thigh flaps was conducted between March 2016 and February 2021. Among them, 37 perforators (group A) were detected using the preoperative color Doppler ultrasound, and the other 40 perforators (group B) were tested using a hand-held Doppler only. All patients in group A underwent color Doppler ultrasonography performed by a radiologist at our institution. The nature and course of the perforator vessels were recorded, and their precise locations were plotted in an orthonormal coordinate system.

Results: A total of 37 anterolateral thigh perforator flaps (group A) were successfully dissected. The median distance between the preoperative color Doppler ultrasonography and the real location during surgery of the perforators was 7.50 mm, which was statistically smaller than 10 mm ($p<0.001$). This preoperative ultrasound test also had a success rate of 94.6% to determine the nature of the perforators (musculocutaneous type vs. septocutaneous type).

Conclusion: Preoperative color Doppler ultrasonography provides a harmless, reliable, and accurate technique for visualizing the vascular anatomy of anterolateral thigh flaps. It has a high correlation with surgical findings, allowing surgeons to cope with variable vascular anatomy.

Keywords: Color Doppler ultrasonography, Perforator flaps, Operative time

INTRODUCTION

The anterolateral thigh (ALT) flap has been one of the most frequently used flaps since it was first reported in 1984 [1]. The versatility of the ALT flap allowed its application to a variety of body sites such as the genitals, abdomen, pelvis, chest wall, extremities, head, and neck [2-7]. In addition, the ALT flap has many advantages: a reliably long pedicle, a good caliber, combination with cutaneous sensation, minimal donor site morbidity, and extendibility as a fasciocutaneous or musculocutaneous flap [8]. There might be an anatomic variability during most flap dissections, depending on the location of the donor site. Locating and dissecting the perforators could be difficult, particularly when raising a thin flap at the superficial fascial level. Reliable preoperative imaging evaluation would help anticipate the nature, location, and course of the perforators, improving surgical

planning. Color Doppler ultrasonography (CDU) was recommended by Blondeel et al. [9] for planning other flaps such as the deep inferior epigastric perforator and the thoracodorsal artery perforator flap. Most recent studies have shown the reliability of CDU for detecting ALT perforators [10,11].

This study demonstrated CDU as a useful preoperative perforator assessment for successful surgical planning of ALT flaps by localizing the specific sites of perforators and predicting course and flow. Moreover, we explored the possibility of efficient surgery by decreasing the surgical duration.

MATERIALS AND METHODS

Between March 2016 and February 2021, 77 ALT flaps were harvested, and 37 perforator vessels (group A) were identified, of which 40 ALT flaps (group B) were attempted with handheld Doppler assessment only. High-frequency CDU was conducted by a radiologist at our institution. Thirty-seven preoperatively observed perforators (group A) were found a day before flap surgery. An EPIQ 5 portable ultrasound machine with a 17-MHz linear probe (Koninklijke Philips N.V., Amsterdam, Netherlands) was used.

Before ultrasound scanning, the ABC system was set up on the thigh [8]. Once the leg was supinely positioned, the anterior superior iliac spine (ASIS) and superolateral corner of the patella (SLCP) were marked. The anterior superior iliac spine to superolateral corner of the patella (AP) line was drawn between the ASIS and SLCP. The midpoint of the AP line was marked, and area A had a 3-cm radius around the midpoint. Areas A and C were located 5 cm superior and 5 cm inferior to area B, respectively. In addition, areas A and C both had a 3-cm radius. Finally, an orthonormal coordinate system was defined; the x-axis was lined transversely at the midpoint, and the y-axis was lined along with the AP line.

The ultrasound scan began around the midpoint and progressed in a centrifugal manner until a perforator was detected (Fig. 1A). An upsurge through the vastus lateralis aponeurosis was marked on the skin. If the perforator ran transversely or obliquely, the route was marked. For precise measurement of the AB distance, which is the distance between the ultrasound location (A) and the surgical finding (B), point A was also recorded according to the orthonormal coordinate system. This procedure was repeated until the necessary number of perforators was determined. We also determined the ranking of observed perforator flows by Doppler flowmetry.

The ALT flap was undermined and elevated on the superficial fascia plane at the subcutaneous level (Fig. 2) in accordance with a previous study [12]. The point of emergence through the superficial fascia became point B and was recorded in the coordinate system. Point A, which was used for preoperative ultrasound assessment, and point B, which was observed during surgery, were recorded. Thus, the AB distance can be calculated using the following formula:

$AB = \sqrt{(Bx-Ax)^2+(By-Ay)^2}$, with Ax, Ay, Bx, and By being the coordinates of A and B along the x and y axes, respectively.

We also evaluated the precision of the type of perforators (musculocutaneous or septocutaneous type) by comparing the findings of the preoperative ultrasound assessment with their nature during surgery. Among 77 ALT flaps, we analyzed the

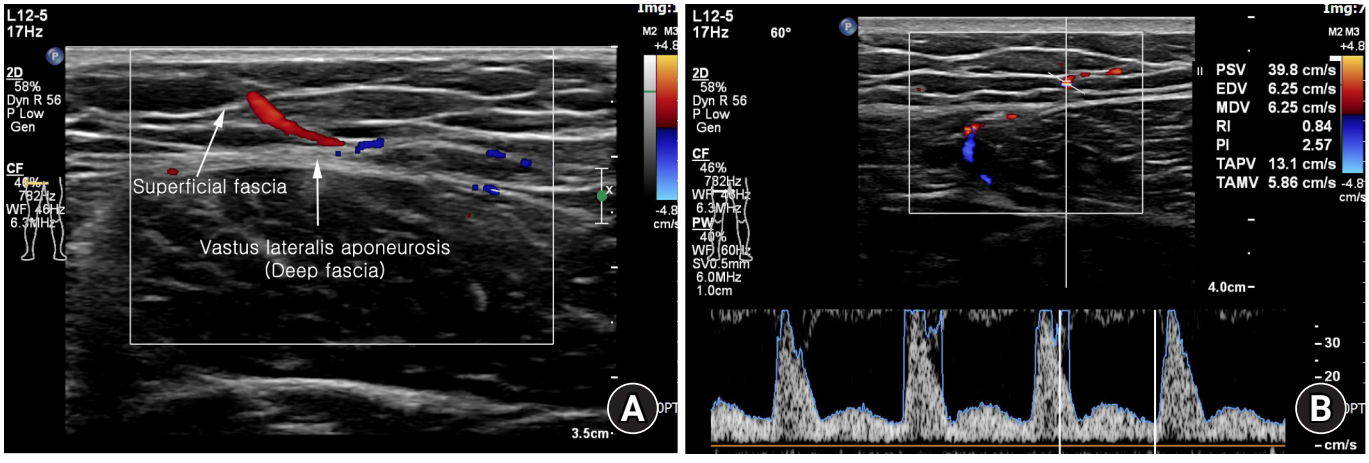

Fig. 1. Color Doppler ultrasound preoperative assessment (perforator 33). (A) The location and course of the perforator surges through the superficial fascia (left arrow) from the vastus lateralis aponeurosis (deep fascia, right arrow). (B) The flow of the perforator is measured using the color Doppler flowmeter.

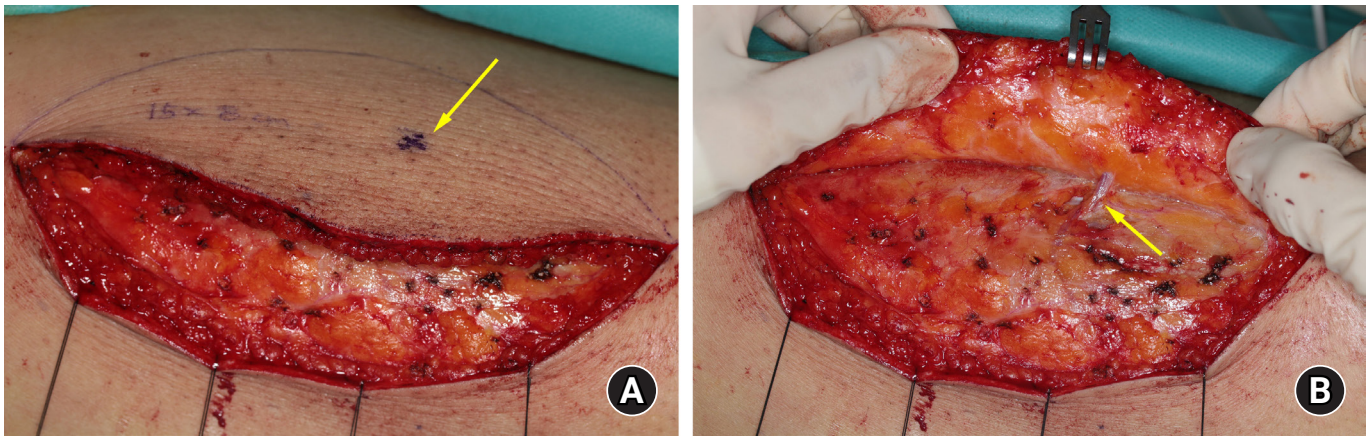

Fig. 2. Intraoperative photographs of harvesting a thin anterolateral thigh (ALT) flap (perforator 33). (A) The ALT flap is harvesting on the plane of the superficial fascia, being careful for the predicted perforator (arrow). (B) The perforator (arrow) is saved, and recorded in the orthonormal coordinate system. The patient provided written informed consent for the publication and the use of his images.

preoperative CDU would affect each operative time between group A with the preoperative CDU and group B with hand-held Doppler assessment only.

Statistical analyses were performed using IBM SPSS Statistics ver. 26 (IBM Corp., Armonk, NY, USA), and the statistical level of significance was set at $p < 0.05$.

This study was approved by the Institutional Review Board of Gwangmyeong Sungae General Hospital (No. KIRB-2020-N-007) and performed in accordance with the principle of the Declaration of Helsinki. The patients gave written informed consent for publication of this study and accompanying images.

RESULTS

At least one perforator was detected in each thigh. All flaps were elevated successfully, and no surgical design modifications occurred during surgery. A total of 37 perforators (group A) from 34 patients who underwent preoperative CDU scans were analyzed (Table 1). The median AB distance was 7.50 mm (interquartile range, 3.75 mm), which is statistically smaller than 10 mm ($p < 0.001$, Kolmogorov-Smirnov test). The success rate of the preoperative CDU test was 94.6% based on the detection of the nature of the perforators in 35 of the 37 cases. The ultrasound assessment had a sensitivity of 100%, a specificity of 80%, a positive predictive value of 93.8%, and a negative predictive value of 100% for the determination of musculocutaneous perforators. The coordinates and vascular types of all perforators during the surgery are shown in Fig. 3. The midpoint region (area B) had a total of 22 (59.5%), followed by areas A and C with 11 (39.7%) and 4 (10.8%) perforators, respectively.

Regarding the operating time, the average surgical duration

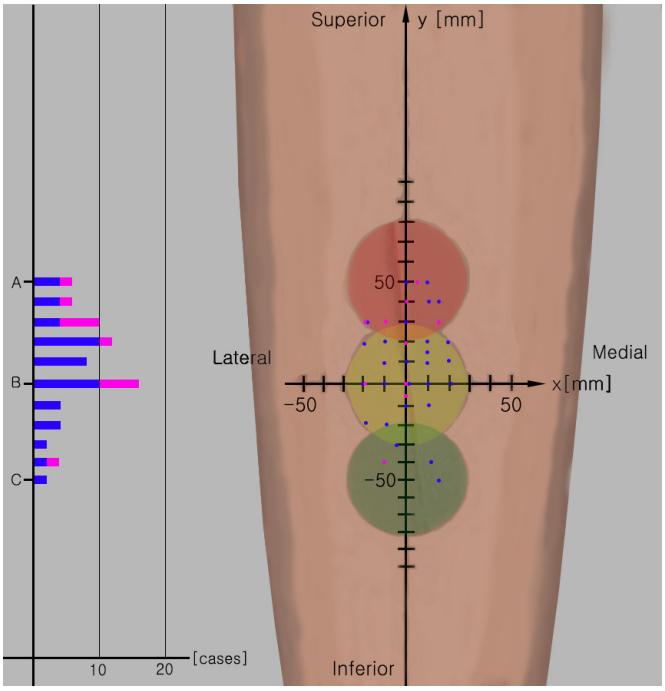

Fig. 3. Overall distribution of perforators during surgery. A total of 37 perforators during surgery were plotted in the orthonormal coordinate system. Area B has the most perforators (22), followed by areas A and C. Blue, musculocutaneous type; pink, septocutaneous type.

of group A (with preoperative CDU) was 243.78 minutes (Table 1). On the other hand, the average surgical duration of group B (with hand-held Doppler only) was 258.65 minutes (Table 2). Although the average duration of group A was approximately 15 minutes shorter than that of group B, it was not statistically significant ($p = 0.355$, Mann-Whitney test).

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Table 1. Results for the 37 perforators (group A, with the color Doppler ultrasonography)

Perforator No.	Sex/age (yr)	Preoperative prediction	Surgical finding	AB distance (mm)	Flap size (cm)	Artery	Vein	Operating time (min)
1	Female/52	M	I	7.5	6.0×15.0	1	1	250
2	Male/59	M	I	3.7	6.0×15.0	1	1	145
3	Male/41	M	I	7.5	7.0×15.0	1	2	265
4	Male/57	S	I	11.2	5.0×5.0	1	2	210
5	Female/64	M	I	0	3.0×8.0	1	2	230
6	Male/19	M	I	7.5	7.0×15.0	1	2	205
7	Male/44	M	I	14.0	8.0×18.0	1	1	315
8	Male/62	M	I	11.2	7.0×12.0	1	2	170
9	Male/58	M	I	7.5	6.0×12.0	1	2	310
10	Male/45	M	I	7.5	8.0×15.0	1	1	370
11	Male/29	S	I	10.0	9.0×22.0	1	2	300
12	Male/30	M	I	0	5.0×14.0	1	2	300
13	Male/54	M	I	7.5	3.5×9.0	1	1	120
14	Male/54	M	I	10.0	4.5×9.5	1	1	135
15	Male/54	M	I	22.4	4.0×5.0	1	1	120
16	Male/54	M	I	11.2	4.0×10.0	1	1	120
17	Male/32	M	S	10.0	5.0×12.0	1	2	355
18	Male/50	S	I	11.2	6.0×15.0	1	2	345
19	Male/61	M	I	7.5	5.0×12.0	1	2	275
20	Female/65	M	I	14.0	4.0×9.0	1	1	270
21	Female/22	M	I	11.2	5.0×8.0	1	1	200
22	Male/72	M	I	7.5	6.0×15.0	1	2	290
23	Male/63	S	I	5.0	6.0×15.0	1	2	215
24	Male/53	M	S	7.5	4.0×7.0	1	2	300
25	Male/57	M	I	7.5	5.0×10.0	1	1	225
26	Male/67	S	I	10.0	7.0×17.0	1	2	305
27	Male/60	M	I	14.0	4.0×11.0	1	1	200
28	Male/32	S	I	11.2	7.0×7.0	1	1	120
29	Male/62	M	I	7.5	4.0×9.0	1	2	300
30	Male/30	M	I	14.0	4.0×15.0	1	1	220
31	Male/59	S	I	7.5	8.0×20.0	1	2	260
32	Male/66	M	I	10.0	8.0×18.0	1	2	310
33	Male/41	M	I	14.0	8.0×15.0	1	1	235
34	Male/56	M	I	7.5	7.0×20.0	1	1	300
35	Male/44	S	I	10.0	7.0×17.0	1	2	330
36	Male/51	M	I	7.5	6.0×10.0	1	2	235
37	Male/46	M	I	0	5.0×15.0	1	1	165
	Median AB distance			7.5	Average operating time			243.78

AB distance, distance between the ultrasound location (A) and the surgical finding (B); M, musculocutaneous perforator; S, septocutaneous perforator; I, identical surgical finding.

DISCUSSION

Computed tomographic angiography (CTA) and CDU are currently the most widely used imaging modalities for flap surgery. However, which preoperative modality is better between CTA and CDU remains controversial. Shen et al. [13] stated that CTA can provide three-dimensional information about the origin, direction, and caliber of perforators and is more accurate than the CDU when detecting ALT perforators. However, the critical problem is how to accurately transfer the preoperative information into real-time surgery; therefore, it requires a special image-guided navigation or printed templates. It is also clear that CTA cannot avoid the risk of radiation, disturbance due to metallic artifacts, and contrast media reactions [14].

Table 2. Results for group B (without the color Doppler ultrasonography)

Perforator No.	Sex/age (yr)	Flap size (cm)	Artery	Vein	Operating time (min)
1	Male/50	7.0×15.0	1	2	275
2	Female/30	5.0×18.0	1	2	315
3	Female/21	3.0×7.0	1	1	315
4	Male/55	6.0×18.0	1	2	300
5	Male/45	5.0×12.0	1	2	260
6	Male/52	7.0×18.0	1	1	380
7	Male/69	6.0×15.0	1	1	295
8	Male/54	5.0×13.0	1	2	290
9	Female/48	5.0×12.0	1	1	195
10	Male/50	10.0×17.0	2	1	290
11	Male/57	7.0×13.0	1	2	215
12	Male/57	4.0×7.0	1	1	175
13	Male/58	7.0×18.0	1	2	305
14	Male/45	8.5×17.0	1	2	285
15	Male/64	7.0×13.0	2	3	290
16	Male/52	3.0×4.0	1	2	190
17	Male/27	10.0×19.0	1	2	295
18	Male/21	3.0×10.0	1	2	175
19	Male/40	5.0×14.0	1	3	275
20	Male/42	6.5×15.0	1	1	285
21	Male/47	3.0×7.0	1	1	300
22	Male/58	6.0×13.0	2	2	255
23	Male/55	3.0×11.5	1	1	175
24	Male34	6.0×15.0	1	1	225
25	Female/57	5.0×8.0	1	1	175
26	Male/56	3.5×9.0	1	1	265
27	Male/29	7.0×15.0	1	2	375
28	Male/29	5.0×10.0	1	1	295
29	Male/47	5.0×10.0	1	2	250
30	Male/41	6.0×8.0	1	1	180
31	Male/34	7.0×15.0	2	2	295
32	Male/21	5.0×9.5	1	1	165
33	Male/59	4.0×10.0	1	2	200
34	Male/41	3.0×10.0	1	2	190
35	Male/55	4.5×12.0	1	2	255
36	Male/36	10.0×15.0	1	2	265
37	Male/33	5.0×15.0	1	2	300
38	Male/55	7.0×15.0	1	2	275
39	Male/57	5.0×5.0	1	2	210
40	Male/57	7.0×14.0	1	1	235
Average operating time					258.65

On the other hand, CDU imaging correlated with the actual perforator location and course [15] and hemodynamic data from color Doppler flowmetry could help in selecting the appropriate perforators (Fig. 1B) [16]. Our study showed reliable results for the detection of ALT perforators using preoperative ultrasound scans. It had a 10-mm AB distance threshold, similar to a previous study, although ours was more accurate when determining the nature of the vessels (musculocutaneous vs. septocutaneous perforators) [10]. Two cases with septocutaneous vessels were misled for the musculocutaneous vessels. This suggests that it is difficult to differentiate musculocutaneous vessels around the septa from septocutaneous vessels between the septa.

While Debelmas et al. [10] labeled points A and B for the AB distance as the point of emergence through the deep fascia of the perforators, we defined these as the point of emergence through the superficial fascia. If the vessels ran transversely or obliquely near the subcutaneous layer, a marked discrepancy due to the gap in flap elevation can occur, which could reduce the possibility of misleadingness.

Through the CDU scan, we also demonstrated the distribution of perforators according to the ABC system (Table 3). Most perforators appeared in area B, correlating the course of the pedicle, descending branch of the lateral circumflex femoral artery, as in a previous study (Fig. 3) [17].

The present study has significant limitations. First, we compared the operating time between group A (with the CDU) and group B (without the CDU). However, the flap size varied, which affected the total surgical time. Additionally, it was not analyzed by dividing the flaps according to size. Second, variable factors such as the number of anastomosed arteries and veins were not limited. If more cases are accumulated, the study could be analyzed by flap size, anastomosed vessels, body mass index, etc. Indeed, elevation time would be more associated and a more correct factor for verifying the useful preoperative modality.

Table 3. Perforator locations and characteristics

Characteristic	Perforator (n=37)		
	A	B	C
Presence	11 (29.7%)	22 (59.5%)	4 (10.8%)
Musculocutaneous type	6	18	3
Septocutaneous type	5	4	1
Average x axis (mm)	−0.4 (−20 to +15)	+0.7 (−20 to +20)	+10 (−20 to +15)
Average y axis (mm)	+36.7 (+30 to +50)	+4.1 (−20 to +20)	−40 (−50 to −30)

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CONCLUSION

The CDU is an innocuous, reliable, and accurate modality for preoperative evaluation of ALT flaps because of its high correlation with surgical findings, enabling surgeons to make appropriate decisions. It also helps determine the precise origin, location, and course of perforator vessels through the superficial fascia and the vastus lateralis aponeurosis. Furthermore, CDU could potentially reduce the flap elevation time and the entire operating room time.

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CONFLICTS OF INTEREST

The authors have nothing to disclose.

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