FREESTYLE PEDICLED PERFORATOR FLAPS FOR THE RECONSTRUCTION OF LOWER EXTREMITY DEFECTS

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ABSTRACT

Background: *Lower limb soft tissue defects present unique challenges due to the region's anatomical and functional characteristics. Freestyle pedicled perforator flaps (FPPFs) represent a local skin flap that utilizes adjacent identified perforators, regardless of their source vessel, to cover soft tissue defects. This study evaluated the outcomes of using freestyle perforator flaps to reconstruct lower limb soft tissue defects.*

Subjects and methods: *A prospective study was conducted on 41 patients with 41 lower limb soft tissue defects treated using FPPFs at the Hue University of Medicine and Pharmacy Hospital from March 2022 to September 2024. Data collected included defect characteristics, surgical techniques, and postoperative outcomes. Flap designs included peninsular, advancement/Keystone, and propeller flaps, selected based on defect location and size. Outcomes were evaluated during hospitalization and long-term follow-up.*

Results: *The mean defect size was 27.3 ± 13.2 cm², with infection being the most common cause (73.2%). Among the 41 flaps performed, 87.8% achieved complete survival, and 97.6% maintained optimal outcomes at 6 months, including functional mobility and aesthetic satisfaction. Complications occurred in 12.2% of cases, primarily marginal or distal flap necrosis, but none resulted in total flap loss. Donor site closure was achieved with direct suturing in 90.2% of cases, while skin grafting was needed in 9.8%.*

Conclusion: *FPPFs are reliable for lower limb defect reconstruction with their flexibility and donor site preservation. The modified techniques demonstrated high survival rates, aesthetic compatibility, and improved postoperative quality of life. Further research is needed to minimize venous congestion risks and optimize outcomes.*

Keywords: *Perforator flaps, lower limb, soft tissue defects, Freestyle Pedicled perforator flap.*

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Ngày gửi bài: 05/12/2024; Ngày nhận xét: 18/12/2024; Ngày duyệt bài: 28/12/2024
https://doi.org/10.54804/

p-ISSN 1859 - 3461
e-ISSN 3030 - 4008

1. INTRODUCTION

With its anatomical structure and weight-bearing function, the lower limb is prone to injury and challenging to restore when soft tissue defects occur. Studies have shown that the lower limb has the highest rate of soft tissue defects requiring coverage and the highest complication rates associated with flap surgery [1]. Axial skin-muscle flaps often require sacrificing underlying muscles and the main arteries supplying the flap, leading to compromised function, aesthetics, and sometimes prolonged donor site pain, reducing reconstruction quality. Moreover, flaps based on fixed axial vascular pedicles have limited rotation angles and movement patterns, reducing flexibility.

In 1987, Taylor and Palmer, building on the anatomical studies of Manchot and Salmon, introduced the concept of angiosomes, identifying that a specific vascular pedicle supplies each area of the body's skin. They found approximately 400 perforating vessels with a diameter >0.5 mm across the body, making any skin area a potential source for perforator flaps [2]. The most significant advantage of perforator flaps (PFs) lies in preserving the functionality of related muscles and minimizing donor site deformities. The muscle is spared even when partially dissected, with maximal preservation of the donor site and reduced postoperative pain. PFs can be designed freely based on defect templates without restrictions on pedicle length, providing sufficient coverage comparable to, or even more extensive than, traditional skin-muscle flaps.

The evolution of perforator flaps began in the 1980s, spearheaded by surgeons such as Koshima and Soeda, who introduced using skin flaps nourished by perforating vessels without including muscle [3]. This approach significantly minimized donor-site morbidity while preserving function and appearance. Building on this foundation, the concept of "freestyle" perforator flaps emerged in the early 2000s, championed by pioneers like Wei and Hallock [4]. The term "freestyle" reflects the freedom to harvest flaps based on the surgeon's intraoperative identification of perforators rather than strict anatomical landmarks. This technique harnessed advancements in Doppler imaging to expand the versatility of flap options, particularly in areas with challenging anatomy or irregular defects [5].

Thus, Freestyle Pedicled Perforator Flaps (FPPFs) for managing lower limb soft-tissue defects is a flexible and effective solution. However, FPPF surgery reduces the need for advanced dissection techniques and is susceptible to venous congestion risks. Improved FPPF designs need further research to enhance flap survival rates and treatment efficacy while minimizing limitations [6-8]. Motivated by these realities, we conducted this study, titled *"Freestyle Pedicled Perforator Flaps for the Reconstruction of Lower Extremity Defects."* aiming to:

- Describe the clinical characteristics of lower extremity soft tissue defects treated with FPPF.
- Evaluate the treatment outcomes of lower extremity soft tissue defects using FPPF.

2. SUBJECTS AND METHODS

2.1. Study subjects

The study included 41 patients with 41 lower limb soft tissue defects (STDs) treated with 41 FPPFs at the Department of Orthopedic and Thoracic Surgery, Hue University of Medicine and Pharmacy Hospital, from March 2022 to September 2024.

Inclusion criteria:

- Patients with lower limb STDs reconstructed using freestyle perforator flaps designed based on adjacent perforators identified preoperatively using a handheld Doppler ultrasound device.
- Soft tissue defects located from the thigh to the foot.

Exclusion criteria:

- Patients whose STDs were treated by other methods, such as primary closure, skin grafting, axial flaps, or free flaps.
- Presence of acute local infection.
- Patients who declined to participate in the study.

2.2. Study methods

This was a prospective longitudinal observational study.

** Study steps included:* Clinical examination, assessment of injuries via clinical and radiographic evaluation, surgical planning, flap selection, surgical procedure, and postoperative follow-up and outcome evaluation.

**** Research characteristics:***

- Demographic characteristics: age and sex.

- Clinical features of STDs: cause, location, size, and wound bed condition.

- Surgical characteristics and outcomes: flap movement technique, donor site coverage method, postoperative flap and donor site condition, and aesthetic evaluation.

** Technical Procedure:*

- Step 1: Clinical examination to evaluate the defect: Identify the cause, local condition, and patient's general health, followed by surgical planning and flap design.

- Step 2: Preoperative Doppler ultrasound was performed using the HADECO BIDOP ES-100V3 handheld Doppler device (Japan) with an 8.0 MHz probe to identify perforator locations. Perforators with strong Doppler signals (3 - 4 in number) were mapped and marked on the skin. The strongest perforator was selected as the main perforator for the flap design (Figure 2.1).

- **Step 3:** Intraoperative debridement and preparation of the recipient site, with re-measurement of the defect. The flap was elevated starting from the anterior border and moving toward the center of the marked perforator area. Dissection was carried out carefully to identify the perforator as preoperatively marked. Intraoperative visual assessment guided the final choice of perforator with the highest viability. Based on the location of the defect, appropriate flap movement techniques were applied (peninsular, advancement/Keystone, or propeller). The donor site was closed primarily or covered with a skin graft as needed.

- **Step 4:** Postoperative care included antibiotics, anti-inflammatory drugs, analgesics, and fluid therapy. Flap viability was monitored closely through clinical indicators such as color, temperature, and capillary refill time. Any complications at the recipient or donor sites were also recorded and managed accordingly.

p-ISSN 1859 - 3461
e-ISSN 3030 - 4008

Figure 2.1. Preoperative identification of the perforator using a handheld Doppler ultrasound and FPPF design based on this perforator to cover the soft tissue defect of the heel.

**** Variations of transfer methods for Freestyle Pedicled Perforator Flaps***

- Peninsular rotation-advancement flap: In cases where a perforator is identified near the soft-tissue defect, a peninsular flap can be designed to ensure adequate coverage and enhance flap viability (Figure 2.2).

- V-Y or Keystone advancement flap: For more minor defects, the perforator-based flap can be advanced in a V-Y pattern or Keystone configuration, utilizing the mobility of the perforator pedicle to cover the defect (Figure 3.1).

- Propeller rotation flap: In cases of larger defects or when the identified perforator is not adjacent to the defect, the flap can be rotated around the perforator (propeller-style). The distance from the perforator pedicle to the proximal end of the flap should be 0.5 - 1 cm greater than the distance to the most distal point of the defect (Figure 3.2).

Figure 2.2. (A) Soft tissue defect at the medial aspect of the right lower leg with adjacent perforators marked. (B) Elevation of a peninsular flap. (C) Flap rotation and advancement to cover the defect, immediate postoperative result. (D) Follow-up at 6 months.

2.3. Evaluation of outcomes

The treatment outcomes were evaluated based on flap viability, wound healing at both donor and recipient sites, and functional and aesthetic results. Criteria from Oberlin C and Duparc J were applied to assess both early postoperative outcomes (during hospitalization) and long-term outcomes (at > 6 months postoperatively).

**** Early outcomes:***

- Flap:

- Good: Complete flap survival with primary wound healing.
- Fair: Partial flap compromise, including epidermolysis or marginal necrosis involving < 1/3 of flap area, with or without need for skin grafting; the presence of hematoma or wound infection.
- Poor: Necrosis involving > 1/3 of the flap or total flap loss, requiring excision and alternative reconstruction.

- Donor site:

- Good: Satisfactory wound healing, no infection, viable skin graft (if applicable).
- Complications: Infection, fistula formation, or skin graft necrosis.

**** Long-term outcomes (after 6 months):***

- Flap:

- Good: Full flap survival, soft and mobile tissue, no ulceration, hyperpigmentation, or fistula formation; aesthetically acceptable scarring.
- Fair: Hypertrophy or recurrent fistula formation is manageable with dressing and debridement; there is no need for further coverage surgery.
- Poor: Flap fibrosis, dark discoloration, chronic ulceration, or fistula requiring secondary reconstruction or defect padding procedures.

- Donor site:

- Good: Well-healed, flat, or slightly raised scar.
- Complications: Fistula formation, hypertrophic scarring, or contracture.

** Aesthetic outcome:* The Vancouver scar scale was employed to assess the aesthetic integration of the flap with the recipient site, focusing on color, texture, hair pattern, and contour matching [9].

3. RESULTS

3.1. General characteristics

From March 2022 to September 2024, 41 patients (27 males and 14 females) with 41 lower limb soft tissue defects underwent reconstruction using freestyle pedicled perforator flaps at Hue University of Medicine and Pharmacy Hospital. Patients ranged in age from 11 to 74 years, with a mean age of 47.5 ± 14.2 years.

3.2. Clinical characteristics

** Etiology of defects:*

The most common cause was infection or abscess formation, accounting for 73.2% of cases. Trauma-related defects constituted 19.5%, post-burn contractures 4.9%, and post-tumor excision defects 2.4%.

** Location of defects:*

Most defects were located in the lower leg (25 cases, 61.0%). Ankle and heel defects accounted for 9 cases (22.0%), followed by thigh defects in 4 cases (9.8%) and knee defects in 3 cases (7.2%).

** Characteristics of defects*

Simple defects with no exposure of tendons or bones but requiring soft tissue padding due to depth were observed in 36.6% (15/41). The remaining 63.4% of

p-ISSN 1859 - 3461
e-ISSN 3030 - 4008

defects involved exposure of critical underlying structures: 19.5% with exposed tendons, 26.8% with exposed bone, and 17.1% with both tendons and bone exposure.

** Defect dimensions*

The average defect measured 7.2 ± 2.4 cm in length (range: 4.0 - 20.0 cm), 4.5 ± 1.1 cm in width (range: 3.0 - 8.0 cm), with a mean surface area of 27.3 ± 13.2 cm^2 (range: 10.5 - 125.0 cm^2).

Figure 3.1. Soft tissue defect in the distal third of the anterior-lateral aspect of the lower leg exposing the anterior tibial tendon:
(A) Design of a Keystone perforator-based flap (two arrows indicate the locations of the perforators); (B) Intraoperative coverage of the defect; (C) Dressing change after 5 days; (D) Follow-up at 6 months.

3.3. Treatment outcomes

** Types of flap movement*

Table 3.1. The flaps were categorized based on their transfer method

Perforator Flap	Number (n)	Percentage (%)
Peninsular rotation-advancement flap	7	17.1
Advancement/Keystone perforator-based flap	19	46.3
Propeller perforator flap	15	36.6
Total	41	100.0

** Donor site coverage*

Primary donor site closure was achieved in 90.2% (37/41) of cases, while skin grafting was necessary for the remaining 9.8% (4/41).

** Monitoring flap and donor site conditions in the postoperative period*

- Condition of the flaps in the postoperative period: There were 36 viable, healthy flaps with good color, accounting for a high percentage (87.8%), and five flaps had complications (12.2%). Among

these, 3 cases had partial necrosis at the edge of the flap, and 2 cases had partial necrosis at the distal end of the flap (< 1/3 of the flap area).

- Condition of the donor site in the postoperative period: 40 out of 41 cases (97.6%) had good wound healing, with a 100% survival rate of the skin grafts (4/4). Only 1 case (2.4%) had a superficial infection at the edge of the donor site wound, which was treated with subcutaneous debridement, dressing changes, and antibiotic therapy. The outcome was successful wound healing at the second stage.

** Flap complications and risk factors*

Table 3.2. Analysis of risk factors for complications

Risk Factors		No Complication (n)	Complication (n)	p-value
Gender	Male	23	4	p > 0,05
	Female	13	1	
Age	≥ 60 years	12	3	p > 0,05
	< 60 years	24	2	
Diabetes Mellitus	Yes	3	1	p > 0,05
	No	33	4	
Smoking	Yes	14	3	p > 0,05
	No	22	2	
Flap Area	≥ 60 cm^2	8	2	p > 0,05
	< 60 cm^2	28	3	

Figure 3.2. Chronic infected wound in the distal third of the anterior aspect of the left lower leg:
(A) Design of a propeller FPPF based on a perforator branch of the peroneal artery; (B) 180^0 rotation of the flap to cover the defect; (C) Postoperative day 5 showing flap congestion and marginal ischemia; (D) Follow-up at 6 months.

p-ISSN 1859 - 3461
e-ISSN 3030 - 4008

3.4. Evaluation of treatment outcomes

**** Early outcomes (During hospitalization)***

Good outcomes were achieved in 36/41 cases (87.8%), with complete wound healing. While 5 out of 40 cases (12.2%) had complications categorized as moderate outcomes, with no cases having poor results.

**** Long-term outcomes (After 6 Months)***

We followed up with patients 6 months after surgery. 97.6% of the flaps survived well, were soft and mobile, and showed no signs of ulceration, darkening, fistula formation, or well-healed scars. One case (2.4%) had a moderate result due to recurrent ulceration at the pressure point over the lateral malleolus. For the donor site, 100% showed promising results with no ulceration or fistula formation cases.

**** Aesthetic evaluation***

The aesthetic results of the flaps were evaluated using the Vancouver Scar Scale, with an average score of 2.5 ± 1.5, reflecting good integration with the surrounding tissue.

4. DISCUSSION

For lower limb soft tissue defects, the predominant cause in this study was infection (73.2%), which often originated from chronic abscesses, surgical site infections, pressure ulcers, or diabetic foot complications. Similar findings were reported by Usama Abdelfattah et al. [10], where infection accounted for 51.4% of defects, including diabetic foot infections, post-traumatic sequelae, osteomyelitis, and soft tissue infections. Trauma was the second most common cause (17.5%) in this study, consistent with other research by Bekara [11] (55.2%), Phanette Gir [12] (38.8%), and Tripathee [13] (68.9%).

The size of the defects varied widely, with an average area of 27.3 cm^2. This aligns with studies like Lee et al. [14], which reported an average defect size of 24 cm^2.

Advantages of perforator flaps include preserving muscles and their functions, preserving major blood vessels, compatibility between the donor and recipient sites; the donor site is often closed completely; reduced donor site morbidity, and the potential for achieving better aesthetic outcomes. Local perforator-based flaps, such as the propeller flap introduced by Hyakusoku et al., have expanded reconstructive options for the lower extremities. The keystone flap is another type of perforator-based flap, wherein a V-Y advancement flap is utilized for relatively easy closure of defects. Recent advancements in the use of perforator flaps require a paradigm shift in approaching lower extremity defects. Depending on the location of the soft tissue defect, perforator flaps are mobilized in tailored configurations [15, 16].

Small defects (3 - 4 cm wide) can be managed using V-Y advancement flaps, based on perforators, without the need for dissecting the vascular pedicle. Keystone flaps, used to cover elliptical defects, act as advancement flaps supported by underlying perforators and require local tissue laxity. Keystone flaps have higher success rates and lower complexity compared to free or propeller flaps. However, when there is insufficient local tissue laxity for advancement, the keystone flap cannot be applied for reconstruction [17, 18].

The propeller perforator flap allows the donor site to be positioned higher on the lower leg, where the limb circumference is larger, providing more soft tissue for an optimized flap size. This facilitates direct closure of the donor site without the need for skin grafting. Additionally, the broad perforator-based pedicle reduces the need for extensive pedicle dissection and minimizes the risk of injury to the perforating vessels. These flaps can vary in size depending on the defect, and due to their direct vascular supply, relatively large flaps can be harvested when necessary [11, 12, 16].

Perforators from the superficial femoral artery, descending genicular artery, and saphenous artery branches can be used for thigh defects. Perforators from the genicular system are utilized for knee defects, while leg defects can rely on perforators from any of the three major blood vessels [15].

By utilizing perforator-based flaps, reconstruction becomes more flexible and tailored to the defect's requirements, thus sparing donor site tissues and enabling more favorable donor site closure. In this study, 90% of donor sites were primarily closed, aligning with reports by authors such as Bekara (69.7%), Lecours (69.8%), Qian Y (88.8%), and Mendieta (85.7%) [11, 16, 19, 20].

Using 41 flaps in clinical practice, we obtained the following results: 36 out of 41 flaps (87.8%) had complete survival, while five flaps had complications, accounting for 12.2%. Specifically, 3 cases had small necrosis at the flap edge, which did not require surgical intervention, only dressing changes and wound care. 2 cases had necrosis of less than 1/3 of the distal flap, one of which had deep necrosis that required debridement followed by thick skin grafting, and the other only required dressing changes and wound care.

After additional interventions, all defects healed well, ensuring sufficient coverage function. Thus, there were no cases of total flap necrosis in this study. The complication rate in studies by Bekara [11] was 25.2%, while Gir's study [12] showed a complication rate of 25.8%, with 6.45% requiring additional reconstructive surgery. In Sisti's study [1], the complication rate was 31.8%, and 5.2% of patients needed a second surgery. Our study's rate of patients requiring a second surgery was 2.4% (1 case of additional skin grafting).

Evaluation of lower extremity defect management with perforator-based pedicled flaps (FPPF): Both early outcomes at hospital discharge and follow-ups at > 6 months revealed favorable results for both flaps and donor sites. This underscores the indispensable role of FPPF in addressing lower extremity defects, offering advantages such as viability, flexibility, safe preservation of perforators, and aesthetic and functional restoration, ultimately improving patients' postoperative quality of life. Nonetheless, a small percentage of partial flap necrosis due to venous congestion remains a recognized limitation.

5. CONCLUSION

In this study, 41 Freestyle pedicled perforator flaps for lower limb defect reconstruction demonstrated several advantages, including high flexibility, minimal donor site sacrifice, improved aesthetic and functional outcomes, and shorter operative times without requiring

p-ISSN 1859 - 3461
e-ISSN 3030 - 4008

microvascular techniques. The freestyle pedicled perforator flap is an excellent choice for rapid and effective soft tissue defect coverage, ensuring safety, functional preservation, and enhanced quality of life for patients post-surgery.

ACKNOWLEDGMENTS

This work was supported by Hue University under the Research Program ID No. DHH2024-04-217.

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