CLINICAL ARTICLE

Variations of Extended Latissimus Dorsi Musculocutaneous Flap for Reconstruction of Large Wounds in the Extremity

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Objective: The aim of the present study was to report a novel nomenclature system for extended latissimus dorsi musculocutaneous (LD) flaps. To evaluate the clinical application and surgical efficacy of the different extended LD flaps for large wounds in the extremities.

Methods: From January 2004 to December 2018, 72 consecutive patients who received extended LD flaps were retrospectively analyzed. Patients' ages ranged from 2 to 68 years with 37 males and 35 females. All wounds were extensive in either the upper or lower limbs, while the skin defect area ranged from 18 cm × 10 cm to 37 cm × 21 cm. Forty-one wounds were located in the calf, 18 in the foot and ankle, six in the shoulder and upper arm, four in the thigh, and three at the knee joint. Twenty-eight patients had fractures, and six of these patients with segmental bone defects (ranging in size from 3 to 7 cm) required secondary orthopaedic procedures. Single- and double-wing extended LD flaps were designed and harvested according to the shape of the wounds.

Results: The flaps received consisted of 64 single-wing and eight double-wing extended LD flaps, and the mean flap harvest time was 56.2 min. The donor sites were closed primarily for all patients. Additional subcutaneous veins were anastomosed to the recipient's vessels in 14 patients. The venous crisis was noticed on the first postoperative day in four cases. Two flaps were salvaged after emergency re-exploration, and another two patients' flaps were necrosed. In these two patients, lower limb amputation and extended LD flap on the other side were used, respectively, for the final treatment. The wounds healed well, providing reliable soft tissue coverage and good contour in the reconstructed areas. Six patients had segmental bone defects that required secondary orthopaedic procedures, two patients were repaired with vascularized iliac crest bone grafts, and another four patients were reconstructed by the Ilizarov technique. All the patients' bone defects achieved union and most patients achieved good functional recovery at the recipient site. The mean follow-up was 15.7 months (range, 10–56 months). No significant donor site morbidities limiting patients' daily activities occurred during the follow-up. Eight patients developed a donor site hypertrophic scar, three patients on the back, and five on the anterolateral thigh.

Conclusion: Single- and double-wing extended LD flaps are simple and reliable methods for large skin and soft tissue defects in the extremity, with good functional and aesthetic results.

Key words: extended latissimus dorsi musculocutaneous (LD) flap; extremity; free tissue flaps; large soft tissue defects; microsurgery

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Introduction

With the development of industry and transportation, large soft tissue defects caused by high-energy trauma are becoming more and more common, which poses challenges to plastic surgeons. Those kinds of defects are usually combined with exposed critical components, such as bones, tendons, and joints, thus early flap reconstruction is necessary for their functional recovery. The usage of pedicle flap is usually limited in this situation, for there is little expendable donor tissue for large defect coverage. Free tissue transfer, such as a large perforator flap, has been reported to solve these problems. But the donor site morbidities still need to be considered. For instance, donor sites functional loss because of harvesting a large flap. Thus, large skin and soft tissue defects in the extremity are difficult to reconstruct. Moreover, strategies should be used to reduce donor site complications. With improved reconstructive methods, chimeric, sequential, and combined perforator flap transplantations are ideal methods to repair large wounds, with minimal donor site morbidities[1–3]. However, additional microsurgical anastomosis was more time-consuming and technically demanding, increasing surgical complexity. Besides, the patients' tolerance of surgical procedures still needs to be improved, especially for severely injured or elderly patients.

The latissimus dorsi musculocutaneous (LD) flap is a feasible method for repairing large skin and soft tissue defects[4,5]. After the thoracodorsal artery perforator flap was proposed, the LD flap was gradually discarded due to the resultant limitation in the shoulder. But the LD flap has the advantages of a large flap size, less susceptibility to infection, and the recurrence of osteomyelitis, which should be considered in large soft tissue reconstruction. A major issue with the traditional design of the LD flap repair for large defects is that it cannot close the donor site directly. Extended LD flaps increase the flap size and tissue volume via harvesting additional fat or muscle. These flaps were first described for breast reconstruction to increase tissue volume and to avoid implants[6–9], but reports regarding large wound reconstruction of the upper and lower limbs are rare. Although the latissimus dorsi muscle-chimeric thoracodorsal artery perforator flaps and multilobed LD flaps have been reported for the reconstruction of a large defect just with one micro-anastomosis and less risk of combination than the prefabricated chimeric flap, extended LD flap operation is simple, and the risk of surgery is lower. Extended LD flap can be harvested at the same size as the prefabricated chimeric flap while the patient tolerates the surgical procedures well.

To evaluate the clinical application and surgical efficacy of the different extended LD flaps for large wounds in the extremities. A novel nomenclature system for LD flaps is reported based on the location of harvested muscle relative to the skin paddle. Skin paddle with LD muscle on one side was designed as "single-winged," and LD muscle on either side of the skin paddle was designed as "double-winged." Extended LD flaps increase the flap size and tissue volume via harvesting additional muscle without harvesting accompanying extra skin and fat tissue. This technique allows for the primary closure of the donor site. Herein we report the largest case series of extended LD flap variations for reconstructing large soft tissue defects in the upper and lower extremities. This study aimed to: (i) assess the feasibility and reliability of this new design; (ii) list key surgical points.

Patients and Methods

All surgical procedures were conducted in the Department of Hand and Microsurgery. This study followed the guidelines of the Medical Ethics Committee of Xiangya Hospital Central South University (202107118), and the protocol was developed in accordance with the ethical standards of the Helsinki Declaration of 1975 and all subsequent revisions. Written informed consent was obtained from the patients.

Inclusion and Exclusion Criteria

Inclusion criteria: (i) large area of soft tissue defect after debridement; (ii) patients who have undergone reconstruction with extended latissimus dorsi musculocutaneous flap; (iii) postoperative follow-up term of at least 10 months.

TABLE 1 Demographic data of patients who underwent extended latissimus dorsi musculocutaneous flap reconstruction

Patient characteristics*	No.
No.	72
Age (years)	25.2 ± 18.9
Demographics	
Male	37
Female	35
Cause	
Motor vehicle accident	56
Crush injury	5
Burn scar contracture	4
Chronic ulcer	3
Machine injury	2
Tumor resection	1
Motorcycle spoke injury	1
Comorbidity	
Age >60 years	4
Type 2 diabetes	3
Smoker	9
Peripheral vascular disease†	2
Fracture	28
Segment bone defect	6
Location	
Shoulder and upper arm	6
Thigh	4
Knee joint	3
Calf	41
Ankle and foot	18
Skin defects(cm^2)	18 × 10 to 37 × 21

* Patients' mean age was 25.18 years (range, 2–68 years).; † Diagnosed either on computed tomographic angiography or arteriography.

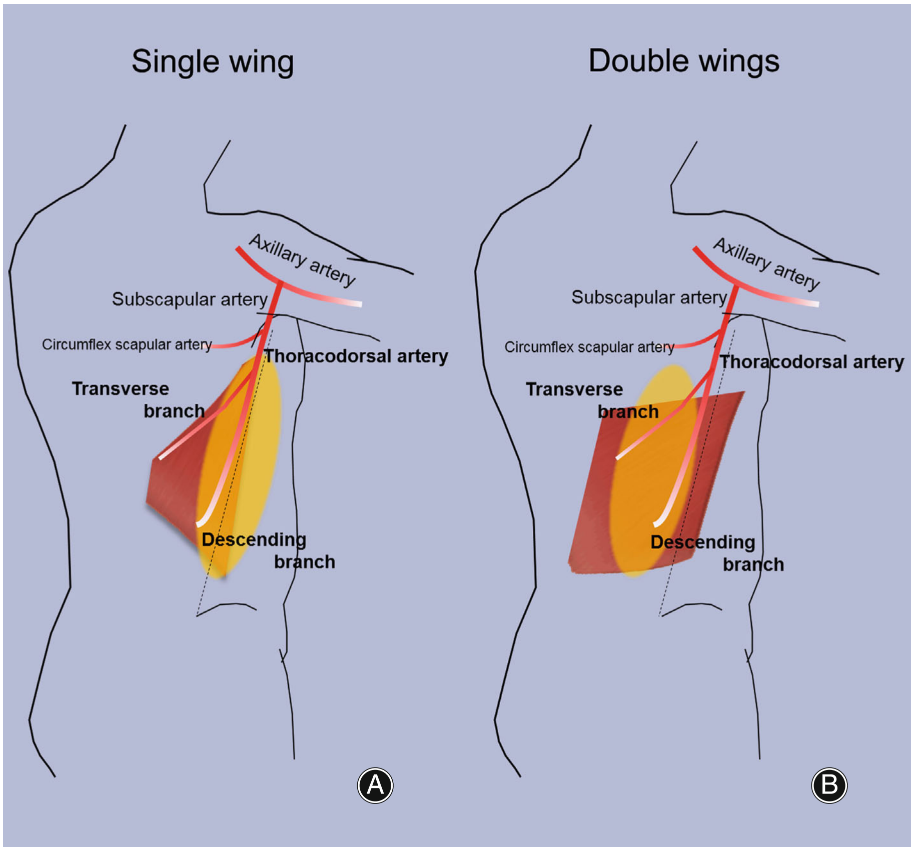

FIGURE 1 Schematic diagram of design variations of the extended latissimus dorsi musculocutaneous (LD) flap. (A) Single-wing extended LD flap design; (B) Double-wing extended LD flap design

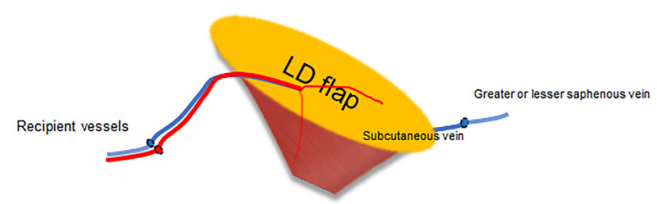

FIGURE 2 Schematic diagram of vascular anastomosis

Exclusion criteria: (i) lost patients; (ii) combined flaps reconstruction; (iii) previous flap surgery had failed; (iv) injury history in donor sites; (v) patients with serious underlying disease.

Patient Data

From January 2004 to December 2018, 72 consecutive patients aged 2 to 68 years (37 men and 35 women) underwent extended LD flap reconstruction. Forty-one wounds were located in the calf, 18 in the foot and ankle, six in the shoulder and upper arm, four in the thigh, and three at the knee joint. The skin defect area ranged from 18×10 cm^2 to 37×21 cm^2. Twenty-eight patients had fractures, and six patients had segmental bone defects (size range, 3–7 cm) requiring secondary orthopaedic procedures. Patients' characteristics are summarized in Table 1.

Flap Design

The soft tissue defect was first radically debrided and measured. If the width of the defect template did not exceed the 2/3 width of the latissimus dorsi muscle, the single-wing flap was chosen. Otherwise, the double-wing flap was used, especially for extensive or circumferential wounds. Of note, the skin pinch test was routinely performed to confirm that the donor site could be closed primarily after flap harvest. When designing single-wing extended LD flaps, the axis of the flap was the line connecting the midpoint of the axilla and the posterior superior iliac spine, lateral portion of the skin paddle can be extended beyond the lateral border of the LD muscle to avoid harvesting more LD muscle and reduce donor site morbidities. The design of double-wing LD flaps differed slightly from that of single-wing LD flaps in that the axis of the flap was parallel to the single-wing design, which left space to harvest another wing (Figure 1).

Approach and Pedicle Dissection

The following surgical procedures were used to harvest extended LD flaps[10]. The skin and subcutaneous tissue was first incised according to the design, and the subcutaneous fat was divided down to the level of the LD muscle. If a subcutaneous vein in the distal part of the flap was found, preserving it for venous super drainage was suggested. Then the subcutaneous tissue with the LD muscle around the skin flap was detached to expose the LD muscle. Next, the single- or double-wing latissimus dorsi muscle was harvested. Once the LD muscle was dissected, the thoracodorsal vessels were identified and clamped.

Flap Transfer and Donor Site Closure

Then, the extended LD flap was transferred to the recipient site to cover the large soft tissue defect. The remaining muscle flap was covered with split-thickness skin grafts, which were harvested from the anterolateral thigh. The thoracodorsal vessels were anastomosed to the recipient's vessels with either an end-to-side or end-to-end technique. The greater or lesser saphenous vein was identified and dissected, leaving sufficient length for an anastomosis with the subcutaneous vein for superdrainage (Figure 2). The donor site was closed primarily after complete hemostasis and sufficient drainage was achieved.

Postoperative Treatments

The repaired extremity was warmed and elevated postoperatively. Postoperative monitoring constituted hourly flap checks to evaluate color, capillary refill time, skin turgor, and surface temperature. After surgery, patients also received appropriate antibiotics according to wound microbiological cultures, anticoagulation, physical deep vein thrombosis prophylaxis, and multi-modal pain management.

Secondary orthopaedic procedures, such as vascularized iliac crest bone graft and the Ilizarov technique, were used in segmental bone defects, and all orthopaedic procedures were performed within 4–8 weeks after the initial reconstruction.

Evaluation of Complications and Outcomes

Intraoperative

The flap size, harvest time, and recipient's vessels were recorded.

Complications

Complications at both recipient site and donor site were carefully recorded, including flap or skin graft necrosis, infection, vascular crisis, and delayed wound healing.

Clinical Outcomes

The survival and infection of flaps were evaluated postoperatively. During follow-up, the appearance and function of the donor and recipient site were observed.

Results

Intraoperative Results

Seventy-two flaps were successfully harvested: five pedicled flaps and 67 free flaps. The flaps received were consisted of 64 single-wing and eight double-wing extended LD flaps, and the mean flap harvest time was 56.2 min (Table 2). The donor sites were closed primarily in all patients. Additional subcutaneous veins were anastomosed to the recipient's vessels in 14 patients. The recipient vessels and type of microvascular anastomoses are shown in Table 2. Six patients had segmental bone defects required secondary orthopaedic procedures: two patients were repaired with vascularized iliac crest bone grafts, and the other four patients were reconstructed by the Ilizarov technique.

Complications

Venous crisis was noticed on the first postoperative day in four cases. Two flaps were salvaged after emergency re-exploration and two patients' flaps were necrosed. In these two patients, lower limb amputation and extended LD flap on the other side were used, respectively, for the final treatment.

TABLE 2 Intra-operative data, complications, and follow-up data for patients who underwent extended latissimus dorsi musculocutaneous flap reconstruction

Parameter	No.
Flap size (cm^2)	
Single wing extended LD flap	
Skin paddle	18 × 5 to 27 × 10
Muscle segment	12 × 5 to 37 × 7
Double-wings extended LD flap	
Skin paddle	21 × 6 to 37 × 7
Muscle segment 1	11 × 4 to 37 × 8
Muscle segment 2	11 × 4 to 32 × 7
Type of transfer	
Pedicle	5
Free	67
Flap harvest time, min	56.4 (ranged 30 to 120)
Recipient vessels	
Radial artery	1
Descending branch of the LCFA	2
Descending genicular artery	2
Lateral superior genicular artery	2
Branch of the popliteal artery	4
Anterior tibial artery	34
Posterior tibial artery	16
Peroneal artery	2
Medial sural artery	4
Orthopaedic procedures	
Bone graft	2
Ilizarov	4
Complications	
Venous comprise	4
Flap failure	2
Hypertrophic donor-site scars	8
Type of microvascular anastomoses	
End-to-end	42
End-to-side	25
Follow-up	
Loss of follow-up	5
Follow-up period (months)	15.7 (ranged 10 to 56)

Abbreviations: LCFA, lateral circumflex femoral artery; LD, latissimus dorsi musculocutaneous.

FIGURE 3 A 20-year-old woman with a large lower extremity wound. (A) After radical debridement, which left a large skin and soft tissue defect, and showed a segmental bone defect; (B) Single-wing extended LD design; (C) Single-wing extended LD harvest; (D) Intraoperative view of the flap; (E,F) Postoperative view of the recipient site and donor site at the 27-month follow-up

Surgery Outcomes and Follow-up

All the wounds healed well, providing reliable soft tissue coverage and good contour in the reconstructed areas, six patients' bone defects achieved union, and most patients achieved good functional recovery at the recipient site. The mean follow-up was 15.7 months (range, 10–56 months). No patients developed significant donor site functional damage that limited their daily activities during follow-up. Eight patients developed a donor site hypertrophic scar; three patients on the back, and five on the anterolateral thigh (Figures 3–5).

Discussion

High-energy trauma, malignancy, and infection can lead to large soft tissue defects in the extremities. To simplify a path to a reconstructive strategy in these patients, we examined our 14-year experience with repairing large soft tissue defects. A novel nomenclature system for LD flaps is created based on the location of harvested muscle relative to the skin paddle.

Current Situation of Treatments for Large Soft Tissue Defects

Large soft tissue defects caused by high-energy trauma are challenging for reconstructive surgeons[11–13]. These wounds are usually combined with exposed bones, tendons, and joints, and flap coverage is essential. Local flaps are limited in this situation because there is little expendable donor tissue for large wound coverage. Some authors reported using large flaps, such as anterolateral thigh (ALT) flaps and deep inferior epigastric perforator (DIEP) flaps to reconstruct large wounds[14–16]. However, donor site morbidities may limit the use of these large flaps. Even without other complications, the cosmetic appearance of the donor sites is poor because these sites are closed with skin grafts. To address this, Yoshimatsu *et al.* reported combining the superficial circumflex iliac artery perforator flap with the superficial inferior epigastric artery flap or the deep inferior epigastric artery perforator flap for coverage of large soft tissue defects in the extremities[17]. But their flap size is small compared to the extended LD flap.

Kiss flap and sequential chimeric perforator flap transplantation have been used to repair large soft tissue

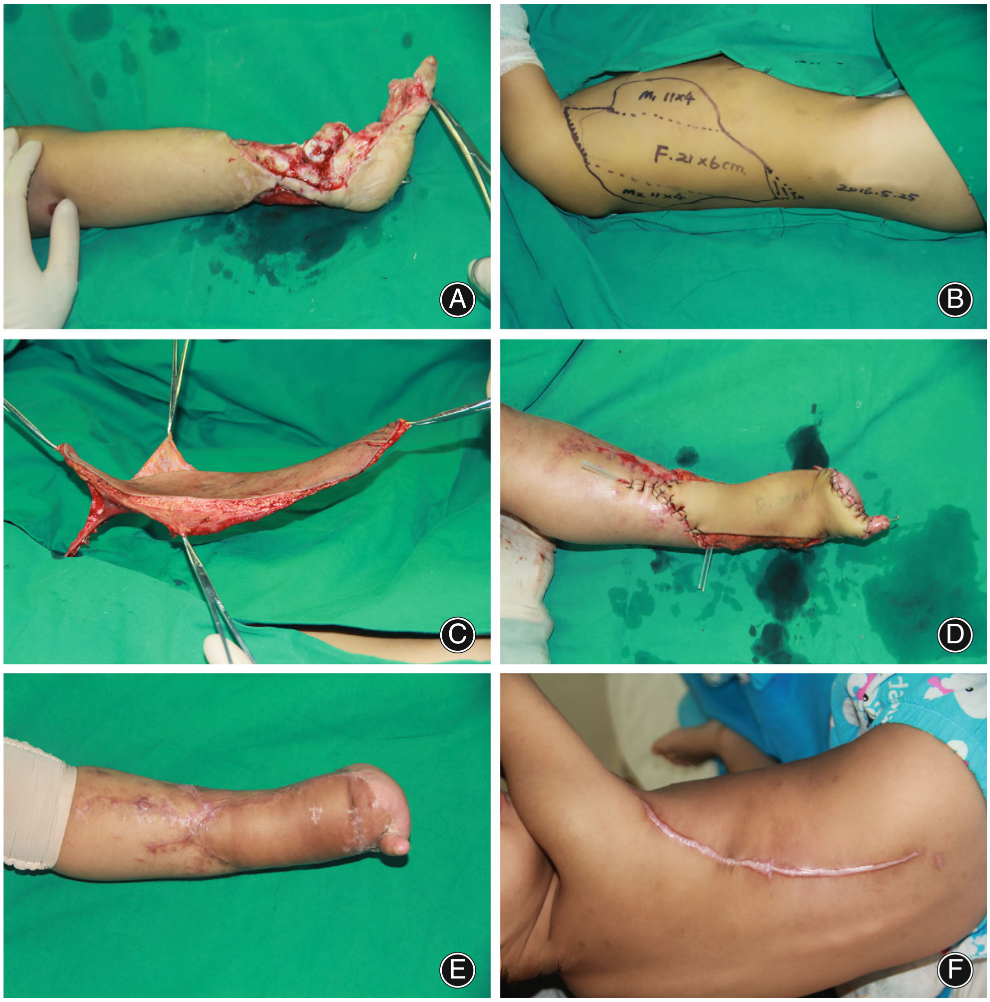

FIGURE 4 A 4-year-old girl with a large lower extremity wound. (A) After radical debridement, the right foot and ankle have exposed large skin and soft tissue defects; (B) Double-wing extended LD design; (C) Double-wing extended LD harvest; (D) The flap is transferred to the recipient site to cover the exposed foot and ankle; (E, F) Postoperative view of the recipient site and donor site at the 1-year follow-up

defects[18–20]. Qing *et al.* reported using bilateral chain-linked ALT perforator flaps for large wounds[21]. All of the patients achieved good results with limited donor site morbidities. However, these methods require using more than one flap and involve additional surgical risks associated with each flap. Moreover, flap harvest requires extensive intra-muscle dissection, which increases the complexity of the surgery.

Characteristics of Traditional LD flap

The LD flap, since its first description by Tanzini in 1906, has been used for both breast reconstruction and reconstruction in other parts of the body[22–24]. With the development of the thoracodorsal artery perforator flap (TDAP), the LD flap has been gradually disregarded because of donor site morbidities[25,26]. However, the LD flap still plays an important role in repairing large skin and soft tissue defects[27,28]. Ma *et al.* used pedicled LD flaps for large wounds in the upper extremity[29]. Their patients achieved good functional results; wounds healed primarily with minor complications. Yu also reported using bilateral LD flaps to cover large soft tissue defects of the lower limb[30]. Combined transplantation of bilateral LD flaps can be used to repair extensive wounds without significant functional impairments at the donor site. However, cross-bridge flaps from the contralateral leg were used in four of Yu's cases because no vessels were available for anastomosis at the recipient site. Thus, various modifications to increasing flap volume have been reported to simplify the operation and avoid additional vascular anastomoses.

A novel design of the flap is how it uses multiple separate skin paddles to repair very large defects while maintaining primary donor-site closure[27]. However, this flap was not recommended for flat defects (such as defects located on the extremity or trunk) because the extra muscle volume can take up some of the skin for coverage. The extended LD flap was designed to harvest additional LD muscle to obtain a sufficiently large LD flap. Moreover, LD flaps were individually designed as single- or double-wing flaps to ensure that the donor site can be closed primarily without tension. To date, there are no reports in the

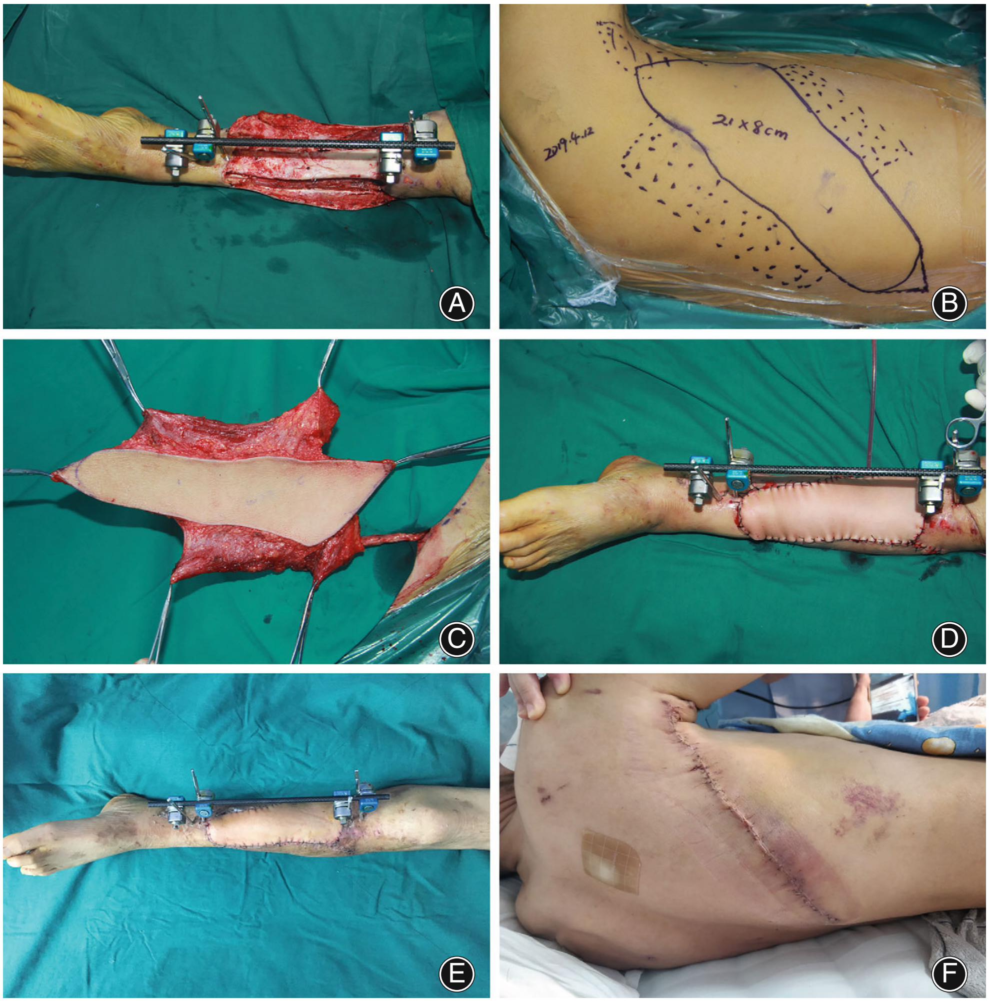

FIGURE 5 A 51-year-old man sustained soft-tissue injuries with Gustillo Anderson type IIIC open left tibial fracture. (A) After radical debridement and external fixation, extensive soft-tissue defects and two large dead spaces around the tibial were seen; (B) Double-wing extended LD design; (C) Double-wing extended LD harvest; (D) The flap is transferred to the recipient site to cover large soft tissue defect and fill dead spaces; (E, F) Postoperative view of the recipient site and donor site

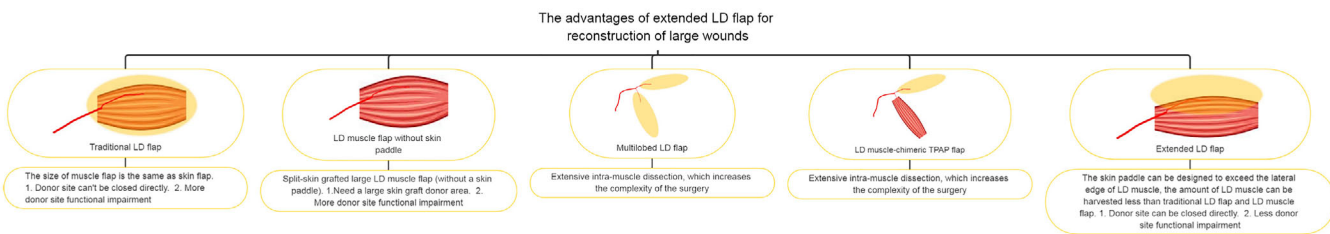

FIGURE 6 Schematic diagram showing the advantages of extended LD flap for reconstruction of large wounds

literature describing these two variations for large soft tissue defects in the extremities nor any case series of this magnitude.

Advantages of Extended LD Flap for Large Soft Tissue Defects

In this report, most patients achieved good results. The mean flap harvest time was 56.2 min, and all patients' donor sites closed directly without a skin graft. Although the donor site scar is difficult to hide with this approach, donor site function was not significantly affected. No patients developed late wound complications or breakdown during follow-up.

Compared to split-skin grafted large LD muscle flaps (without a skin paddle), the extended LD flap has the following advantages (Figure 6). First, the postoperative monitoring will be much easier having a skin paddle. Second, with extended LD flap design, the skin paddle can be designed to exceed the lateral edge of LD muscle (single wing), thus the amount of LD muscle can be harvested less than traditional LD muscle flap when the same size of the wound was repaired. Third, the skin graft area can be reduced by extended LD flap design to avoid potential donor site scar issues. Furthermore, the skin paddle of extended LD flaps shows more wear-resistant ability than skin graft, which can bear shear fore coming from wearing shoes.

The extended fleur-de-lis LD flap is a variation that was first introduced by McGraw and Papp in 1991 for breast reconstruction but was later applied in other reconstructions as well[31]. Ciudad *et al*. also used modified extended fleur-de-lis LD flaps for large soft tissue defects[32]. This design is similar to the double-wing extended LD flap, but the design is useful for multi-directional defects with a single flap by positioning vertical and horizontal parts in different combinations. The donor site is closed in a Y-shape. All donor sites in this study were closed linearly.

Technical Essential for Extended LD Flap

One of the biggest concerns regarding the application of extended LD flaps is donor site functional loss because of the need to harvest a large volume of latissimus dorsi muscle[33]. The muscle-sparing descending branch latissimus dorsi flap and split LD flap may be a useful method to reduce donor site complications, and this flap is recommended if the wound is not extensive[34,35].

In this case series, some of the patients showed signs of venous congestion in the early stage, the reason may be the extended flap only has one vein accompanied with a thoracodorsal artery; however, none developed venous crisis when additional subcutaneous veins were anastomosed. According to the anatomic characteristic of LD flap, harvesting additional subcutaneous veins and anastomosing to the recipient's vessels is recommended.

Other authors have reported donor site hypertrophic scars, which were observed in three patients[36]. The pinch test is a simple and effective way to evaluate donor site tension to reduce the incidence of donor site scar. Split-skin grafted large LD muscle flap (without a skin paddle) seems more simple than extended LD flap[37]. However, the anterolateral thigh hypertrophic scar should be considered. Interestingly, donor site seroma is reported a lot in breast reconstruction, rare in the extremity reconstruction[38]. Extended LD flaps with additional fat tissue in breast reconstruction may be the main reason for seroma formation. In this report, the additional muscle was harvested. Moreover, the quilting procedure was used in all cases to obliterate the dead space[39]. Besides, all the donor sites were closed directly without tension and sufficient drainage is helpful to avoid seroma.

Limitations

The primary limitations of this report are the lack of a comparative group and the lack of a standardized measure for long-term outcomes after large wound reconstruction. In future study, other reconstruction techniques, such as combined perforator flap transplantation and pre-expanded flap can be applied to better clarify the effectiveness of extended LD flap.

Conclusions

This retrospective case series demonstrates that extended LD flaps are suitable for the reconstruction of large skin and soft tissue defects in the extremities with fewer complications at the donor site. Single- and double-wing extended LD flaps are simple and reliable methods to repair large wounds. They can provide good outcomes both functionally and aesthetically.

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Conflict of Interest

All of the authors declare no conflict of interest.

Authors' Contributions

Study conceptualization was performed by JH and JT. Data collection was performed by JH, LQ, PW, SK, and FY. The first draft was written by JH. Data analysis, review, and editing were performed by all the authors.

Ethics Statement

Ethical approval was obtained from the Institutional Review Board of the Xiangya Hospital of Central South University.

Supporting Information

Additional Supporting Information may be found in the online version of this article on the publisher's web-site:

Video 1 Case 1 lower extremity functional recovery at the 27-month follow-up

Video 2 Case 2 lower extremity functional recovery at the 12-month follow-up

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