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# Alternative Design for Anterolateral Thigh Multi-Paddled Flaps: The 3-5 System

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**Background:** The design and harvest of the anterolateral thigh (ALT) multi-paddled flap is a critical step in reconstructive surgeries. However, limited perforator distribution patterns of traditional design methods have gradually emerged in clinical practice. The aim of this study was to investigate the effect of a new technique (the 3-5 system) on ALT multi-paddled flap design.




**Material/Methods:** A total of 151 ALT flaps were harvested from 149 patients over a 26-month period. Among them, 100 ALT flaps were examined preoperatively using a handheld Doppler device to localize vascular perforators.

**Results:** By detecting perforator penetration points through the vastus lateral muscle (VLM) or the intermuscular septum and perforator entry points to the deep fascia, precise ALT flap perforator distribution patterns were found. Meanwhile, a 3-5 system was developed to design ALT flaps based on these findings. The remaining 51 ALT flaps from 49 patients during a 9-month period did not require the use of preoperative handheld Doppler. In addition, preoperative handheld Doppler and intraoperative findings demonstrated that all ALT flap penetration points through the VLM or intermuscular septum and the perforator entry point in the deep fascia were closely related based on 3 longitudinal lines and 5 horizontal lines.

**Conclusions:** ALT flaps were successfully harvested using a 3-5 system without the need for preoperative handheld Doppler analysis. Moreover, the 3-5 system is a simple and practical approach for preoperative ALT multi-paddled flap design.

**MeSH Keywords:** **Doppler Effect • Research Design • Surgical Flaps**

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## Background

The anterolateral thigh (ALT) free skin flap was first described by Song et al. [1] in 1984. It has been shown that the ALT flap is an extremely versatile flap for the reconstruction of skull, face, neck, extremities, and trunk. Meanwhile, ALT free skin flap has gained popularity in recent years [2–7]. Advantages of this type of flap include consistent and reliable perforators of good caliber, and the availability of a large amount of subcutaneous tissue for reconstruction. Moreover, ALT flaps have the ability to incorporate flaps into different tissue types, such as muscles and deep fascia, to reconstruct complex defects [8]. Therefore, ALT flaps have become workhorse flaps in reconstructive surgeries worldwide, especially in Asian countries [9].

The design and harvest of the ALT flap is a critical step in reconstructive surgeries. So far, 2 major studies on ALT flaps have been published. In 1998, Xu et al. [10] described the distributive patterns of perforator penetration points. They proposed that a 3-cm radial circle could be made, centered at the midpoint of the line connecting the anterior superior iliac spine and the superolateral border of patella, thereby serving as the body surface zone for major ALT perforators. The aforementioned described method is referred to as the circle method. In 2006, Yu et al. [11] proposed the application of the ABC system in preoperative ALT flap design. By using these 2 methods, traditional ALT flaps are easy to harvest. However, the limited perforator distribution patterns of the 2 methods are gradually emerging in clinical practice.

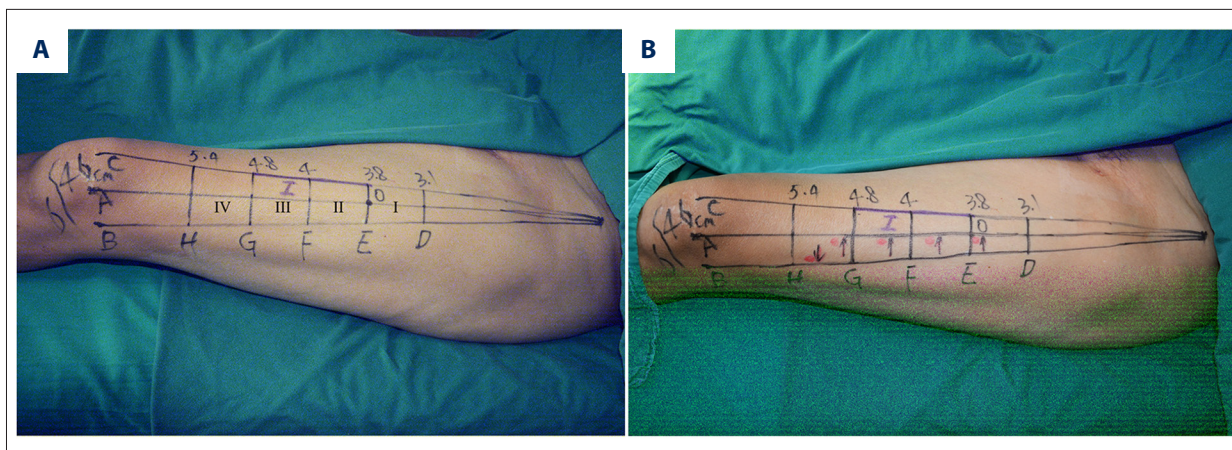
At present, a new trend in complex defect reconstruction is to minimize donor site morbidity by using small sized flaps, bi-paddled flaps, multi-paddled flaps, and even chimeric flaps composed of different tissue types [12–14]. Therefore, more thorough ALT flap perforator distribution patterns should be elucidated to make the aforementioned types of flaps successfully designed and harvested. In the present study, we introduced a new design method for ALT flap, namely the 3-5 system. Meanwhile, we examined ALT flap perforators for penetration points through the vastus lateral muscle (VLM) or intermuscular septum, their entry points to the deep fascia, and the distance between these 2 sets of points. The 3-5 system was developed, which could be used to design ALT multi-paddled flaps more easily before the operation. Subsequently, this system was used to harvest ALT multi-paddled flaps in 49 patients. The main characteristic of the 3-5 system is that traditional perforator points are changed to multiple paddles to harvest multi-paddled flaps. Moreover, this new method is complementary to the circle method and the ABC system, which could serve as an alternative design for ALT multi-paddled flaps.

## Material and Methods

A total of 151 free ALT flaps were harvested from 149 patients (132 males and 17 females) over a 26-month period by the same surgeon at the Department of Plastic Surgery, Affiliated Hospital of Zunyi Medical College. All enrolled patients were diagnosed with skin defects requiring debridement and reconstruction with flaps. The mean age  $\pm$  standard deviation (SD) of all the patients was  $38 \pm 12$  years (ranging from 18 to 73 years).

The cutaneous perforators from the first 100 patients participated in the study were examined clinically 1 day before surgery using the Huntleigh Mini Dopplex D-900 unit with an 8 MHz probe (Huntleigh Diagnostics Ltd., Cardiff, UK). All Doppler examinations were performed or verified by the operating physician to avoid interpersonal variations. During the Doppler examination, patients were placed in the supine position with his or her legs in a neutral position (without rotation). The A-line was drawn to connect the anterior superior iliac spine and the superolateral border of the patella. The distance between the 2 points was measured, and midpoint of the A-line was marked with "O". The line connecting the anterior superior iliac spine and the lateral epicondyle of the femur was referred as the B-line. The line connecting the anterior superior iliac spine and the superoanterior border of the patella was the C-line. The E-line was drawn perpendicularly intersecting through the midpoint of the A-line. The D-line was located 5 cm proximal and parallel to the E-line, while the F-line was 5 cm distal and parallel to the E-line. The G-line was 10 cm distal and parallel to the E-line, and the H-line was 15 cm distal and parallel to the E-line. Different zones of the graft donor site were formed when the A- and B-lines intersected with the D-, E-, F-, G-, and H-lines, respectively (Figure 1). Doppler signals were detected in different zones and marked accordingly (Figure 1). Based on the perforator location detected by Doppler signals, ALT flaps were harvested. During the surgery, ALT flap perforator penetration points through the VLM or the intermuscular septum, as well as their entry points into the deep fascia were marked on the skin surface. The perforators between the 2 points were designated as the sub-fascial segment of perforators (SFSP). The length of SFSP was measured, and the course of the vessels was observed. Meanwhile, the number of perforators in different zones was calculated.

Intraoperative mapping of perforators' locations revealed that each ALT flap had perforator penetration points through the VLM or intermuscular septum, which were lateral to the A-line and anterior to the B-line. All ALT flap perforator entry points into the deep fascia were lateral to the C-line and anterior to the B-line. The A-line and B-line intersected with the D-, E-, G-, F-, and H-lines to form zones I, II, III, and IV, respectively. ALT flap perforators with penetration points through the VLM or intermuscular septum in zones II and III might enter the deep



**Figure 1.** The design of the 3-5 system (A); the red points represented Doppler signal from perforators in the zones I, II, III, and IV (B).

**Table 1.** The data of perforators in zone I, II, III, IV (n=51, cm).

	Zone I	Zone II	Zone III	Zone V
Number (branch)	1.22±0.43	1.17±0.51	2.21±0.53	1.31±0.70
No branch (case)/percent (%)	3/6%	5/10%	1/2%	8/16%
SFSP (cm)	1.51±0.96	2.21±0.53	1.87±0.53	1.11±0.47
DBPI (cm)		0.73±0.43	0.72±0.50	

SFSP – subfasial segment of perforators; DBPI – the distance between perforator entry points to deep fascia and I line.

fascia near and lateral to the C-line. To account for this, the line segment between the intersection point of the E-line and C-line, as well as the intersection point of the G-line and C-line were represented as the I-line. This was specifically aimed to mark the locations of ALT flap perforator entry points into the deep fascia that were close to the lines, and to avoid intraoperative perforator damage during ALT flaps elevation. Therefore, a “3-5 system” was fully developed by using 3 longitudinal lines (A, B, and C) and 5 horizontal lines (D, E, F, G, and H). This 3-5 system was used to design ALT flaps in the remaining 51 patients included in the study. However, preoperative Doppler was not used for these 51 ALT flaps.

After the design of the ALT flap was finished, flap harvest and skin defect debridement were conducted simultaneously in the 2 surgical groups. A 20-cm long anterior incision along the C-line was performed. Sub-fascial dissection was performed laterally until all cutaneous perforators were identified. The intermuscular space between the VLM and rectus femoris muscle was entered to trace the perforators back to their origins off the descending branch of the lateral circumflex femoral artery (LCFA). When the perforators penetrated VLM, they were isolated by removing a piece of surrounding circumferential muscle. Therefore, a perforator with a muscle cuff around the vessel could be preserved. Lateral incisions were successfully made along the B-line, which were also extended laterally

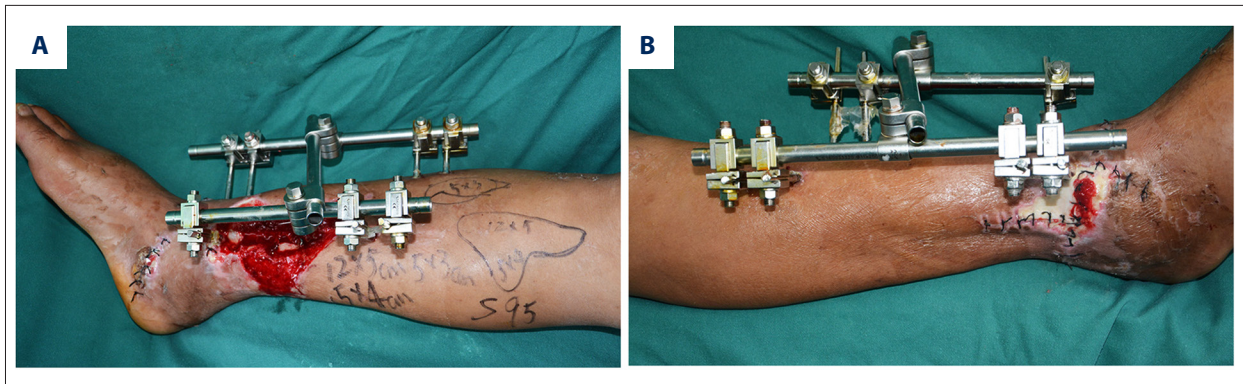
according to the defect size. Before dissecting all perforator, the ALT flaps were not elevated.

The study was conducted according to the principles of the Declaration of Helsinki. Protocols applied in this study and patients’ details were approved by the Ethical Committee of Affiliated Hospital of Zunyi Medical College. Informed consents were obtained before the study.

## Results

In this study, we collected and analyzed the data from 51 limbs in 49 patients older than 18 years old. The average ±SD length of the A-line and F-line was 43.26±1.97 cm and 4.03±0.30 cm, respectively. Both preoperative and intraoperative findings demonstrated that all the ALT flap perforator penetration points through the VLM or intermuscular septum were located laterally to the A-line and anterior to the B-line. Moreover, all ALT flap perforator entry points to the deep fascia were located laterally to the C-line and anterior to the B-line. Some perforator entry points into the deep fascia in zones II and III were found near and laterally to the I-line. The indices of perforators detected intraoperatively are listed in Table 1. The average ±SD number of perforators in zone I was 1.22±0.43, and the average ±SD length of SFSP was 1.51±0.96 cm. Meanwhile, the



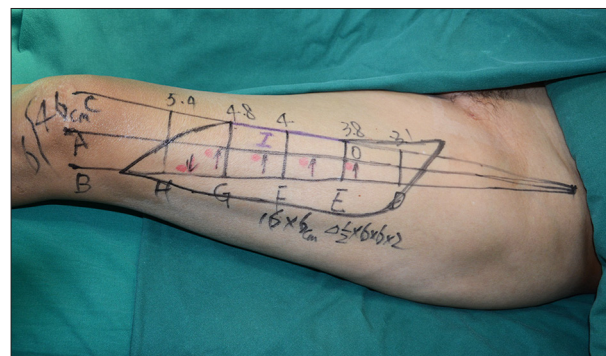


**Figure 2.** Preoperative view: a wound located on the medial malleolus (A) and another wound located on the lateral malleolus (B).

average  $\pm$ SD number of perforators in zone II was  $1.17\pm 0.51$ , and the average  $\pm$ SD length of SFSP was  $2.21\pm 0.53$  cm. The SFSP in zone II took an oblique and anterior course. The average  $\pm$ SD distance between the perforator entry points of the fascia and the I-line was  $0.73\pm 0.43$  cm. The average  $\pm$ SD number of perforators in zone III was  $2.21\pm 0.53$ , and the average  $\pm$ SD length of SFSP was  $1.87\pm 0.53$  cm. The SFSP in zone III took an oblique and anterior course. The average  $\pm$ SD distance between the perforator entry points to the deep fascia and the I-line was  $0.72\pm 0.50$  cm. The average  $\pm$ SD number of perforators in zone IV was  $1.31\pm 0.70$ , and the average  $\pm$ SD length of SFSP was  $1.11\pm 0.47$  cm. Perforators originating from LCFA oblique branches were found in 18 limbs (35.3%). Of all 51 ALT flaps designed with the 3-5 system, 24 were uni-paddled flaps (4 chimeric muscular flaps or fascial flaps), 18 were bi-paddled flaps (6 chimeric muscular flaps or fascial flaps), 7 were tri-paddled flaps (2 had single-paddle necrosis), and 2 were quadro-paddled flaps (1 chimeric muscular flap). Single-paddle necrosis occurred in the non-chimeric quadro-paddled flap. Two flaps developed vein crisis: 1 flap survived and the other became necrotic after secondary surgical exploration. Two donor sites were covered with skin grafts. Four donor sites were covered with homo-lateral V-Y perforator advancement ALT flaps, ranging from  $12\times 5$  cm to  $17\times 6$  cm; 1 flap became necrotic and required the use of a secondary flap. Six donor sites were covered with superficial circumflex iliac perforator flaps, ranging from  $18\times 6$  cm to  $28\times 6$  cm; all 6 flaps survived.

### Case reports

A 49-year-old male patient complained a skin defect caused by trauma. He was admitted to our hospital 3 weeks after external fixation for an open fracture of the right calf. Physical examination revealed external fixation with a stent on the right calf, 2 irregular lesions ( $12\times 5$  cm and  $5\times 3$  cm) over the medial malleolus, and a  $5\times 3$  cm irregular lesion over the lateral malleolus. Full preoperative examination was performed prior to surgery.

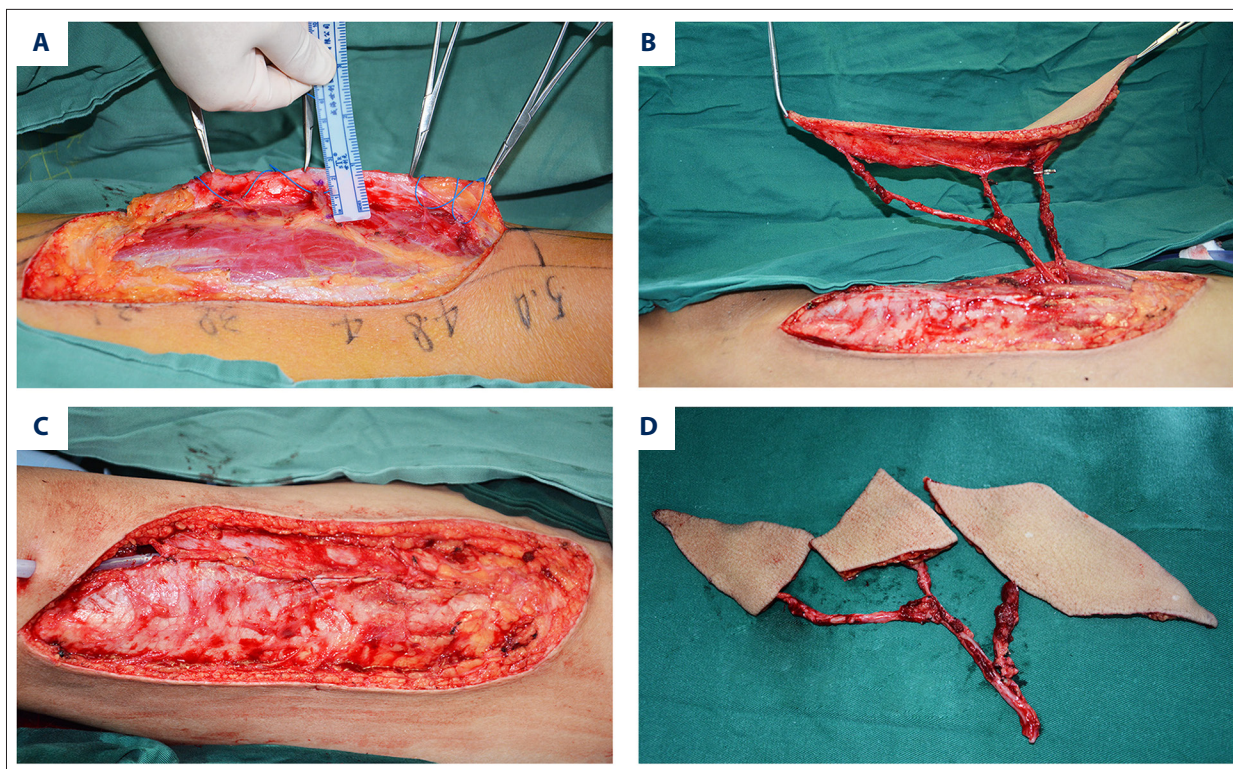


**Figure 3.** Preoperative flap design.

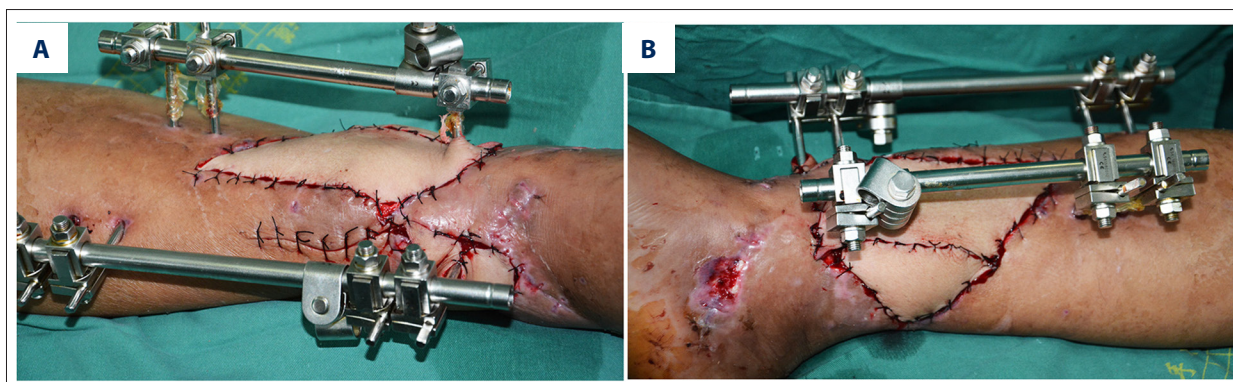
Additional examinations on the skin defects were carried out preoperatively, and the extent of each tissue defect was assessed (Figure 2). There was an irregular wound on the medial crus that could be broken down into 2 areas, including a  $12\times 5$  cm and a  $5\times 4$  cm area. The second wound ( $5\times 3$  cm) was located on the lateral malleolus. The defects covered a total area of approximately  $95$  cm<sup>2</sup>. A flap from the left thigh was designed with the 3-5 system (Figure 3). A rectangular flap ( $6\times 16$  cm in size) with the capability to expand by 20% was designed accordingly. Two  $6\times 6$  cm triangular flaps located on the cranial and caudal ends were also designed. The medial edge of the flap was along the I-line (Figure 3).

The medial incision was made first, and the flap was then dissected along the membrane of the muscle. The perforator penetration points through the VLM or intermuscular septum and their entry points into the deep fascia were detected. SFSPs were measured (Figure 4). Subsequently, superior and inferior borders were dissected, followed by cutting of perforators running through the rectus femoris, whereas those running through the VLM were preserved. After the perforators were dissected out, the lateral side of the flap was dissected, and the flap was removed (Figure 4). The fascia lata and the cutaneous wound were sutured (Figure 4). The flap was divided into 3 paddles based on the configuration of the wound requiring reconstruction (Figure 4) and then transferred





**Figure 4.** The measurement of the length of sub-fascial segment of perforator (A); elevation of the flap (B); the fascia lata was sutured (C); the flap was divided into 3 paddles (D).



**Figure 5.** Early postoperative view of the flap inset: the medial malleolus wound (A); the lateral malleolus wound (B).

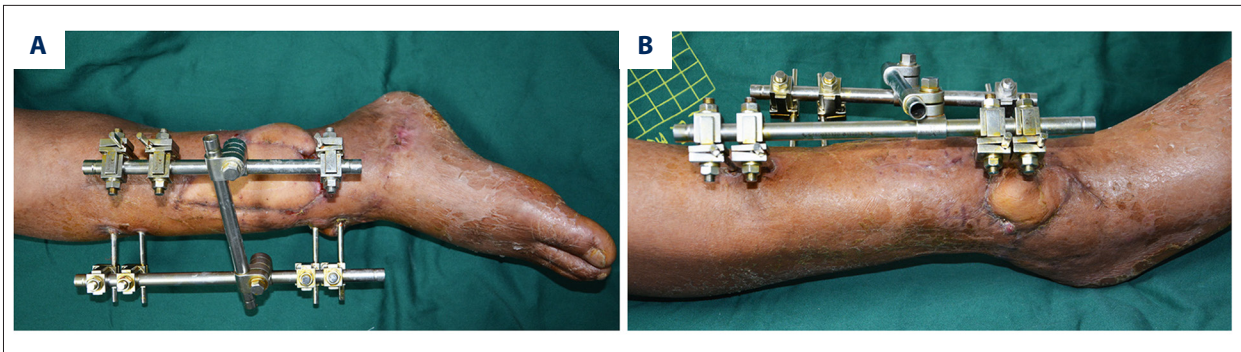
to the defect sites (Figure 5). Follow-up was conducted at least for 40 days after operation. The data revealed a satisfactory flap appearance (Figure 6) and S-shaped linear scar formation (Figure 7). Telephone follow-up continued for a total of 6 months after discharge.

## Discussion

Musculocutaneous and septocutaneous perforators should be dissected out prior to flap removal. Consequently, accurate localization and identification of perforator course and length are

necessary to ensure the optimal preoperative ALT flap designs. There exists great variability with perforators in regard to morphology and anatomy [15,16]. Eliminating the effect of individual differences and anatomical variations is of utmost importance to improve accuracy of perforator localization and operative successful rates in reconstruction surgery. Multiple methods of preoperative ALT flap design currently exist are guided by ultrasonography, color Doppler ultrasound, high frequency color Doppler flow imaging, contrast-enhanced ultrasound, digital subtraction angiography, computer tomography, magnetic resonance angiography, etc. [17–23]. Among them, handheld Doppler is a widely used method due to its simple and convenient procedures.





**Figure 6.** The appearance of flap on the 40<sup>th</sup> postoperative day: the medial malleolus wound (A); the lateral malleolus wound (B).

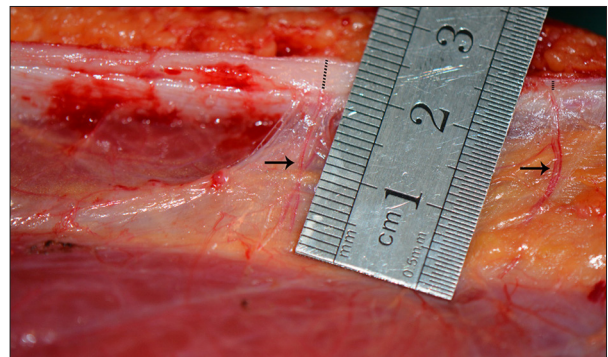


**Figure 7.** S-shaped linear scar formation on the donor site.

However, preoperative handheld Doppler examination is generally not considered as the most accurate method to identify perforators. In our series, the sensitivity of handheld Doppler was high (100%). Some discrepancy between the number of handheld Doppler signals and the number of actual perforators indicated some false positive results. Handheld Doppler may depend both on characteristics of the operator (with individual experience having some effects on the accuracy of Doppler results) and characteristics of the patient (such as patients with high body mass indices in whom the accuracy of handheld Doppler is lower). Our results are consistent with those reported by Yu et al. [11]. Our results considered that the discrepancy in perforators detected by Doppler versus detected intraoperatively was a result of the oblique course of subcutaneous segments of perforators in a thick flap that undermined the ability of the Doppler device to detect the main perforator.

#### The relationship between perforator penetration points through the VLM and the A- or B-lines

The A-line was drawn to connect the anterior superior iliac spine and the superolateral border of the patella, demarcating the body surface projection of the intermuscular space between the VLM and the rectus femoris muscles. In our findings, all perforator penetration points through the VLM were localized lateral to the A-line. Anatomically, the blood supply to the anterior thigh comes from the numerous large-diameter perforators



**Figure 8.** The DBPI (left dotted line) was 0.3 cm; the SFSP (left black arrow) was 2 cm in zone II; the DBPI (right dotted line) was 0.1 cm; the SFSP (right black arrow) was 2.7 cm in zone III. SFSP – sub-fascial segment of perforators; DBPI – the distance between perforator entry points to the deep fascia and the I-line.

deriving from the superficial femoral artery. No branches originating from the LCFA were found to supply blood to the skin over the rectus femoris muscle. Therefore, it is unnecessary to detect ALT flap perforators anterior to the A-line.

The B-line connects the anterior superior iliac spine and the lateral epicondyle of the femur along the anterior border of the iliotibial tract. The iliotibial tract is a longitudinal fibrous reinforcement of the fascia lata. The iliotibial tract and its associated muscles work to extend, abduct, and laterally rotate the hip joint. Additionally, the iliotibial tract contributes to lateral knee stabilization. In our series, all perforator entry points to the deep fascia were located anterior to the B-line.

We hypothesized that the perforators are prone to pierce through the thinner, softer fascia lata rather than the thick and resilient iliotibial tract, which would be difficult to pierce through. Consequently, the perforator penetration points through the VLM should be identified anterior to the B-line.

### The relationship between perforator penetration points through the VLM and the 5 horizontal lines in the 3-5 system

Perforator penetration points through the VLM were detected by Doppler signals and intraoperatively confirmed to be located between the D-line and H-line, with the distance of approximately 20 cm. The blood supply to the lateral thigh proximal to the D-line is derived from the traverse branches of the descending branch of the LCFA. Perforators deriving from the descending branch of the LCFA proximal to the D-line were not found in our series. Most large perforators were localized in zones I, II, and III, which were in congruence with previous findings. Perforators deriving from the descending branch of the LCFA distal to the H-line were small and frequently anastomosed with branches of the superior genicular artery, providing no blood supply to the skin. The probability of perforators originating from oblique branches of the LCFA in zone I was greater than those of other zones. In our series, the perforators were found to originate from oblique branches in 53 (35.1%) limbs. The perforators in zone IV were small. In the microsurgery, perforators in zone IV may be used to design perforator flaps, particularly multi-paddled flaps. In our series, 1 of the 3 multi-paddled flaps become necrotic because of thin perforators and vasospasm. Understanding perforator distribution patterns facilitates small flap size, and bi-paddled and multi-paddled flap designs.

### Distance between perforator penetration points through the VLM or intermuscular septum and perforator entry points into the fascia

The perforator segment between the penetration point through the VLM or intermuscular septum and the entry point to the deep fascia was labeled the sub-fascial segment of perforators (SFSP). Data of the SFSP in 4 zones were as follows. In zone I, the average  $\pm$ SD length of SFSP was  $1.51\pm 0.96$  cm, and most perforators had an oblique, lateral, and upward course. When the Doppler probe was focused on the perforator blood flow, the signals were louder and easier to detect. In zone II, the average  $\pm$ SD length of SFSP was  $2.21\pm 0.53$  cm, and most perforators took an anterior course. In zone III, the average  $\pm$ SD length of SFSP was  $1.87\pm 0.53$  cm with most perforators taking an anterior course. In zone IV, the average  $\pm$ SD length of SFSP was  $1.11\pm 0.47$  cm with most perforators taking a lateral and downward course. The perforator entry points to the deep fascia in zones II and III were located close to and lateral to the I-line, with a minimum distance of 0.1 cm between the perforator entry point of the fascia and the I-line (Figure 8). To avoid risk of damage to the perforators, the anterior incision along the I-line should preferably be made close to the vastus medialis muscle.

An absence of perforators was found in all zones with varying frequencies: 6% in zone I, 10% in zone II, 2% in zone III, and

16% in zone IV. However, no cases existed where perforators were absent from all 4 zones simultaneously. In 1 case, perforators were absent from both zones I and IV. In all other cases, perforator absence occurred only in a single zone. Therefore, localization of perforator penetration points through the VLM or intermuscular septum in all 4 zones is feasible. Similar to Yu's ABC system, the 3-5 system can be used to design and harvest ALT flaps without the need for preoperative handheld Doppler.

Two triangular flaps were designed on the ends of the ALT flap to account for a shortage of flap tissue after flap contraction. The 2 ends of the donor site can be easily and primarily closed without dog-ear formation. This allows for utmost tissue preservation at the donor site [20]. One research group from Japan found that dog-ear formation was limited when S-shaped skin resection was performed. Consequently, the S-shaped scar formation is ideal [24], as was seen in our patient. Caution should be taken, however, with additional perforator dissections, which increase the risk of damage to the VLM and have the potential to increase risk of wound infection. Additionally, the more paddles that are harvested, the more scars that are formed. With the axis of the proximal triangular flap going medially and the axis of the distal triangular flap going laterally, an S-shaped suture was formed to avoid the effects of a linear scar on the hip and knee joints. Although donor-site complications from ALT flaps have been well documented [25–30], the long-term results and complications from our series of patients should also be observed.

In our series, single-paddle necrosis occurred in 3 cases. The absence of a paddle blood supply was found in 1 case immediately after the flap was harvested and on the first day post-operatively in the other 2 cases. Originally, we thought blood supply deficiency resulted from skeletonized perforator vessels and consequent vasospasm. Therefore, preservation of some muscle cuff surrounding the perforators should be performed during dissection to reduce the risk of flap necrosis. Some have proposed that perforators with small caliber and bad quality should not be used. The influence of the donor site on the motor function of the hip and knee joints is limited when the fascia lata is harvested over the thigh.

## Conclusions

Preoperative handheld Doppler examination is unnecessary when using the 3-5 system to design ALT multi-paddled flaps. ALT flap perforator penetration points through the VLM or intermuscular septum were located lateral to the A-line and anterior to the B-line. ALT flap perforator entry points to the deep fascia were located lateral to the C-line and anterior to the B-line. Meticulous anatomical zoning facilitates small sized flaps, and bi-paddled and multi-paddled flap designs.

## Conflict of interest

None.

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