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Research article

Individualized design program of multiple flaps for adapting different zones to repair large irregular wounds in children

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ABSTRACT

Objective: Management of large irregular wounds in children had been confusing plastic and reconstructive surgeons. Herein, this study was aimed to propose a new treatment method based on the principle of adapting different recipient zones to overcome the intractable wounds, simplifying and programing the design process of targeted flaps for covering large irregular soft-tissue defects.
Patients and methods: From January 2009 to December 2020, 31 children (9 girls and 22 boys) aged 3–16 years (mean 9.8 years) underwent multiple modular flaps with edge to edge splicing reconstruction of the lower extremities. All the wounds were large with non-adjacent defects and with or without a dead space. Several variants of flaps were harvested according to the needs and reconstruction requirements of patients.
Results: A total of 71 flaps were harvested from 31 patients and all flaps donor sites received primary closure. Nine patients underwent split-thickness skin grafting, and three cases of flaps survived from vascular crisis by rebuilding the vessels and the rest accepting LD flap transplants. And five partial necrosis of the distal epidermis flaps recovered using skin grafting and dressing change. No major complication was encountered in other patients and donor sites, except one heel ulcer. During the follow-up (ranging from 16 to 38 months, mean 27.7 months), aesthetic and functional results of reconstructed limbs were satisfactory in all patients.
Conclusions: The Individualized design program of multiple flaps for adapting different recipient zones is an alternative for repairing large irregular soft-tissue defects in children, beneficial for plastic and reconstructive surgeons to simplify and program the process of designing and perform multiple flaps to achieve this goal.
Level of evidence: III, Retrospective.

1. Introduction

A variety of reconstruction procedures have been reported for repairing the huge skin and soft tissue defects, such as multi-territory

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Abbreviations

ALTP	Anterolateral thigh perforator flap
DIEP	Deep inferior epigastric artery perforator flap
LD	Latissimus Dorsi flap
TDAP	Thoracodorsal artery perforator flap
PAP	Profunda artery perforator flap
CSAPF	Circumflex scapular artery perforator flap
2-PD	two-point discrimination

perforator flap with turbocharged technique [1–4], pre-expanded perforator flap [5–8], free muscle flaps with skin grafting [9,10]. However, skin grafting is required for closing the donor sites after multi-territory perforator flap harvested [2]. Pre-expanded perforator flap is a time-consuming reconstructive procedure, not suitable for acute defects repairing, which is required multiple operations and long-term hospitalization. And free muscle flaps with bulky appearance, is unsuitable for the load-bearing area and unable to rebuild feeling [9]. Especially in children, complex soft-tissue defects of lower extremities still have a high rate of amputation, due to a slower development of microsurgery in child than in adult, and the small size of vessels has decreased the successful rate of harvesting the flap. As a result, a single largest flap has been selected to cover the complex soft-tissue defects in most of time, but the appearance, functional reconstruction, feeling had to be ignored.

As we know, different region of defects has different reconstruction demanding. And huge defects with multi-region can be divided into different reconstruction units according to the function, esthetics and characteristics of the skin. It is difficult to obtain good reconstruction effects by a single flap. And the novel design for reconstructing different recipient zones using multiple perforator flaps is proposed for reconstruction of large areas of soft tissues [11]. However, with so many alternative flaps, plastic surgeons feel very confused for choice and embarrassed for connecting these pedicles of flaps. In order to simplify the surgical technique to achieve extensive and complex wounds repair, we proposed a novel concept of adaptation to recipient conditions for large irregular soft-tissue defect in children in this study which not only achieved three-dimensional repair, but also may be widely used in complex operation process of chimeric, flow-through and microdissection flap.

2. Patients and methods

From January 2009 to December 2020, 31 patients with complex soft-tissue defects in lower extremity reconstruction using chain-linked multiple flaps. The age of patients ranged from 3 to 16 years (mean 9.8 years, 9 girls and 22 boys). Of these patients, 6 cases were caused by crushing injury, and the other 25 cases were caused by traffic accidents. The wounds were located in heel, plantar, ankle, dorsum and calf which were with the exposure of tendon, bone and joint, and the bone defects. Patient details were shown in Table 1. The study followed the ethical guidelines of the Hospital Ethical Committee of the Xiangya Hospital. The protocol was performed in accordance with the ethical standards of the Helsinki Declaration of 1975 and all subsequent revisions.

ALTP: Anterolateral thigh perforator flap. TDAP: Thoracodorsal artery perforator flap. LD: Latissimus dorsi myocutaneous flap. PAP: Peroneal artery perforator flap. DIEP: Deep inferior epigastric perforator flap. CSAPF: Circumflex scapular artery perforator flap.

*LD flaps were used to replace the flaps of vascular crisis in the ankle.

2.1. Surgical technique

The donor areas were evaluated before the operation by pinch test which was used to establish the width of the flap that could be harvested allowing primary closure of the donor site. Candidate flaps inclusion criteria were able to cover large areas of defects, including anterolateral thigh perforator flap (ALTP), thoracodorsal artery perforator flap (TDAP), latissimus dorsi myocutaneous flap (LD), deep inferior epigastric perforator flap (DIEP), profunda artery perforator flap (PAP), and circumflex scapular artery perforator flap (CSAPF). The candidate flaps have their own characteristics. Among these candidate flaps, the ALTP is the main flaps, carrying "T" vascular pedicle to form flow-through ALTP to link other flaps, muscles to form chimeric ALTP and the lateral femoral skin nerve to reconstruct the sensation. Besides, to some extent, other mentioned-above perforator flaps have various characteristics like the blood supply, no-bloated flap texture, wear-resistant sole and sensation re-obtainment.

After thorough debridement and copying the shape of the defects, the paper templet was divided into different reconstruction modular units based on the principle of adaptation to recipient conditions. Each reconstruction unit requires different reconstruction methods, such as heel and plantar needing to be reconstructed the sensation, the ankle needing a thickness flap, and deep tissue defects needing a chimeric flap. The requirements of units are matched with the characteristics of the candidate flaps to select the appropriate flaps as "like with like" principle. Then, multiple flaps were spliced with skin and vascular anastomosis according to pre-marked surfaces to achieve this goal. Meanwhile, the anterolateral femoral cutaneous nerves carried by ALTP were anastomosed with the peripheral cutaneous nerves. Meanwhile, the perioperative managements including anesthesia, operating room and nursing care were also worth noting. Based on the experience of large-sample flap operations in our center, three main aspects needed to be considered. 1) Anesthesia management: a. circulation management was set as infusion of 3.5–6 ml/kg/h crystal solution and additional blood transfusion in the perioperative 24 h. b. temperature management was suggested that average and minimum central temperature of

Table 1
Detailed information of patients.

No	Age/sex	Mechanisms of injury	Defect location	Surgical indications	Type of chain-linked and flap size(cm)	Number of flaps	Total area of flap (cm^2)	Skin graft	Complications	Follow-up (mo)
1	3/F	Crush injury	Right ankle, dorsum and medial foot	Exposure of bone and tendon	Left flow-through, sensate, thin ALTP (13.5 × 6.5) + left LD (14 × 6)	2	171.75	No	No	16
2	4/F	Crush injury	Right ankle and medial foot	Exposure of bone and tendon	Left flow-through, sensate, thin ALTP (14.5 × 6) + left LD (15 × 6)	2	177	No	Vascular crisis	18
3	4/M	Traffic accident	Left heel and plantar	Exposure of bone and tendon	Right flow-through, sensate, thin ALTP (18 × 7) + left thin ALTP (13 × 5)	2	191	No	No	38
4	5/F	Traffic accident	Left heel and plantar	Exposure of bone and tendon	Right flow-through, sensate, thin ALTP (17 × 7) + left sensate, thin ALTP (14 × 5)	2	189	No	No	30
5	6/F	Traffic accident	Left dorsum and forefoot	Exposure of bone and tendon	Right flow-through ALTP (16 × 6) + left Modified LD (skin paddle:16 × 5, muscle paddle:17 × 5)	2	261	Yes	No	30
6	7/M	Traffic accident	Left dorsum and forefoot	Exposure of bone and tendon	Right flow-through ALTP (17 × 6) + left Modified LD (skin paddle:15 × 5, muscle paddle:16 × 5)	2	257	Yes	No	30
7	8/F	Crush injury	Right ankle and dorsum	Exposure of bone and tendon	Right flow-through thin ALTP (23 × 7) + left thin ALTP (16 × 6)	2	257	No	Vascular*crisis	18
8	8/M	Traffic accident	Left ankle	Exposure of bone and tendon, bone defect	Right flow-through ALTP (16.5 × 6) + right chimeric PAP (skin paddle 11 × 5, bone paddle: 5 × 1.2 × 1)	2	154	No	No	28
9	8/M	Traffic accident	Right distal tibia 1/3, ankle, dorsum and medial foot Left ankle and medial foot	Exposure of bone and tendon Exposure of bone and tendon	Left flow-through, sensate, thin ALTP (28 × 8) + left CSAPF (15 × 8) + left TDAP (17 × 8) Right flow-through, thin ALTP (23 × 8.5) + thin DIEP (20 × 7)	3 2	480 335.5	No No	No No	16
10	9/M	Traffic accident	Left distal tibia 1/3, ankle, dorsum and plantar	Exposure of bone and tendon	Right flow-through, sensate, thin ALTP (21 × 8) + left flow-through, thin ALTP (26 × 8) + modified LD (skin paddle:27 × 5, muscle paddle:25 × 7)	3	686	Yes	No	35
11	9/F	Crush injury	Right ankle	Exposure of bone and tendon, bone defect	Left flow-through ALTP (17.5 × 6) + Left chimeric PAP (skin paddle 12 × 5, bone paddle: 5 × 1.2 × 1)	2	165	No	No	20
12	9/M	Traffic accident	Right ankle and heel	Exposure of bone and tendon	Left flow-through, sensate, thin ALTP (27 × 8) + right thin ALTP (24 × 7)	2	384	No	Vascular crisis	35
13	9/M	Traffic accident	Left shins, ankle and dorsum	Exposure of bone and tendon	Right flow-through, ALTP (25 × 7.5) + Left flow-through ALTP (23 × 7.5) + modified LD (skin paddle:21 × 6, muscle paddle:12 × 5)	3	546	Yes	No	36
14	10/M	Traffic accident	Left distal tibia 1/3, ankle and dorsum	Exposure of bone and tendon	Right flow-through, ALTP (27 × 7.5) + Left flow-through ALTP (25 × 7.5) + modified LD (skin paddle:20 × 7, muscle paddle:13 × 5)	3	595	Yes	Partial flap necrosis	28

(*continued on next page*)

Table 1 (*continued*)

No	Age/sex	Mechanisms of injury	Defect location	Surgical indications	Type of chain-linked and flap size(cm)	Number of flaps	Total area of flap (cm^2)	Skin graft	Complications	Follow-up (mo)
15	10/M	Traffic accident	Right shins, ankle and dorsum	Exposure of bone and tendon	Right flow-through, ALTP (26 × 7.5) + Left flow-through ALTP (24 × 7.5) + modified LD (skin paddle:20 × 6, muscle paddle:12.5 × 5)	3	558	Yes	No	26
16	10/M	Traffic accident	Left foot total degloving	Exposure of bone and tendon	Right flow-through, sensate, thin ALTP (28 × 8) + left sensate thin ALTP (25 × 7)	2	399	Yes	Partial flap necrosis	31
17	10/M	Traffic accident	Left heel, dorsum and plantar	Exposure of bone and tendon	Right flow-through, sensate, thin ALTP (24 × 8) + thin DIEP (22 × 11)	2	434	No	No	18
18	11/M	Traffic accident	Left heel, dorsum and plantar	Exposure of bone and tendon	Right flow-through, sensate, thin ALTP (23 × 8) + thin DIEP (21 × 11)	2	415	No	No	28
19	11/M	Traffic accident	Right distal leg and ankle	Exposure of bone and tendon	Left flow-through, thin ALTP (23 × 9) + thin DIEP (28 × 9)	2	459	No	No	21
20	11/M	Traffic accident	Left distal tibia 1/3, ankle, dorsum and plantar	Exposure of bone and tendon	Right flow-through, sensate, thin ALTP (28 × 8) + left thin ALTP (26 × 7.5)	2	419	Yes	Partial flap necrosis	34
21	11/M	Traffic accident	Left distal tibia 1/3, and ankle	Exposure of bone and tendon	Right flow-through, thin ALTP (24 × 8) + thin DIEP (27 × 9)	2	435	No	No	35
22	11/M	Traffic accident	Left distal tibia 1/3, ankle, dorsum and plantar	Exposure of bone and tendon	Right flow-through, sensate, thin ALTP (27 × 7) + left thin ALTP (26 × 7)	2	371	No	No	28
23	11/M	Crush injury	Left heel, dorsum and plantar	Exposure of bone and tendon	Right flow-through, sensate, thin ALTP (24 × 8) + thin DIEP (21 × 10)	2	402	No	No	35
24	12/M	Traffic accident	Left heel and plantar	Exposure of bone and Achilles tendon	Right flow–through, sensate, thin ALTP (19 × 8) +left thin ALTP (15 × 8)	2	272	No	No	28
25	12/F	Traffic accident	Right distal tibia 1/3, and ankle	Exposure of bone and tendon	Left flow-through, thin ALTP (24 × 9) + thin DIEP (27 × 8)	2	432	No	No	35
26	13/M	Traffic accident	Right ankle and heel	Ankle joint opening and tendon exposure	Left flow-through, sensate, thin ALTP (22 × 12) + left thin TDAP (26 × 10)	2	524	No	Partial flap necrosis	24
27	13/F	Crush injury	Left heel and plantar	Exposure of bone and Achilles tendon	Left flow–through, sensate, thin ALTP (17 × 9) +right sensate, thin ALTP (16 × 8)	2	281	No	Plantar ulcer	28
28	14/F	Traffic accident	Right ankle and heel	Ankle joint opening and tendon exposure	Left flow-through, sensate, thin ALTP (21 × 13) + left thin TDAP (25 × 10)	2	523	No	No	24
29	14/M	Traffic accident	Left heel, dorsum and plantar	Exposure of bone and tendon	Right flow-through sensate, thin ALTP (26 × 8) + right Modified LD (skin paddle:24 × 6, muscle paddle:26 × 11)	2	638	Yes	No	28
30	15/M	Traffic accident	Left foot total degloving	Exposure of bone and tendon	Right flow-through, sensate, thin ALTP (24 × 7) + left sensate, thin ALTP (25 × 7) and thin DIEP (19 × 8)	3	495	No	No	28

(*continued on next page*)

Table 1 (*continued*)

No	Age/ sex	Mechanisms of injury	Defect location	Surgical indications	Type of chain-linked and flap size(cm)	Number of flaps	Total area of flap (cm^2)	Skin graft	Complications	Follow-up (mo)
31	16/ M	Traffic accident	Right foot total degloving	Exposure of bone and tendon	Left flow-through, sensate, thin ALTP (26 × 7) + right sensate, thin ALTP (25 × 6) and thin DIEP (19 × 8)	3	484	No	Partial flap necrosis	30

body is higher than 37 °C and 35 °C by increasing the operating room temperature, using heating blankets, and heating treatment measures for blood transfusion and infusion. c. pain management was reducing the effect of endogenous catecholamine releasement and small vessel constriction in superficial tissue on flap perfusion during intraoperation and post-operation. 2) Operating room care: close collaborations between surgeon and nursing staff were emphasized. 3)Nursing management included environmental management, psychological nursing, pain nursing management, nutritional support and prevention and care of complications ect. The representative skin and soft-tissue defects of lower extremity was explained in Fig. 1, details in discussion section.

The surgical technique has been widely described in this literature and our team previous studies [12–21]. Multiple groups of doctors simultaneously operated, harvested different flaps according to the design, and then assembled different units. Additionally, the Semmes–Weinstein monofilament testing results, two-point discrimination(2-PD), pain sensation, cold sensation and warmth sensation were recorded in the last follow up. The central area of transplanted flaps were identified as the subject area for sensory measurement [22,23]. The details of flap selection, vascular anastomosis and sensory recovery status were shown in Table 1.

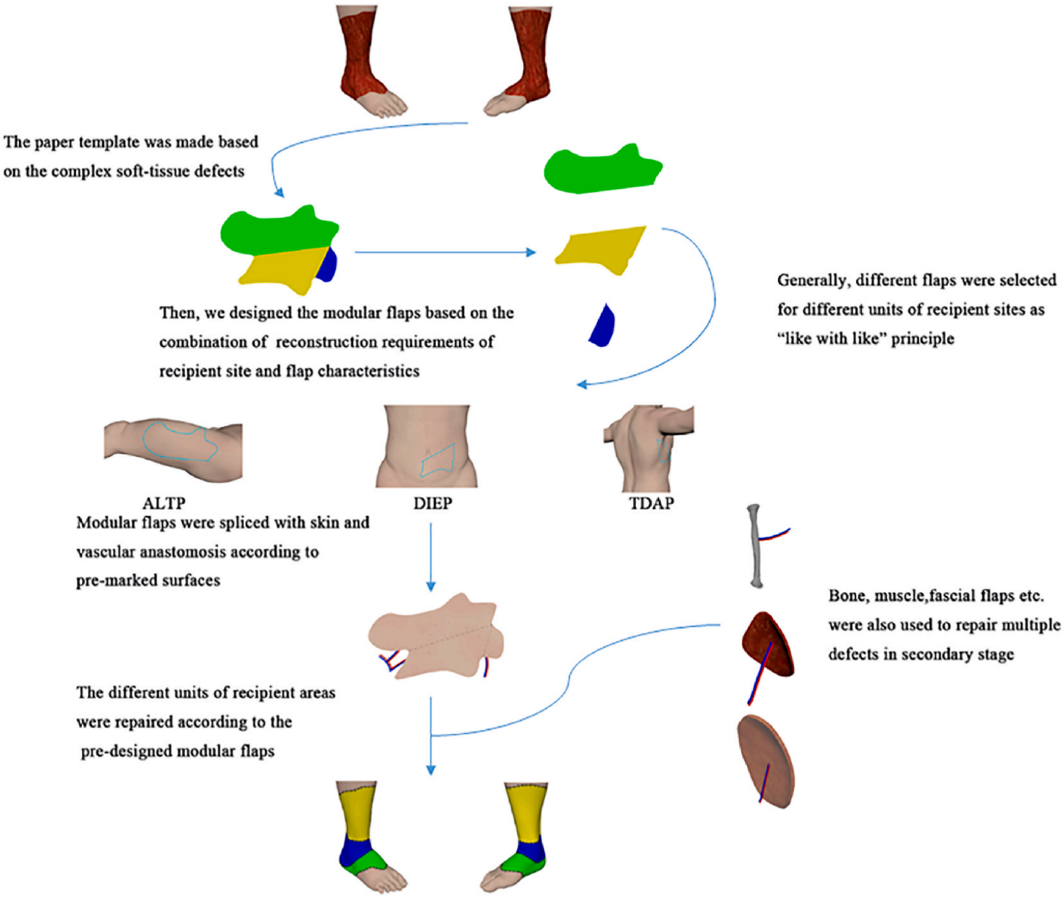

Fig. 1. The flowchart of flap design and splicing based on the principle of adaptation to recipient conditions.

3. Results

A total of 71 flaps were harvested from 31 patients (average 2.3 flaps/patient), including 47 ALTP, 9 LD, 9 DIEP, 3 TDAP, 2 PAP, and 1 CSAPF. Area of flaps for all patients range from 154 cm^2 to 686 cm^2. All flaps donor sites were capable of primary closure. 9 patients underwent split-thickness skin grafting, 7 of them were performed to overlap the muscle paddle of modified LD. Most patients were stable under close observation after operation. Vascular crisis occurred in 3 patients at 12 h after operation. Timely explorations of blood vessels were conducted, and 2 of them survived successfully after resection of embolized blood vessels and transplantation of great saphenous vein to rebuild the venous vessels. The crisis flap was replaced by LD flap in 1 case. In 5 cases, the distal epidermis of the flap was partially necrotic due to the crossing area of the skin flap. Among them, 3 patients were cured successfully by skin grafting, and the other 2 patients were cured successfully by dressing change. The average follow-up time were 27.7 months (range from 16 months to 38 months) and only one patient developed a heel ulcer with no major complication encountered in other patients. The patient details are shown in Table 1. Aesthetic and functional results of reconstructed limbs were satisfactory in all patients. The donor healed well in all cases without complications. Additionally, the sensory recovery status was checked by various tests. During the first-year follow up, functional and sensory outcomes of recipient sites were recorded in Table 2. ALTP skin flap with cutaneous nerve was used to repair the weight-bearing area of the foot. During the follow-up, sensation was gradually recovered effectively, while no significant recovery was found in other ingredient flaps.

4. Case reports

4.1. Case 1

A 14-year-old girl with opening and dislocation of the ankle, and soft tissue defect around the ankle caused by car accident, was underwent emergency debridement, ankle reset and external fixation, and the defects covered with negative pressure attraction materials. All candidate donor sites were evaluated before flaps transplants. And the duplicate soft tissue defects around ankle divided into two reconstruction modular units after re-debridement. Left flow-through, thin ALTP (21 cm × 13 cm) and left thin TDAP (25 cm × 10 cm) were choosed for repairing the defects from the candidate flaps. Both flaps were thinning in one-staged under microscopy before being ligated the pedicle of flap. The distal of descending branch of lateral femoral circumflex vessels was carried to build type

Table 2
Functional and sensory outcomes were followed up (6–12 months) .

Patients	Final functional outcome	Sensational outcome			
		Flap 2-PD (mm)	S–W test	Cold-Hot sensation	Sharp/Dull test
1	Good walking ability	20	4.74 (6 g)	Yes	Protective sensation
2	Good walking ability	20	4.31(2 g)	Yes	Protective sensation
3	Good walking ability	25	5.07 (10 g)	Yes	Protective sensation
4	Good walking ability	25	5.07 (10 g)	Yes	Protective sensation
5	Good walking ability	20	4.74 (6 g)	Yes	Protective sensation
6	Good walking ability	20	4.31 (2 g)	Yes	Protective sensation
7	Good walking ability	25	5.18 (15 g)	Yes	Protective sensation
8	Good walking ability	25	5.07 (10 g)	Yes	Protective sensation
9	Right poor walking ability	30	5.46 (26 g)	Yes	Protective sensation
9#	Left medium walking ability	25	5.18 (15 g)	Yes	Protective sensation
10	Poor walking ability	35	5.46 (26 g)	Yes	Protective sensation
11	Good walking ability	20	4.56 (4 g)	Yes	Protective sensation
12	Good walking ability	25	5.18 (15 g)	Yes	Protective sensation
13	Medium walking ability	30	5.18 (15 g)	Yes	Protective sensation
14	Poor walking ability	35	5.46 (26 g)	Yes	Protective sensation
15	Medium walking ability	35	5.88 (60 g)	Yes	Protective sensation
16	Good walking ability	30	5.46 (26 g)	Yes	Protective sensation
17	Good walking ability	30	5.18 (15 g)	Yes	Protective sensation
18	Medium walking ability	25	5.18 (15 g)	Yes	Protective sensation
19	Medium walking ability	35	5.88 (60 g)	Yes	Protective sensation
20	Medium walking ability	30	5.46 (26 g)	Yes	Protective sensation
21	Medium walking ability	25	5.07 (10 g)	Yes	Protective sensation
22	Good walking ability	20	4.74 (6 g)	Yes	Protective sensation
23	Good walking ability	25	5.07 (10 g)	Yes	Protective sensation
24	Good walking ability	20	4.56 (4 g)	Yes	Protective sensation
25	Good walking ability	30	5.46 (26 g)	Yes	Protective sensation
26	Medium walking ability	35	5.46 (26 g)	Yes	Protective sensation
27	Good walking ability	20	4.74 (6 g)	Yes	Protective sensation
28	Medium walking ability	35	5.88 (60 g)	Yes	Protective sensation
29	Medium walking ability	35	5.46 (26 g)	Yes	Protective sensation
30	Poor walking ability	30	5.46 (26 g)	Yes	Protective sensation
31	Good walking ability	30	5.18 (15 g)	Yes	Protective sensation

9#: Left limb of patient 9; 2-PD: Static 2-point discrimination; S–W test: Semmes–Weinstein.

"T" vascular pedicles. The proximal vessels were anastomosed with the posterior tibial vessels and distal vessels with the thoracic dorsal vessels. ALTP and TDAP survived very well and had a good appearance of leg. Both donor sites were closed directly, and only liner scar reserved (Fig. 2a–j).

4.2. Case 2

An 11-year-old boy suffered a traffic accident, causing left leg bone fracture and skin degloving injury. When the vital signs were stable, the boy underwent a thorough debridement, and bone fractures were fixed by external fixation and Kirschner wire fixation with skin graft performed at poor blood skin. Three weeks later, most of the skin survived. Due to skin necrosis around the ankle joint and heel, right flow-through ALTP (length: 23 cm, width: 8 cm, with nervus cutaneous femoris lateralis) and DIEP (length: 21 cm, width: 11 cm) were designed. After the perforator flaps were harvested by two groups at the same time, those flaps were assembled according to the marked on the skin. The right descending branch of lateral circumflex femoral artery and veins were anastomosed with posterior tibial artery and veins (1A, 2V), and the nervus cutaneous femoris lateralis anastomosed with the part of tibial nerve. The distal of descending branch of lateral circumflex femoral artery and veins which is nourish the rectus femoris and rectus intermedius were anastomosed with inferior epigastric artery and veins (1A, 2V). Flaps survived well, and only line scar was observed at donor sites (Fig. 3a-p).

5. Discussions

The large area of complex skin and soft tissue defects in children caused by high energy had a very high disability rate, which was an insurmountable obstacle for reconstruction surgeons [24]. Ricci JA et al. [24] suggested that despite of the recent data showing the increased complications and flap loss rate, limb salvage with free flap remained candidates for Gustilo type IIIB and IIIC. However, smaller vessel diameters, more limited donor sources and poorer compliance in children may pose much more difficulty on repairing and reconstruction, and super-microsurgical anastomosis technology also may solve the above problems to a certain extent [25,26]. Meanwhile, Khouri RK et al. [27] and Culliford AT 4th et al. [28] both found that the incidence of lower extremity flap loss and complication appeared to be higher than free flaps transplanted in other locations due to the poor blood supply and low tissue mobility. Luckily, for recovering multiple-soft-tissue defects, "like with like" reconstruction principle remained important, resulting in various types donor site cut [29]. And a single medical center's experience over two decades pointed the essential role of a more critical selection of free-flap candidates in successful plastic reconstruction [28]. In this study, a variety of vascularized free flaps including ALTP, DIEP, LD etc. combined with bone/muscle flaps to recover the flow-through blood supply, flimsy shape, deep dead space and

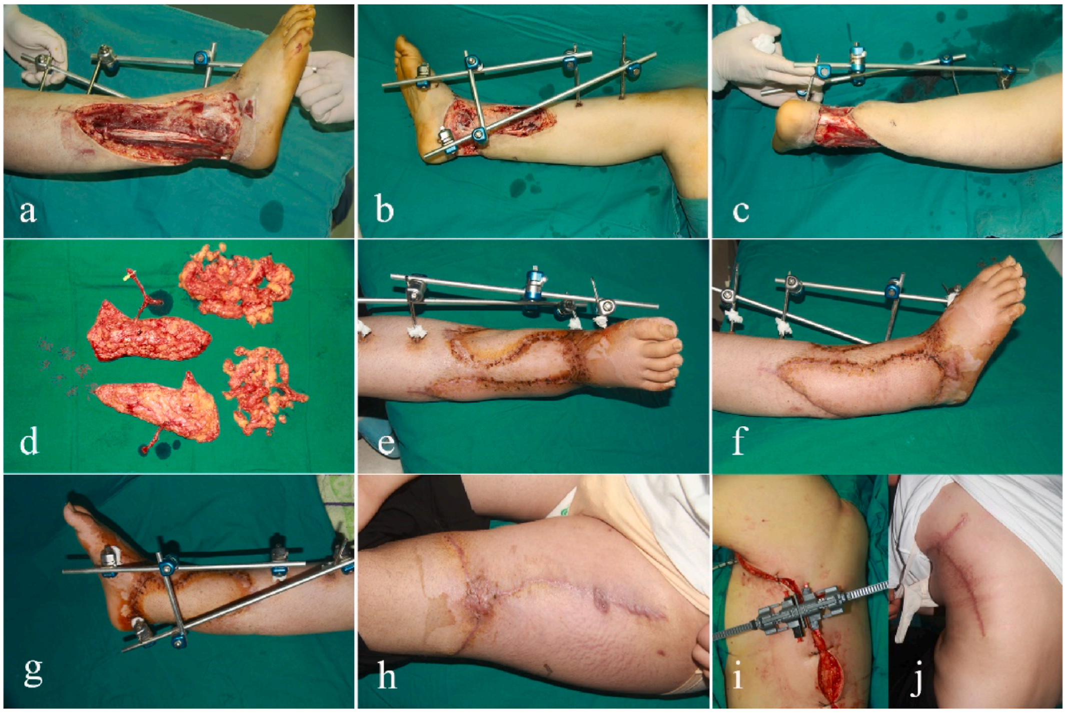

Fig. 2. a-c. Lateral, medial and rear view of preoperative wound. **d**. Flaps splicing of left flow-through, thin ALTP and left thin TDAP. **e-g**. Good union view of postoperative 24-months recipient site. **h**. Lateral view of postoperative 24-months donor site. **i-j**. Preoperative and postoperative view of TDAP.

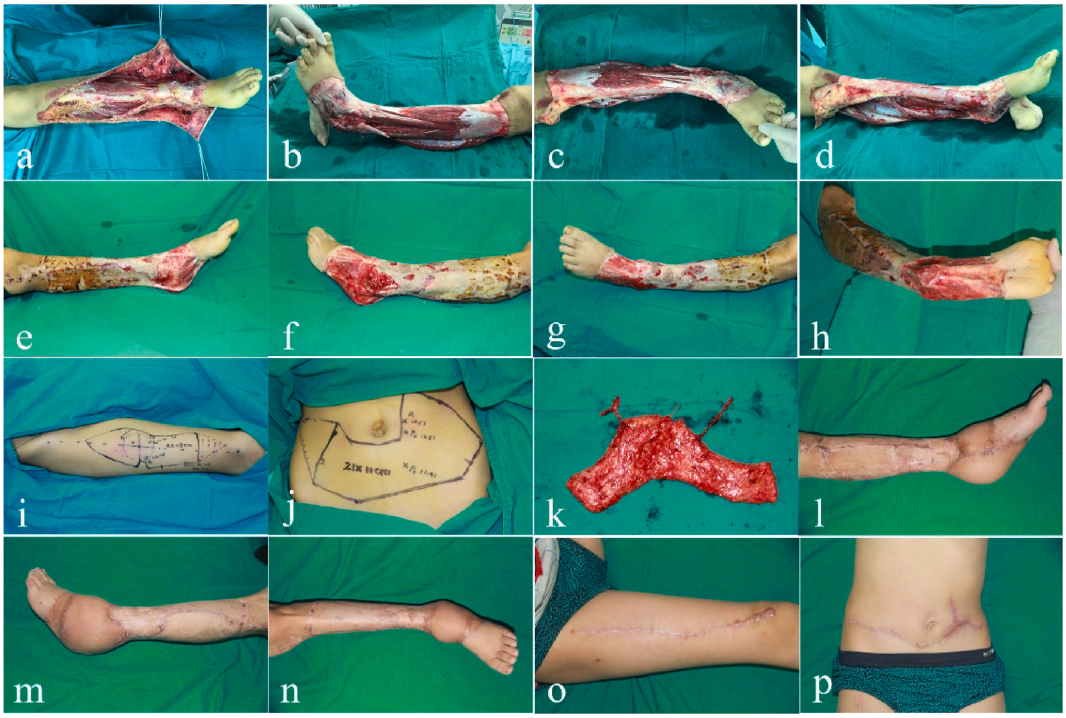

Fig. 3. a-d. Superior, lateral and medial view of preoperative wound. **e-h.** Medial, lateral, superior and inferior view of postoperative three-weeks skin graft. **i-j.** Design of right flow-through ALTP and DIEP. **k.** Flaps splicing of targeted two flaps. **l-n.** Medial, lateral, superior view of postoperative 18-months recipient site. **o-p**. Good union view of postoperative 18-months donor site.

sensation were performed. Therefore, the injury status poses a huge challenge on selecting an appropriate and comprehensive flap for reconstructive shape and function.

To address the aforementioned problems, this study was aimed to propose a new treatment method for different zones reconstruction based on the principle of adaptation to recipient conditions to overcome the intractable wounds, simplifying and programing the design process of targeted flap for covering large irregular soft-tissue defects. As mentioned before, the bank of candidate flaps needed to be established at first, which could cover large area of wound, harvest a "T" sharp vascular pedicle, rebuild the feeling, shape an adjustable thickness and obtain a vascular bone, fascial and muscle flap to achieved three-dimensional and modular reconstruction. It was worth mentioning that there were a large number of anatomical studies on ALTP showing the abundantly distal flow-through vascular used for chaining flaps and recovering blood trunk defects as the foundational flap of modular splicing flaps [30]. The chosen flaps of each medical center are inconsistent, due to the personal preference, the patient's physical condition and the way of operation related to the technique. In our department, ALTP, LD, DIEP *etc.* were used the most frequently to repair complex soft-tissue defect in children. However, to data, there is no systematic literature reporting the repair of large irregular soft-tissue defects in children based on the principle of adaptation to different recipient zones conditions.

Segmentation design of wounds as "like with like" principle is vital to the design of free flaps. Among the abovementioned flaps, ALTP was performed to be one of the best options due to reliability and versatility [31] and multiple advantages including [32–35] (1) flow-through vessel for chaining other flaps or recovering continuity of the superficial blood vessels damage; (2) multiple levels of muscle flaps for the three-dimensional functional repair; (3) sensation transference for wear-resistant and skin ulcer avoidance; (4) enough donor site for covering the wide and huge defect area; (5) micro-dissected thin technique for improved bulky flap shape, if necessary. Additionally, a novel option of double skin paddle ALTP flaps was presented by our team [14], showing the useful reference of three variants for microvascular reconstruction of complex soft tissue defects. In terms of DIEP and LD, the previous study and our team work showed their multiple characteristics in reconstruction of pediatric extremities. DIEP was generally developed and applied due to (1) extended donor area; (2) distinguished anti-infective ability with the reliable blood supply; (3) difficulty to repair thin area; (4) not suitable usage for female children [12,36–38]. Meanwhile, LD also had above mentioned items like DIEP expect the fourth [39]. Besides, for TDAP and CSAPF, some own characteristics were also revealed [25,40–43] such as (1) homogeneous thin back tissue for pliable soft tissue coverage; (2) small and single wound recovery; (3) variations of anatomical site.5

The main principles of recovering large irregular soft-tissue defects in children were ALTP for functional zone, ALTP and CSAPF for shape repair, LD and ALTP with muscle flap for deep dead space reconstruction, ALTP for vascular continuity recovery of recipient site, DIEP, TDAP and ALTP for huge skin and soft-tissue defects. This may avoid the embarrassment of a single flap with impracticality of direct closure of the donor site, injury of the function and appearance of the recipient site and the minimization of the surgical injury of the patient, and program and simplify flap design. In the cases of our medical center, there remain some representative injury statuses.

Notedly, the choice of flaps was based on reconstruction requirements of different recipient sites. Wound repair was mainly in the lower extremities. And these injuries usually occurred in the following situations like (1) CSAPF or ALTP for dorsalis pedis defects only; (2) ALTP for heel and sole injury; (3) Splicing of DIEP, TDAP and ALTP or not for no-functional zone defects such as ankle and calf **(Case 1 and Case 2)**; (4) Splicing of CSAPF and ALTP(unilateral or bilateral) for degloving injury of foot**(Supplementary Materials 1)**; (5) Multiple flaps of CSAPF, ALTP, DIEP, TDAP and LD for relatively huge area tissue defects including calf, ankle and degloving injury of foot**(Supplementary Materials 1)**; (6) ALTP with T-shape vascular pedicle for trunk vascular defects, ALTP with nerve cutaneous for sensation recovery**(Case 2 and Supplementary Materials 2)**;(7) muscle flap for deep space filling and bone flap for bone loss, if necessary for delayed repair.

The flap design and surgical technique were discussed before in this study and our group work [11–15,17,19–21,25,35,44]. But there remain some specially mentioned notes for reconstruction based on the principle of adaptation to different recipient zones conditions. Firstly, more T-shape vascular pedicle should be performed to chain adjacent flaps or recover trunk blood supply. Secondly, due to the irregular and wide template, different zones should be divided according to the recipient requirements like coverage, shape, blood reconstruction, sensation etc. And then different flaps mentioned above could be filled in these targeted zones. But direct closure needs to be considered after flap harvest. Thirdly, multi-partition reconstruction makes the whole surgical process time-consuming and complicated. It is vital for surgeons to mark them on the skin and carry out edge to edge for flap splicing before operation, resulting in the connections between different modular flaps like playing puzzles. In general, compared with the traditional flap design surgery, through the mentioned above new flap design, we achieve the accurate repair of the pediatric wound recipient area, and the minimally invasive and aesthetic donor area in order to recover the recipient appearance, function or feeling.

Although this concept may help surgeons to simply and program the flap design to achieve more complicated soft-tissue defect recovery, the work needs more skillful practice and team cooperation. Meanwhile, not only the surgeon's experience is the vital factor for flap success, but management of perioperative period also matters [45]. How to discern a suitable perforator, perform precise anatomy, avoid vasospasm, identify the arterial or venous occlusions, conduct anti-infection therapy, improve body status and manage whole postoperative period are also important to the flap transferring and the successful practice of different unit reconstruction.

5.1. *Limitations*

Firstly, lack of a comparison group and a standardized measure for long-term outcomes are the main limiting factors of this study. This small-scale retrospective case caries should be further attested by more convincing evidence and future similar studies in a long term. Secondly, this may supply more improved skills with adaptation to recipient conditions reconstruction for surgeons. Meanwhile, several popular flaps are described in this study, but this method reconstruction could be applied in almost flaps harvest procedures based on the need to cover the scope and the direct closure of donor area previously described in our team research. Finally, there remained testing bias of the sensory recovery status due to subjective difference from children and various areas of combined flaps.

6. Conclusions

Adaptation to recipient conditions for geometric segmentation of wounds is closely related to the design of perforator flaps. The proposed novel concept is useful to simplify and program the process of design different zonal flap. Furthermore, there are no serious complications observed during the follow-up period. Therefore, our results show that it is applied to the successful practice which explains the usage of multiple popular flaps (ALTP, LD, DIEP, TDAP, PAP and CSAPF) relying on their own unique characteristic.

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Data availability statement

The raw data supporting the conclusions of this article will be made available by the authors, without undue reservation.

Ethics statement

The studies involving human participants were reviewed and approved by the Medical Ethic Committee of Xiangya Hospital of Central South University (Approval Number: 202301057) on Feb 7, 2023. The patients' parents provided informed consent to participate in the study and agreed to disclose his anonymous details and images. The protocol was in accordance with the ethical standards of the Helsinki Declaration of 1975 and all subsequent revisions.

CRediT authorship contribution statement

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Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.heliyon.2024.e31179.

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