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# Perforator navigation using color Doppler ultrasound and three-dimensional reconstruction for preoperative planning of optimal lateral circumflex femoral artery system perforator flaps in head and neck reconstruction

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**KEYWORDS**
Color Doppler ultrasound and three-dimensional reconstruction;
Perforator navigation;
Algorithm;

**Summary** *Background:* The authors introduce an algorithm for preoperative planning of optimal lateral circumflex femoral artery system perforator flap (LCFAPF) supplied by the best quality and the easiest dissection of the perforators and the source vessels for simplified and customized strategies in head and neck reconstruction with perforator navigation using color Doppler ultrasound and three-dimensional reconstruction (3D-CDUS PN).
*Methods:* Between June 2011 and September 2015, a prospective cohort study was performed with an algorithm based on defect site, perforator type, and pedicle length using 3D-CDUS PN to select optimal perforators arising from the different branches of LCFA in 108 patients. The

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Anterolateral thigh perforator flap;
Anteromedial thigh perforator flap;
Tensor fascia lata perforator flap

optimal perforator and flap were determined by perforator caliber and quality, difficulty in flap dissection, and length of the source vessels. Cause and classification of the defect, flap choice, recipient vessels, postoperative course, and complications were analyzed.
*Results:* The source vessels of the perforators were lateral descending branch in 73 cases and oblique branch in 17 cases with ALTPFs, medial descending branch in 12 cases with AMTPFs, and ascending branch in 6 cases with TFLPFs. Straightforward dissection of flaps with septocutaneous ($n = 40$) and semi-septocutaneous ($n = 17$) perforators was performed in 52.8% cases. Successful exploration rate and overall flap survival rate were both 100%. Satisfactory functional and esthetic results in both recipient and donor sites with no serious complications were observed in all patients.
*Conclusions:* Our algorithm using 3D-CDUS PN facilitates selection of optimal flap with better caliber and quality of the perforators and sufficient pedicle length for easy dissection.


## Background

With the development of the perforator flap and the "free-style" concept,[1] modern head and neck reconstruction should be focused on customized reconstruction with not only good postoperative appearance and function but also ease of execution and low donor site morbidity. Free anterolateral thigh perforator flap (ALTPF) is the most popular and versatile technique with many benefits[2-4] to restore head and neck defects. The common source vessel of the ALTPF is the descending branch of the lateral circumflex femoral artery (dLCFA), but some anatomic variations occasionally exist in that the perforators of the ALTPF also originate from the transverse branch or ascending branch of the LCFA (aLCFA).[5] Another branch, named the oblique branch of the LCFA (oLCFA) by Wong et al.,[6] was reported as an alternative source vessel for harvest of the ALTPF.[4,6-10]

For cases without a sizeable perforator in the ALT, a free anteromedial thigh perforator flap (AMTPF)[11-18] harvested from the AMT and a free tensor fascia lata perforator flap (TFLPF)[19-23] harvested from the superolateral thigh can be used as backup flaps for head and neck reconstruction.[24,25] The common source vessels to the AMTPF and TFLPF are the medial dLCFA[12] and the aLCFA,[19-23] respectively.

In actuality, these four branches of the LCFA are in close proximity and similar, and the location of three flaps is usually overlapping so that the AMTPF and TFLPF have the same attributes as those of the ALTPF (Figure 1), and these flaps can be categorized as LCFA system perforator flaps (LCFAPF).[12] Therefore, the AMTPF and TFLPF should be not only the alternative and backup flaps of the ALTPF but also the workhorse for head and neck reconstruction. However, the AMTPF and TFLPF are not as familiar and popular as the ALTPF because of their shortcomings, which include inconsistent presence of perforator and source vessels, relatively shorter pedicle length, and thicker subcutaneous tissue than the latter.

Nevertheless, the anatomical variation of perforators and branches of the LCFA is unpredictable, and the harvest of LCFAPFs may be challenging even for skilled and experienced surgeons. Therefore, perforator navigation by imaging techniques may reveal precise anatomical information about perforators and source vessels to improve surgical accuracy and save operative time. Among the available imaging techniques, color Doppler ultrasound can provide perforator information with more than 96.7% sensitivity and positive predictive value[26] so that satisfactory results of contrast-enhanced color Doppler ultrasound and three-dimensional reconstruction (3D-CDUS) in perforator navigation have been achieved.[27-29]

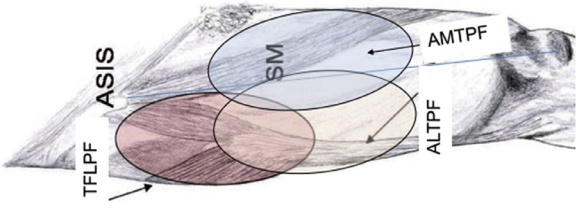


**Figure 1** Flap design sites in three LCFA system flaps. ASIS, anterior superior iliac spine, SM, sartorius muscle, ALTPF, anterolateral thigh perforator flap; AMTPF, Anteromedial thigh perforator flap; TFLPF, Tensor fascia lata perforator flap.

Although our previous results of perforator investigation are acceptable,[4,27-29] the drawbacks of contrast-enhanced ultrasound include allergic reactions to the contrast agent and the additional expense. To overcome these shortcomings and to promote the role of ultrasound investigation in perforator navigation, a prospective cohort study on preoperative perforator navigation using non-enhanced 3D-CDUS to investigate and locate the perforators of the thigh has been performed since 2011. The aim of this study was to facilitate preoperative planning of the optimal LCFAPFs and to identify the best-quality perforators and their source vessels, thereby simplifying dissection and allowing for customized strategies in head and neck reconstruction. In addition to good postoperative results being achieved by preoperative perforator navigation, satisfactory outcomes with AMTPF and TFLPF relied on appropriate indications; hence, an algorithm for the selection of optimal LCFAPFs was developed by the authors. In this article, we describe our experience in preoperative planning of LCFAPFs surgery with perforator navigation by 3D-CDUS and introduce the algorithm for the optimal LCFAPFs based on defect site, perforator type, and pedicle length to shorten the operative time and reduce donor site morbidity.

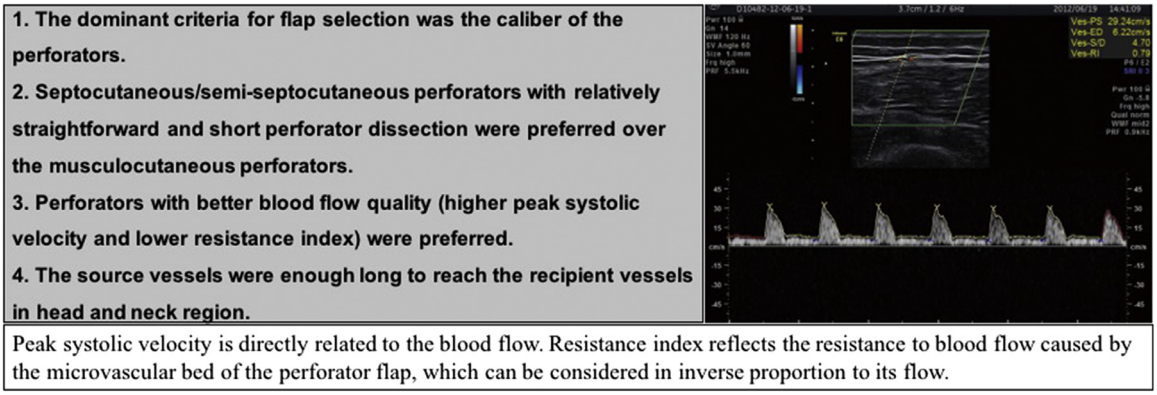


**Figure 2** Our perforator and flap selective criteria. Perforator quality is measured through peak systolic velocity and resistance index.

## Patients and methods

### Patients

Between June 2011 and September 2015, 108 consecutive patients with malignant tumors or acquired defects of the head and neck region underwent reconstruction with LCFAPFs by a single surgical team in our department. Patients who accepted reconstruction with non-LCFAPFs (myocutaneous flaps or other source vessels) were excluded. The sample consisted of 57 males and 51 females with an average age of 50.79 years (range 12–76 years). All flaps were preoperatively planned by perforator navigation using 3D-CDUS to select the optimal perforators arising from the different branches of the LCFA system. Approval for the study was obtained from the research ethics committee of our hospital.

### Ultrasonic device

A GE Voluson E8 ultrasonic device (GE Healthcare, Little Chalfont, United Kingdom) with a 10- to 16-MHz linear probe and a volume probe was used. For the investigation, a 7.5-MHz color Doppler flow meter with its color Doppler flow imaging set in the most sensitive but least noise-generating condition was used to evaluate each case in the same reproducible way.

### Perforator evaluation with 3D-CDUS

All planning of the optimal LCFAPFs was made by two senior ultrasonic radiologists (L. G. L. and H. H. Z.) with long experience in CDUS examinations and analysis in combination with a senior head and neck surgeon (Y. S.) with extensive experience in flap surgery. During the 3D-CDUS investigation, the lower limbs of the patient were held in a supine position that allowed for the best exposure of the investigated area, and this was the most convenient way for the ultrasonic radiologist.

CDUS examination was based on a 2-dimensional image, with the linear probe initially placed on each patient's bilateral thighs to identify the location and course of the perforators. The scanning process started at the base of the thigh, and the proximal end of the limb, then, moved gently and gradually to the distal end of the limb, until the knee joint area. All perforators were marked accurately on the thigh skin, which pointed out that it just perforated the muscle superficial fascia; hence, further analysis of the hemodynamic blood flow could be performed. The perforator data included location, course, number, caliber and quality of the perforators, and the source vessel, all of which were evaluated carefully and recorded. Perforator quality was measured through peak systolic velocity and the resistance index (Figure 2). Subsequently, 3D-CDUS scanning and reconstruction of the vascular network including the vessel axis and the course of perforators in the thighs were performed with the volume probe.

### Perforator and flap selection criteria

The optimal perforator and flap were determined by four factors: caliber of the perforators, perforator quality, difficulty in flap dissection, and the length of source vessels. According to the selection criteria (Figure 2), the flap with better caliber and quality of perforators and enough long pedicle to be dissected easily was preferred in preoperative planning.

### The algorithm in preoperative planning of the optimal LCFAPFs

Our algorithm in head and neck reconstruction was based on defect site, perforator type, and pedicle length (Figure 3). To summarize, to shorten the operative time and reduce donor site morbidity,[27] optimal LCFAPFs with septocutaneous/semi-septocutaneous perforator(s) were preferred in preoperative planning with perforator navigation. Among them, AMTPF (dLCFA) and TFLPF were the preferred selection for the defects in the lower 1/3 face, oral cavity, oropharynx, larynx, and neck. For other defects or cases with vessel-depleted neck, ALTPF (dLCFA) was the first option. For the cases without septocutaneous/semi-septocutaneous perforator, the lateral dLCFA was selected as the source vessel to harvest the ALTPF with musculocutaneous perforators. ALTPF with the oLCFA as the source

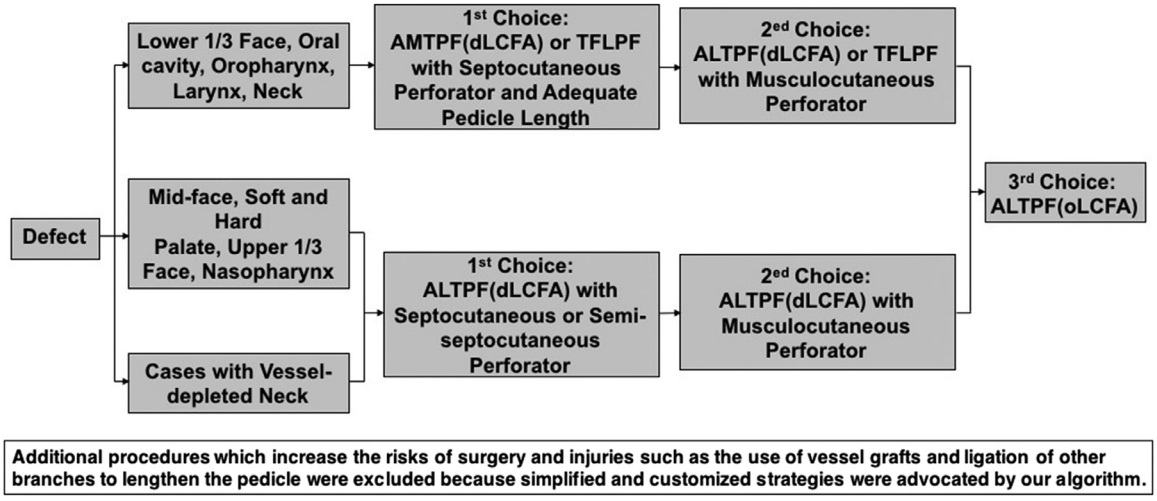


**Figure 3** Our algorithm for preoperative planning of the optimal LCFA system perforator flaps is based on defect site, perforator type, and pedicle length in head and neck reconstruction. ALTPF, anterolateral thigh perforator flap; AMTPF, Anteromedial thigh perforator flap; TFLPF, Tensor fascia lata perforator flap; dLCFA, descending branch of the lateral circumflex femoral artery; oLCFA, oblique branch of the lateral circumflex femoral artery.

**Table 1** Defect location, content, and reconstructive timing in 108 patients.

| Defect location | Defect content | | Reconstructive timing | | No. of cases |
|---|---|---|---|---|---|
| | Soft tissue defect | Soft and hard tissue defect | Primary | Secondary | |
| **Frontal and temporal region** | 0 | 8 | 8 | 0 | 8 |
| **Maxilla and midface** | 6 | 7 | 8 | 5 | 13 |
| **Oral cavity and oropharynx** | 56 | 0 | 55 | 1 | 56 |
| **Mandible and lower face** | 3 | 24 | 22 | 5 | 27 |
| **Parotid region and lateral face** | 1 | 3 | 4 | 0 | 4 |
| **Total** | 66 | 42 | 97 | 11 | 108 |

vessel was our alternative choice for some cases with no ideal perforator from the dLCFA.

### Intraoperative procedures in harvesting LCFAPFs

All LCFAPF harvests were performed by the senior surgeon (Y. S.). Flap size was determined by the ablative oncologic and debridement defects. The skin paddle was designed with the marked perforators within the flap. After the medial border of the ALTPF or TFLPF was incised, the flap was raised laterally through the suprafascial or subfascial plane to identify the perforators, whereas the lateral border of AMTPF was first incised and the flap was elevated medially. Once the designated dominant perforators of the ALTPF were identified, the septum between the rectus femoris and vastus lateralis muscles was opened to expose the lateral dLCFA and/or oLCFA. The perforators were then dissected and traced to the source vessel by a combined retrograde and antegrade approach. Finally, the lateral border of the skin paddle was incised, and harvest of the ALTPF was completed after the pedicle was divided. For AMTPF, the septum between rectus femoris and sartorius muscles was opened to expose the medial dLCFA. As for TFLPF, septocutaneous perforators originating from the aLCFA could be found at one of two septae (anterior septum between rectus femoris and TFL muscles and posterior septum between TFL and gluteus medius muscles); hence, the flap was preferentially raised laterally. Once the designated dominant perforators of the AMTPF and TFLPF were identified, the technique of flap harvest was similar as that of the ALTPF. After the flap was transferred to the defect and shaped, anastomoses were done between recipient and donor vessels.

### Postoperative assessment and follow-up

The length and caliber of the divided flap pedicle were measured and recorded. Cause and classification of the defects, flap choice for reconstruction, flap dissection time, and recipient vessels, as well as postoperative course and complications, were recorded and analyzed. The patients were examined to assess wound healing in donor and recipient sites, function, and esthetics every 3–6 months during follow-up.

## Results

The data of defect location, content, and reconstructive timing are shown in Table 1. A total of 190 perforators with the caliber of 0.6–1.2 mm were identified by preoperative

3D-CDUS. All preoperatively located perforators were confirmed intraoperatively and used to harvest LCFAPFs; 3 additional perforators were found during surgical dissection and were incorporated into the flap. Therefore, the positive predictive value of 3D-CDUS for perforators was 100% with a false-positive rate of 0 and a false-negative rate of 1.6% (3/193). The perforator courses, source vessels, and types of flap are listed in Table 2. Straightforward dissection of flaps with septocutaneous/semi-septocutaneous perforators was performed in 52.8% (57/108) cases.

Flap data and dissection times are given in Table 3. Flap size ranged from $7 \times 3.5$ cm to $25 \times 11$ cm (mean, $15.3 \times 7.8$ cm). Primary thinning of the flap was performed in 4 patients who underwent oral reconstruction with ALTPF ($n = 3$) and AMTPF ($n = 1$). Primary closure of the donor site was completed in 106 patients, and closure of an extensive donor wound with a regional pedicled AMPTF supplied by the superficial femoral artery was performed in the remaining 2 patients. The recipient arteries and veins used for anastomoses are listed in Supplementary Tables 1 and 2, respectively.

## Perioperative complications and follow-up

Perioperative complications for vascular anastomoses are shown in Supplementary Table 3. All the flaps healed uneventfully with no other perioperative complications. The successful exploration rate and the overall flap survival rate were both 100%. During the follow-up period (range, 6–60 months), satisfactory functional and esthetic results without serious complications in both recipient and donor sites were observed in all patients.

## Discussion

Perforator flaps, which do not require the sacrifice of important muscles and main vessels, have been popular for the reconstruction of various defects so that customized reconstruction with good postoperative results and low donor site morbidity can be achieved. However, dissection of musculocutaneous perforators during flap harvest inevitably increases operative time and complexity, as well as the risk of perforator injury, especially for the musculocutaneous perforator with a long and tortuous intramuscular course.

Contrast-enhanced 3D-CDUS using SonoVue (Bracco Imaging, Geneva, Switzerland) as the contrast agent was applied by us in perforator navigation and flap design to improve the quality of conventional CDUS with feasible and accurate results.[27,29] The effect of the contrast agent is to improve the echo signal of the ultrasound, making the sonographer more clear on the tinier blood vessels. However, the purpose of this study was to look for a larger and better perforator to improve flap blood supply and survival rate. Hence, the tinier blood vessels were not preferred, and that is why we did not use an ultrasound contrast agent in this study. Furthermore, this additional study was conducted to address the issues of contrast agent allergic reactions and the additional expense of using contrast agent. It was found that similar results of preoperative planning could be achieved

**Table 2** Perforator course and types of flap in 108 patients.

| Flap | Perforator origin | No. of cases | Perforator course | | | Type of flap | | |
|---|---|---|---|---|---|---|---|---|
| | | | Septocutaneous | Semi-septocutaneous | Musculocutaneous | Fasciocutaneous | Adipofascial | Chimera |
| ALTPF | Lateral dLCFA | 73 | 21 | 12 | 40 | 41 | 0 | 32 |
| | oLCFA | 17 | 4 | 4 | 9 | 14 | 1 | 2 |
| AMTPF | Medial dLCFA | 12 | 11 | 1 | 0 | 9 | 1 | 2 |
| TFLPF | aLCFA | 6 | 4 | 0 | 2 | 5 | 0 | 1 |
| Total | - | 108 | 40 | 17 | 51 | 69 | 2 | 37 |

ALTPF, anterolateral thigh perforator flap; AMTPF, Anteromedial thigh perforator flap; TFLPF, Tensor fascia lata perforator flap; dLCFA, descending branch of the lateral circumflex femoral artery; oLCFA, oblique branch of the lateral circumflex femoral artery; aLCFA, ascending branch of the lateral circumflex femoral artery.

**Table 3** Flap data and dissection times in 108 patients.

| Flap | No. | Flap size (cm) | Flap pedicle | Average length of divided pedicle (cm) | Average caliber of divided pedicle (mm) | Average dissection time (min) |
|---|---|---|---|---|---|---|
| **ALTPF** | 73 | $7 \times 3.5$—$25 \times 9$ | Lateral dLCFA | $8.79 \pm 1.42$ (6.0-14.0) | $2.41 \pm 0.35$ (1.90-2.90) | $88.70 \pm 17.79$ (55.0-120.0) |
| **ALTPF** | 17 | $8 \times 6$—$18 \times 8.5$ | oLCFA | $8.71 \pm 1.65$ (6.0-12.0) | $1.37 \pm 0.22$ (1.00-1.60) | $94.71 \pm 17.81$ (60.0-120.0) |
| **AMTPF** | 12 | $7 \times 5$—$25 \times 11$ | Medial dLCFA | $8.01 \pm 0.79$ (6.0-9.0) | $2.15 \pm 0.31$ (1.80-2.50) | $51.25 \pm 6.50$ (40.0-60.0) |
| **TFLPF** | 6 | $7 \times 4$—$25 \times 9$ | aLCFA | $6.83 \pm 0.75$ (6.0-8.0) | $2.50 \pm 0.38$ (2.00-2.95) | $67.50 \pm 12.55$ (50.0-80.0) |

ALTPF, anterolateral thigh perforator flap; AMTPF, Anteromedial thigh perforator flap; TFLPF, Tensor fascia lata perforator flap; dLCFA, descending branch of the lateral circumflex femoral artery; oLCFA, oblique branch of the lateral circumflex femoral artery; aLCFA, ascending branch of the lateral circumflex femoral artery.

by 3D-CDUS with or without a contrast agent using the same analyzed parameter. The role of 3D-CDUS in perforator navigation lies in accurate preoperative flap planning, selection of the optimal flap, reduction in the risk of surgery, and effective guidance during flap surgery to shorten the operative time and reduce the donor site morbidity. Easy and straightforward dissection could be performed by identifying septocutaneous perforators with a short septal course and semi-septocutaneous perforators that penetrate part of the septum and the thin part of the muscle.

On the basis of accurate perforator navigation using 3D-CDUS to locate the perforators of the thigh, the authors developed an algorithm for the selection of the optimal LCFAPFs to reconstruct head and neck defects. Perioperative complications occurred in 6 patients and were due to problems with the vascular anastomoses rather than flap dissection. Successful exploration and reanastomosis yielded an overall flap survival rate of 100%, which was directly related to the algorithm for the selection of optimal flap, suitable perforator, and source vessels following accurate preoperative perforator navigation by 3D-CDUS.

However, no more than 35% of perforators located in the ALT are septocutaneous perforators[3,4,30] (Figure 4 and Supplementary Figure 4). On the other hand, almost 100% of perforators originating from the medial dLCFA are septocutaneous perforators, although only approximately 50% of medial dLCFAs running medially at the septum between the rectus femoris muscle and sartorius muscle give off a perforator to the AMT.[11,14,31] Therefore, an AMPTF with a septocutaneous perforator is preferred over an ALPTF with a musculocutaneous perforator by the authors, especially for the defects under the plane of the soft palate in the head and neck region. The drawback of the AMPTF is a relatively short pedicle compared with that of ALTPF because the medial dLCFA originates from the lateral dLCFA based on evidence in the literature[11-17] and the measurement of the authors. The average length of medial dLCFA is $8.01 \pm 0.79$ cm in our series, which is in accordance with that in the literature.[14-17] Other attributes of the medial dLCFA and AMT are only one accompanying vein and relatively small caliber vessels, as well as thicker subcutaneous tissue and hairless skin, than that of the lateral dLCFA and ALT. The authors recommend that AMT should be an ideal donor site for intraoral reconstruction because of its hairless skin and septocutaneous perforator. AMTPF is now our primary flap for the reconstruction of defects under the plane of the palate when the septocutaneous perforator and medial dLCFA have sufficient length as identified by preoperative perforator navigation (Figure 5 and Supplementary Figure 5). It also can be used in some cases with maxillary and midface defects when there is adequate pedicle length to reach the cervical or superficial temporal vessels.[32,33]

Furthermore, some musculocutaneous perforators arising from the branch to the rectus femoris muscle, which originates from the dLCFA before it divides into lateral and medial branches,[12] can also be found in the AMT. These perforators are usually too small to harvest without taking a muscle cuff to avoid injury so that it is not advisable. Other perforators in the AMT also originate from the superficial and deep femoral artery in addition to the medial dLCFA and rectus femoris muscle branch of the LCFA.[14-17, 34] These are often short and small, making them better candidates for regional flap closure of thigh wounds rather than head and neck defects.

Our indication for a TFLPF is the same as that for an AMTPF because of their similar anatomical attributes, with more septocutaneous perforators and a shorter source vessel than the ALTPF. Although the majority of septocutaneous perforators originating from the aLCFA are located in the posterior septum,[19,20] some septocutaneous perforators are also identified at the anterior septum in our cases (Figure 6 and Supplementary Figure 6) in accordance with the reports.[21,22] If there is no septocutaneous perforator, musculocutaneous perforators originating from the aLCFA can be identified with a short course in the TFL muscle.[19,23,25] The scar of TFLPF can be hidden by the underwear compared to that of the ALTPF and AMTPF, which is a better choice for patients who care about an inconspicuous donor site. It is notable that the length of the aLCFA is the shortest ($6.83 \pm 0.75$ cm in our series) among the branches of the LCFA so that the TFLPF is often not an ideal option for cases with a vessel-depleted neck after previous surgery, trauma, and radiotherapy. The authors do not suggest ligating other branches to the quadriceps muscle to increase pedicle length, as it increases the complexity of the procedure and risks of quadriceps muscle ischemia and necrosis.

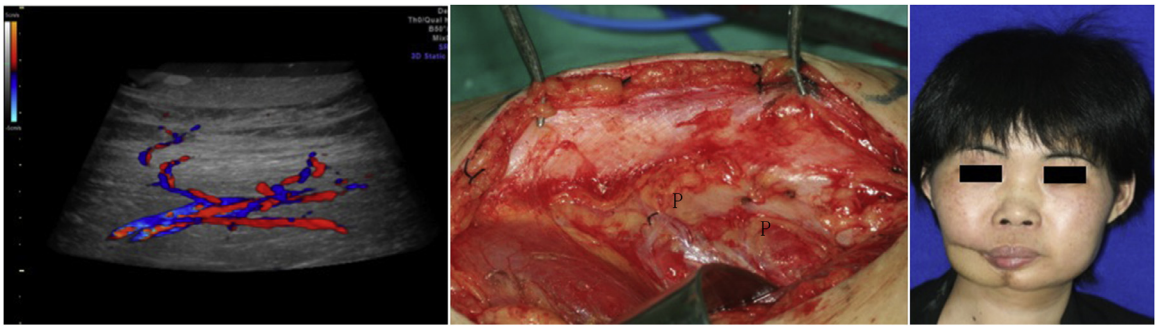


**Figure 4** A 32-year-old female with a neurofibrosarcoma of the right mandible underwent segmental mandibulectomy involving extraoral and intraoral soft tissue and reconstruction with an ALTPF. Preoperative 3D-CDUS images identified two dominant septocutaneous perforators (19.30 cm/s and 29.24 cm/s of peak systolic velocities, 0.73 and 0.79 of resistance indices, respectively) originating from the lateral descending branch and one septocutaneous perforator (12.8 cm/s of peak systolic velocity and 0.95 of resistance index) originating from the medial descending branch in the right thigh, whereas only a single musculocutaneous perforator (12.8 cm/s of peak systolic velocity and 0.95 of resistance index) originated from the lateral descending branch in the contralateral thigh. Therefore, the right ALT with two septocutaneous perforators was selected. In addition, the two septocutaneous perforators enabled us to divide the flap into two parts to reconstruct intraoral and extraoral defects with reliable circulation. (Left) Three-dimensional reconstruction imaging showed two dominant septocutaneous perforators at the septum between the vastus lateralis muscle and rectus femoris muscle originating from the lateral descending branch, and one of them divided into two subperforators to the fascia. (Central) Surgical dissection confirmed the accuracy of information gained preoperatively regarding the perforators (P). (Right) Excellent cosmetic outcome of the lower 1/3 face at 6-month follow-up.

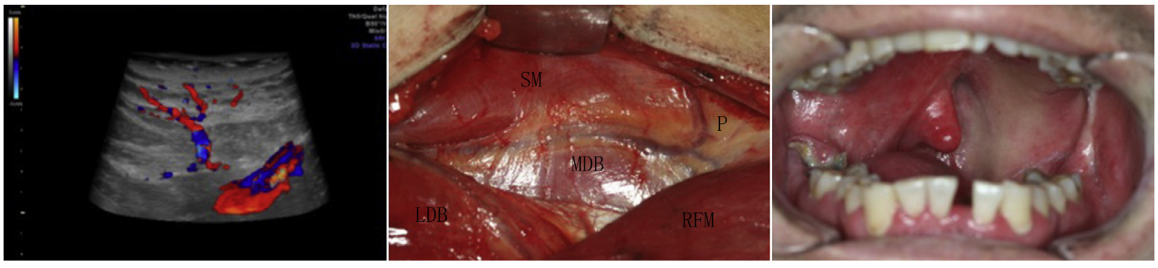


**Figure 5** A 47-year-old male with a recurrent squamous cell carcinoma in the left base of the tongue and lateral oropharyngeal wall after surgery of a primary lesion in the left soft palate, underwent extensive resection and reconstruction with an AMTPF. Preoperative 3D-CDUS images identified two subperforators arising from one large septocutaneous perforator originating from the medial descending branch (MDB) and two subperforators arising from one dominant septocutaneous perforator originating from the lateral descending branch (LDB) in the right thigh, whereas only one small musculocutaneous perforator originated from the lateral descending branch was in the contralateral thigh. Septocutaneous perforators of the right thigh had similar blood flow velocity, with a peak systolic velocity of 22.60 cm/s on the medial side and 16.70 cm/s on the lateral side, and a resistance index on the medial side of 0.66 and lateral side of 0.67. Therefore, a right AMTPF was selected. (Left) Three-dimensional reconstruction imaging showed one big septocutaneous perforator in the septum between the sartorius muscle (SM) and rectus femoris muscle (RFM) originating from the medial descending branch rather than the superficial femoral artery in the right thigh, which divided into two subperforators to the fascia. (Central) Surgical dissection confirmed the accuracy of information gained preoperatively regarding the perforator (P). (Right) Excellent intraoral appearance and mouth opening outcome at 13-month follow-up.

For the defects above the plane of the palate in the cranio-maxillofacial region and cases with a vessel-depleted neck, the ALTPF is the preferred flap due to adequate length of the lateral dLCFA. Although the majority of perforators originating from the lateral dLCFA are musculocutaneous perforators, straightforward dissection of septocutaneous/semi-septocutaneous perforators were still completed under the guidance of accurate perforator navigation using 3D-CDUS in this study. In cases without a suitable perforator from the lateral dLCFA, the oLCFA is an alternative source vessel for harvesting the ALTPF (Supplementary Figure 7). The oLCFA is our last choice because of its smaller caliber, longer intramuscular course running through the vastus lateralis muscle, and less than 50% presence than the lateral dLCFA. In addition to caliber and course of the oLCFA, the average dissection time of ALTPF with this vessel was the longest among that of the four branches and flaps used in this study, hence making these dissections the most difficult with the greatest risk of damage.

The differences in LCFAPFs are summarized in Table 4. To minimize the difficulty of perforator flap surgery, straightforward dissection of an AMPTF or TFLPF is often easier than harvesting an ALPTF with a musculocutaneous perforator.

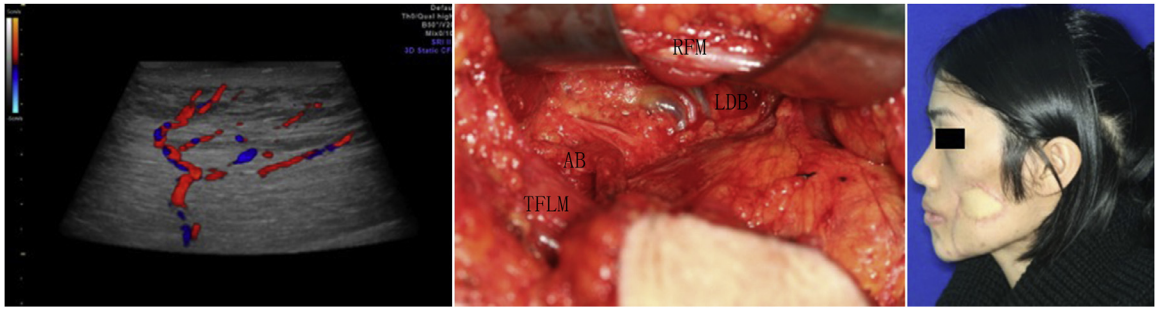


**Figure. 6** A 23-year-old female with scar contracture and a buccal fistula after surgery for a rhabdomyosarcoma followed by radiotherapy underwent debridement and reconstruction with a TFLPF. Preoperative 3D-CDUS imaging identified two subperforators arising from one dominant septocutaneous perforator in the septum between the TFL muscle (TFLM) and rectus femoris muscle (RFM) superficially originating from the ascending branch (AB) and one musculocutaneous perforator originating from the lateral descending branch (LDB) in the right thigh. No perforator originating from the medial descending branch was observed in the ipsilateral thigh. Perforators similar but smaller than those of the right thigh were found in the contralateral thigh. Therefore, a right TFLPF with one septocutaneous perforator originating from ascending branch was selected. (Left) Three-dimensional reconstruction imaging showed one septocutaneous perforator in the septum between the TFL muscle and rectus femoris muscle originating from the ascending branch, which divided into two subperforators to the fascia. (Central) Surgical dissection confirmed the accuracy of information gained preoperatively regarding the perforator. (Right) Excellent cosmetic outcome of lateral face at 6-month follow-up.

**Table 4** The differences in LCFA system perforator flaps.

| | ALTPF (dLCFA) | ALTPF (oLCFA) | AMTPF | TFLPF |
|---|---|---|---|---|
| **Common source vessel** | Lateral dLCFA | oLCFA | Medial dLCFA | aLCFA |
| | Constant | Variant | Variant | Constant |
| | Long (9-16 cm) | Relatively short (8-10 cm) | Relatively short (8-10 cm) | Short(6-8 cm) |
| | Large caliber | Small caliber | Relatively small caliber | Large caliber |
| | Two accompanying veins | Two accompanying veins | One accompanying vein | Two accompanying veins |
| **Dominant perforator** | Septocutaneous <15% | Musculocutaneous> Septocutaneous | Mainly Septocutaneous | Septocutaneous> Musculocutaneous |
| | $n \geqq 1$ | $n \geqq 1$ | $n \geqq 1$ | $n \geqq 1$ |
| | Present rate $\leqq$ 100% | Present rate $\leqq$ 50% | Present rate $\leqq$ 55% | Present rate $\leqq$ 100% |
| | Long course | Relatively long course | Short course | Short course |
| **Flap location at thigh** | Lateral mid 1/3 | Lateral mid 1/3 | Medial mid 1/3 | Lateral upper 1/3 |
| **Flap width for primary closure** | 9 cm | 9 cm | 12 cm | 10-12 cm |
| **Fat thickness** | Thick | Thick | Thicker | Thicker |
| **Dissection difficulty** | Difficult | Difficult | Easy | Relatively easy |
| **Donor site appearance** | Conspicuous | Conspicuous | Relatively inconspicuous | Inconspicuous |
| **Musculomyocutaneous perforator in muscle** | Vastus lateralis muscle | Vastus lateralis muscle | Rectus femoris muscle | Tensor fascia lata muscle |
| **Clinical application** | Popular | Limited | Limited | Limited |

ALTPF, anterolateral thigh perforator flap; AMTPF, Anteromedial thigh perforator flap; TFLPF, Tensor fascia lata perforator flap; dLCFA, descending branch of the lateral circumflex femoral artery; oLCFA, oblique branch of the lateral circumflex femoral artery; aLCFA, ascending branch of the lateral circumflex femoral artery.

However, for adequate pedicle length of the source vessel and thinness of the flap, the ALTPF is preferred. A thinner flap can be gained if the ALTPF is designed in the lower 1/3 of the thigh, but difficulty in dissection of the perforator is also increased as well as the likelihood of a musculocutaneous perforator with a long and tortuous intramuscular course. Furthermore, thickness of the flap is not a main consideration in our algorithm because thinning of the flap is not a difficult technique to be mastered.

The disadvantages of our technique include limitation of the resulting image in width and depth, with the small Doppler probe to detect the original source vessel, high dependence on the experience and skills of the ultrasound radiologist with knowledge of perforator flap anatomy, and

time consumption of the whole procedure (>1 h). We highlight that it is important to make a preoperative planning of perforator navigation in 3D-CDUS investigation by experienced ultrasonic radiologists in collaboration with skilled surgeon.

## Conclusion

Consistently good results following preoperative planning were achieved by 3D-CDUS with or without a contrast agent in perforator navigation using the same analyzed parameter. Our algorithm for preoperative planning of LCFAPFs with perforator navigation by 3D-CDUS is useful for the selection of the optimal flap with better perforator caliber and quality and sufficient pedicle length to be dissected easily.

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## Conflict of interest

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

## Ethical approval

Approval for the study was obtained from the research ethics committee of our hospital.

## Supplementary materials

Supplementary material associated with this article can be found, in the online version, at doi:10.1016/j.bjps.2018.12.025.

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