



Customized reconstruction of complex soft-tissue defect in the hand and forearm with individual design of chain-linked bilateral anterolateral thigh perforator flaps

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KEYWORDS

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Summary *Background:* Complex soft-tissue defects of upper extremities still have a high rate of amputation, as the reconstruction of complex soft-tissue defects is always difficult even with the largest conventional free flap. The anterolateral thigh perforator (ALTP) flap is one of the most popular procedures used for the coverage of complex soft-tissue defects of extremities. However, problems associated with donor-site morbidity and inability to repair complex soft-tissue defects in a one-stage procedure persist. The purpose of this study was to present a novel design of using chain-linked bilateral ALTP flap and its various designs for customized reconstruction of complex soft-tissue defects in the hands and forearms.

Methods: From June 2009 to June 2017, we retrospectively analyzed 15 patients with complex soft-tissue defects in the hands and forearms. All patients in this series underwent extremity reconstruction using the chain-linked bilateral ALTP flaps. Three different types of chain-linked bilateral ALTP flaps were created in this study based on wound characteristics and the maximum available skin paddle size at all donor sites.

Results: The chain-linked bilateral ALTP flaps were successfully harvested for the reconstruction of complex soft-tissue defects in the hands and forearms. Among them, ten cases were repaired with chain-linked bipaddle ALTP flaps, two cases were treated with chain-linked tri-paddle ALTP flaps, and the remaining three cases were used with chain-linked multi-lobed ALTP chimeric flaps. The sizes of the skin paddles ranged from 11 cm × 7 cm to 42 cm × 8 cm. The areas of the total flaps ranged from 245 cm² to 650 cm² (mean 419.6 cm²). Only one case required re-exploration because of the venous congestion. The donor sites were closed directly. The mean follow-up time was 16.4 months. Most cases showed satisfactory contour.

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Conclusion: The chain-linked bilateral ALTP flap is a reliable option for one-stage reconstruction of complex soft-tissue defects in the hands and forearms with limited donor-site morbidity. It also provides various flap designs, which allow for more individualized treatment approaches. © 2019 Published by Elsevier Ltd on behalf of British Association of Plastic, Reconstructive and Aesthetic Surgeons.

Introduction

High-energy trauma often causes complex soft-tissue defects in the hands and forearms, and is always a unique challenging problem for reconstructive surgeons.^{1,2} Numerous reconstructive procedures have been reported in literature, such as pre-expanded flap³⁻⁵ and free muscle flaps with skin grafting.^{6,7} Some authors claimed that a large and well-perfused flap could be raised using pre-transfer expansion; however, the techniques used for tissue expansion were time- and manpower-consuming, which would affect the early function exercise of the upper extremity and result in poor function recovery.^{4,5} Moreover, multiple operations were still required. Free muscle flaps with skin grafting also have been introduced as an alternative approach to repair the complex extremity defect, but frequently led to higher donor-site morbidity, bulky appearance, unsatisfactory color match, and unstable mobile surface.⁸

In the past decade, the reliability of perforator flaps for the extremity reconstruction has been well documented in literature.^{2,9} The anterolateral thigh perforator (ALTP) flap is one of the famous approaches for the reconstruction of soft-tissue defects in extremities because of its large cutaneous area, long vascular pedicle, acceptable donor-site morbidity, and adjustable thickness.^{10,11} However, harvesting an extended ALTP flap for the reconstruction of very large soft-tissue defect presented with a risk of partial necrosis.^{12,13} Furthermore, if the width of the ALTP flap extends 8-10 cm, a skin grafting is required to close the donor site, which can cause an unsightly scar appearance.¹⁴

In this context, multiple perforator flaps in combination offer potential for the reconstruction of large damaged areas of soft tissues. Hayashi et al.¹⁵ reported that pre-fabricated bilateral latissimus dorsi musculocutaneous flap was an alternative to repair extensive defect of the lower leg. Song et al.¹⁶ showed that medial plantar flap combined with latissimus dorsi muscle flap provided an option for the reconstruction of extensive foot defect. However, latissimus dorsi musculocutaneous flap often presented with high donor-site morbidity and bulky appearance. In addition, a contour defect may be left on the back.¹⁷ Furthermore, an intraoperative readjusted position is required. Considering both function and esthetics, we proposed a chain-linked bilateral ALTP flaps design, in which bilateral ALTP flaps were fabricated in combination with microanastomoses. In addition, we also presented three different types of chain-linked bilateral ALTP flap design for customized reconstruction of complex soft-tissue defects in the hands and forearms. To the best of our knowledge, these are the largest series to date reporting microvascular reconstruction of complex soft-tissue defects in the hands and forearms using chain-linked bilateral ALTP flaps. Our report focuses on the various designs of chain-linked bilateral flaps

for customized reconstruction of complex soft-tissue defects to minimize the donor-site morbidity that has rarely been addressed before.

Patients and methods

From June 2009 to June 2017, fifteen patients with complex soft-tissue defects in hands and forearms underwent extremity reconstruction using chain-linked bilateral ALTP flaps. The age of patients ranged from 20 to 53 years (mean 37.5 years; 2 females and 10 males). Of these patients, 3 cases were caused by crushing injury, and the other 12 cases were caused by traffic accident. Patient details are 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.

Flap design

We routinely evaluated the wound and classified in detail to provide a specific customized reconstruction for individual patients. A pinch test was performed preoperatively to assess the maximum available skin size at all donor sites. A paper template with the same dimensions of defects was created, and then the paper template was split into several parts, which can guide each skin paddle to be designed over the donor site. This design limited the width of each skin paddles to less than the maximum available skin size to permit donor-site closure directly.

According to the features of the wound and the maximum available skin size at all donor sites, three different types of chain-linked bilateral ALTP flaps were utilized to repair the defect, including chain-linked bipaddle ALTP flap, chain-linked tripaddle ALTP flap, and chain-linked multi-lobed ALTP chimeric flap ([Figure 1](#)).

Type A, Chain-linked bipaddle ALTP flap

To reconstruct very large soft-tissue defect (the maximum width of the defect is less than 32% of the thigh circumference and more than 16% of the thigh circumference), the bilateral ALTP flaps were harvested. The two skin paddles were placed side-by-side to precisely match the very large defect ([Figure 1A](#)).

Type B, Chain-linked tripaddle ALTP flap

For some super width soft-tissue defects reconstruction (the maximum width of the defect is more than 32% of the thigh circumference), chain-linked tripaddle ALTP flap,

Patient	Age (y)/Sex	Cause of injury	Indication for surgery	Type of design	Dimensions of the Flap (cm)	Total skin paddle area (cm ²)	Complications	Follow-up (mo)
(1)	44/M	Traffic accident	Exposure of bone and extensor tendons	Type A	Right ALTP:42 × 8; Left ALTP:38 × 8	640	None	32
(2)	31/M	Crush injury	Exposure of bone and tendons	Type A	Right ALTP:24 × 7; Left ALTP:11 × 7	248	None	17
(3)	53/F	Traffic accident	Exposure of bone and tendons	Type A	Left ALTP: 25 × 8; Right ALTP: 26 × 7	382	None	11
(4)	47/M	Traffic accident	Exposure of bone and extensor tendons; dead space	Type C	Left chimeric ALTP: skin paddle 24 × 11 and muscle paddle:7 × 4 Right ALTP:18 × 7	390	None	12
(5)	48/M	Traffic accident	Exposure of bone and tendons; dead space	Type C	Right chimeric ALTP: skin paddle27 × 8 and muscle paddle:6 × 2; Left ALTP:27 × 8	432	None	9
(6)	34/F	Traffic accident	Exposure of bone and tendons; circumferential defect	Type A	Left ALTP:28 × 8; Right ALTP:10 × 9	314	None	28
(7)	48/M	Traffic accident	Exposure of flexor and extensor tendons	Type A	Left ALTP: 15 × 7; Right ALTP: 20 × 10	320	None	18
(8)	41/M	Traffic accident	Exposure of radius bone and flexor and extensor tendons	Type A	Left ALTP: 32 × 10; Right ALTP: 27 × 10	590	edge necrosis	13
(9)	24/M	Traffic accident	Exposure of ulnar bone and tendons; circumferential defect	Type A	Left ALTP: 25 × 9; Right ALTP:24 × 9	441	None	12
(10)	20/M	Crush injury	Exposure of bone, flexor, and extensor tendons; thumb defect	Type A	Left ALTP:25 × 9; Right ALTP:15 × 12	405	None	14
(11)	22/M	Traffic accident	Exposure of flexor and extensor tendons; circumferential defect	Type B	Left dual skin paddle ALTP:20 × 8 and 15 × 8; Right ALTP:23 × 7	441	None	30
(12)	36/F	Crush injury	Exposure of radius bone and tendons; dead space	Type C	Left chimeric ALTP: skin paddle 22 × 7 and muscle paddle:7 × 3; Right ALTP:19 × 7	287	None	12
(13)	44/F	Traffic accident	Exposure of flexor and extensor tendons	Type A	Left ALTP:33 × 10; Right ALTP:32 × 10	650	None	10
(14)	27/M	Traffic accident	Exposure of bone and joints; extensor tendon defect	Type B	Left dual skin paddle ALTP: 18 × 6.5 and 15 × 6; Right ALTP:24 × 7	375	Vein crisis	16
(15)	43/M	Traffic accident	Exposure of flexor and extensor tendons	Type A	Right ALTP:22 × 10; Left ALTP:18 × 9	382	None	12

M: male F: female ALTP: anterolateral thigh perforator flap

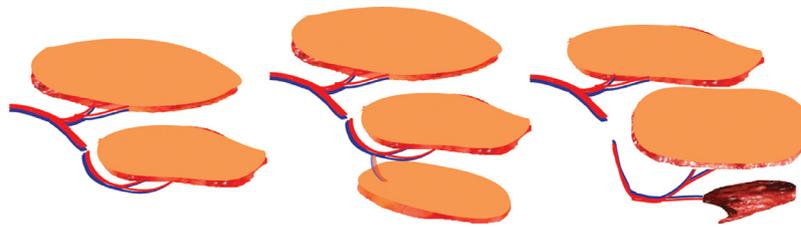


Figure 1 A diagram illustrated three different microsurgical combined flap systems in the study basing. (A): Chain-linked bipaddle ALTP flap (Left); (B): Chain-linked tripaddle ALTP flap (Middle); (C): Chain-linked multi-lobed ALTP chimeric flap (Right).

which consists of a traditional ALTP flap and a dual-skin paddle ALTP flap, was designed to further enlarge the width of the flap. The skin paddles were placed side-by-side to form a single unified flap with the desired width (Figure 1B).

Type C, Chain-linked multi-lobed ALTP chimeric flap

When a complex soft-tissue defect has very large surface and is presented with underlying dead space, its reconstruction often depends on a flap to eliminate the dead space and cover the very large surface soft-tissue defect at one stage. We performed a chain-linked multi-lobed ALTP chimeric flap design, in which a traditional ALTP flap and an ALTP chimeric flap were fabricated in combination with microanastomoses. The skin paddles were placed side-by-side to cover the large surface defect, whereas the muscle component was used to eliminate the dead space (Figure 1C).

Flap elevation

Two surgical teams were used to harvest the flaps, and the two flaps were elevated simultaneously. Harvesting the ALTP flap was the same as it was reported in our previous study.^{10,18,19} Briefly, perforators were mapped on each donor site preoperatively. Initially, only one side of the skin paddle was incised to avoid flap elevation failure because the location of the perforator may vary, and this enables the surgeon to readjust the location of the skin paddle. Several additional perforators were preserved until the main perforator was identified. Then, meticulous perforator dissection was performed. The perforator was traced back to the main trunk of descending branch of the lateral circumflex femoral vessels.

After the flaps were completely dissected, the bilateral ALTP flaps were placed side-by-side to exactly match the size of the large surface soft-tissue defects. The proximal end of the lateral circumflex femoral artery (LCFA) was anastomosed to the recipient artery, and the distal end of the descending branch or a large muscle branch of the LCFA was anastomosed to the pedicle of an additional flap. After the flap was transferred to the defect, the wound of the donor site was closed directly after complete hemostasis and reliable drainage.

Results

Twelve patients were successfully treated using chain-linked bilateral ALTP flaps. Ten cases were repaired with chain-linked bipaddle ALTP flaps, two cases were repaired

with chain-linked tripaddle ALTP flaps, and the remaining three cases were repaired with chain-linked multi-lobed ALTP chimeric flaps. The sizes of the skin paddle ranged from 11×7 cm to 42×8 cm. The area size of the total flaps ranged from 245 cm^2 to 650 cm^2 (mean 419.6 cm^2).

All of the flaps survived. Only one flap required reoperation because of venous congestion. One case presented with minor wound-edge necrosis, and it was treated conservatively. Primary closure of donor sites was successful in all patients, and healed uneventfully. The mean follow-up time was 16.4 months (range 9-32 months). Most cases showed satisfactory contour, and there was no excessive bulk.

Case report

Case 1

A 44-year-old male was injured in a traffic accident and presented with very large soft-tissue defect on the right hand and forearm. Radical debridement led to the exposure of tendons and bones. Type A pattern of chain-linked bilateral ALTP flap was performed to cover the soft-tissue defect. The size of the left ALTP flap was 42×8 cm, and the size of the right ALTP flap was 38×8 cm. The donor sites were closed directly. The postoperative course was uneventful. The recipient site showed satisfactory contour, and there was no excessive bulk (Figure 2). Excessive function recovery was found after 32 months follow-up (*supplementary materials video.1*).

Case 11

A 22-year-old male sustained with a traffic injury that caused a very large soft-tissue defect in the hand and forearm. After radical debridement, the bone, flexor, and extensor tendons were exposed. To reconstruct the extensive soft-tissue defects and maintain the primary closure of donor site, Type B pattern of chain-linked bilateral ALTP flap was designed to cover the wound at one stage. The dual-skin paddle ALTP flap was harvested with skin paddles measuring 20×8 cm and 15×8 cm, and the size of the right ALTP flap was 23×7 cm. These skin paddles were placed side-by-side to precisely cover the soft-tissue defects. The donor sites were closed directly. The postoperative course was uneventful. The recipient site showed satisfactory contour, and there was no excessive bulk (Figure 3). Excessive function recovery was found after 30-month follow-up (*supplementary materials video.2*).



Figure 2 (A): Preoperative view of the recipient site: Dorsal view (Above), Lateral view (Below). (B): Chain-linked bipaddle ALTP flap was designed to cover the soft-tissue defect. Intraoperative view after elevation of the perforator flaps. (C): Postoperative view of the recipient site at 32-month follow-up. (D): Postoperative view of the donor site.

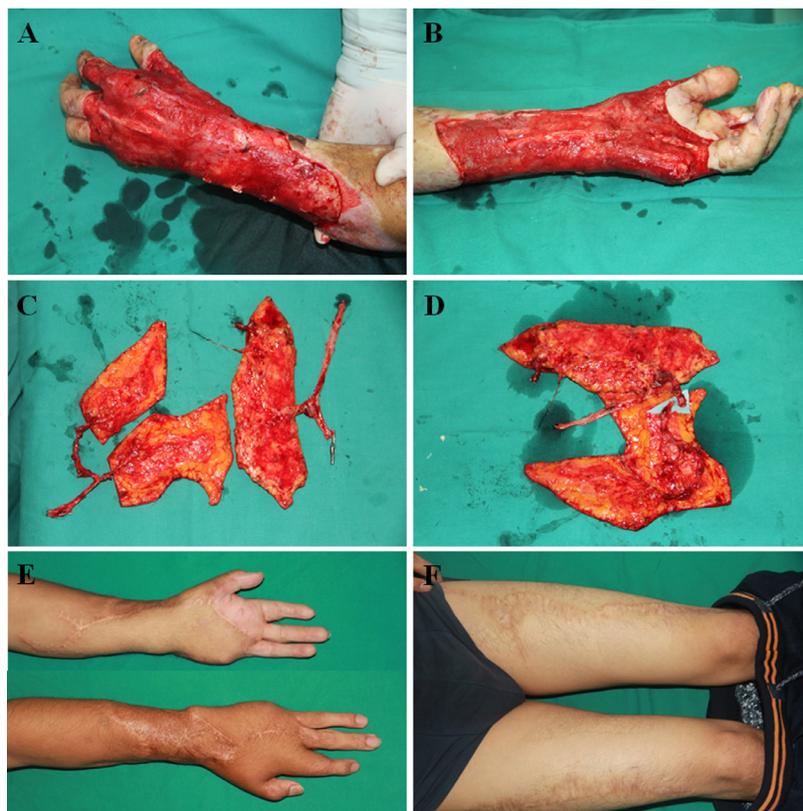


Figure 3 (A), (B): A 22-year-old male sustained a traffic injury in the left hand and forearm that caused a huge soft-tissue defect on the hand and forearm. (C): Chain-linked tripaddle ALTP flap, which consisted of a traditional ALTP flap and a dual-skin paddle ALTP flap designed to cover the very large soft-tissue defect at one stage. The skin paddles were placed side-by-side to expand the width of the flap. (D): Forming a chain-linked tripaddle ALTP flap by the microvascular anastomosis. (E), (F): The recipient site showing satisfactory contour. There was no excessive bulk at 30-month follow-up; Postoperative view of the donor site.

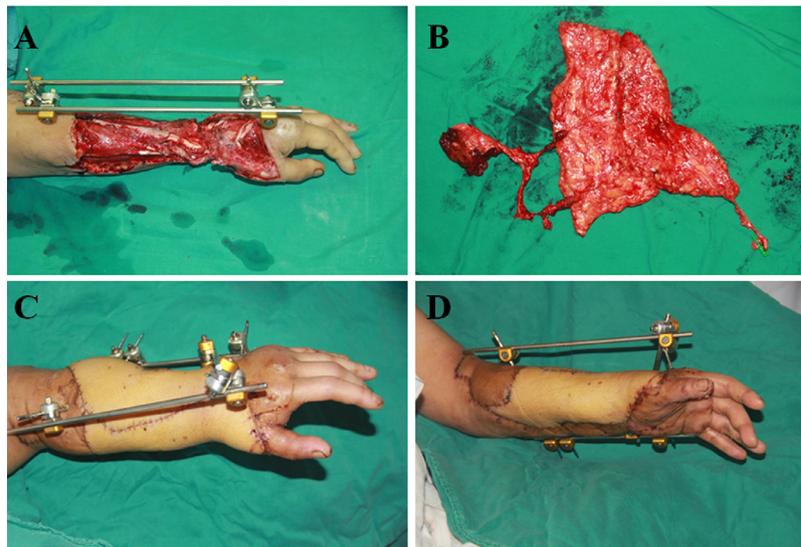


Figure 4 (A): Preoperative view of the recipient site. (B): Chain-linked multi-lobed ALTP chimeric flap was elevated to reconstruct the complex soft-tissue defect. The skin paddles of these flaps were placed side-by-side to cover the surface skin soft-tissue defect. The VL muscle was inserted in the dead space. (C), (D): Postoperative view of recipient site.

Case 12

A 36-year-old female sustained a crushing injury, which caused a very large soft-tissue defect in the left upper extremity. Radical debridement left a dead space. To reconstruct the very large soft-tissue defects and simultaneously eliminate the dead space, Type C pattern of chain-linked bilateral ALTP flap was designed. The size of skin paddle of the ALTP chimeric flap was 22×7 cm, and the size of VL muscle paddle was 7×3 cm. The size of the right ALTP flap was 19×7 cm. The skin paddles of these flaps were placed side-by-side to cover the surface skin defect, and the VL muscle paddle was inserted into the dead space. The donor sites were closed directly. The postoperative course was uneventful. The recipient site showed satisfactory contour, and there was no excessive bulk (Figure 4).

Discussion

The hand and forearm have a unique importance in human function as well as act as an important esthetic organ.^{1,6,20} However, complex soft-tissue defects of upper extremities still have a high rate of amputation as the reconstruction of complex soft-tissue defects is always difficult even with the largest conventional free flap.

Recently, several modified approaches have been reported for repairing the very large soft-tissue defects. Hwang et al.²¹ introduced a chimeric perforator flap to expand the surface of the flap to reconstruct very large wounds, but an additional skin grafting procedure was unavoidable, which resulted in a bulky appearance and unsatisfactory color match. The dual-skin paddle perforator flaps were also recommended as a reliable technique to repair the very large soft-tissue defect with primary closure of donor site.^{22,23} However, the dual-skin paddle perforator flap emphasizes the harvest of a narrow length flap, which

was converted into two skin paddles to enlarge the width of the flap.²⁴ Therefore, this flap is essentially restricted to the area corresponding to the angiosomes of perforators originating from a specific deep vascular branch. In this context, when encountering a very large soft-tissue defect, whose length exceeds the maximum length of the skin paddle that a dual-skin paddle perforator flap can provide, the increased risk of flap partial necrosis could be expected. Our previous study demonstrated that the dual-skin paddle ALTP flap was an alternative option to repair very large soft-tissue defect in the foot and ankle.¹⁸ However, it only allows for primary closure of the donor site when the maximum width of the defect is less than 32% of the thigh circumference. If the width of the defect is greater than 32%, primary closure of the donor site still cannot be achieved.^{25,26} Besides, the feasibility of the dual-skin paddle ALTP flap depends on the presence of at least two suitable perforators and the effective vascular pedicle length between the skin paddles.^{27,28} Unfortunately, ALTP flap is known for its various vascular pedicle.²⁹ Failing to understand its variability can lead to tissue loss.³⁰

The main drawbacks of these approaches for repairing the very large defects have motivated us to research a new method to overcome these limitations. In these present series cases, we proposed a chain-linked bilateral ALTP flap design, which can be harvested for the reconstruction of very large defects with primary closure of the donor site. Furthermore, when the maximum width of the wound is greater than 32% of the thigh circumference, a chain-linked tripaddle ALTP flap, a dual-skin paddle ALTP flap, and conventional ALTP flap can be harvested to further enlarge the width of the flap.

In this study, we also presented a chain-linked multi-lobed ALTP chimeric flap to reconstruct complex soft-tissue defects in the hand and forearm. Large surface soft-tissue defect often accompanies with deep tissue damage, which will lead to dead space.³¹ This type of reconstruction frequently

depended on the requirement of a three-dimensional flap with both volume and surface to cover the very large surface soft-tissue defect and simultaneously eliminate the dead space.^{32,33} ALTP chimeric flap was one of the most popular procedures for the reconstruction of three-dimensional defects. However, the problems associated with donor-site morbidity and its inability to repair very large defects in a one-stage procedure persist. Considering the very large surface soft-tissue defect and dead space, a chain-linked multi-lobed ALTP chimeric flap was proposed, which consisted of an ALTP chimeric flap and a traditional ALTP flap that were fabricated in combination with microanastomoses. The former ALTP chimeric flap was primarily used to eradicate the dead space as well as reconstruct a part of the surface soft-tissue defect. The latter traditional one was recommended to cover the remaining defects. This pattern of flap combination helps in more effective reconstruction of soft-tissue defects with primary closure of the donor site for wound coverage as well as offers more degree of freedom and a flexible design to eradicate the dead space, which helps in the optimal treatment and avoid wound infection and hematoma.

We developed three variants of bilateral ALTP flaps to repair complex soft-tissue defects precisely and effectively in a single procedure. With our novel design, we can achieve customized reconstruction of the complex soft-tissue defect by performing individual design of chain-linked bilateral ALTP flap. Moreover, the flexible shape of this flap permits alteration to match the shape of the recipient site and covers the very large surface soft-tissue defect with primary closure of the donor site. Furthermore, this approach allows the surgeon to harvest various tissue components to eliminate the dead space and cover the very large surface wound simultaneously.

Several tips and tricks for designing and harvesting the chain-linked bilateral ALTP flap can be shared. Firstly, the vascular anatomy of donor site must be identified before operation. Notably, this procedure is especially important for the successful harvesting of the dual-skin paddle ALTP flap. To assess the vascular anatomy of the lateral femoral circumflex system, an extremity computed-tomography-assisted angiography scan was routinely performed preoperatively in our department. Secondly, successful harvesting of bilateral ALTP flap requires longer learning curves and skillful microsurgery techniques. Techniques and designs described in this series were used by senior surgeons in a matured team of microsurgeons with knowledge and regular experience in this field. Thirdly, reconstruction of complex soft-tissue defect in extremities using the chain-linked bilateral ALTP flaps requires more rehabilitation and a longer recovery period than amputation, which necessitates patience and endurance on the part of the patient. Therefore, the general status and the socioeconomic status of the patient with the characteristics of the defect should be evaluated thoroughly before surgery to assist in decision making between amputation and the use of bilateral ALTP flap. These flaps are suitable only for selected patients with complex soft-tissue defects who can endure long rehabilitation.

Some authors claimed that harvesting free flaps for very large defects reconstruction is always associated with risk of complications, which include vascular crisis, partial flap

loss, and wound disruption.^{25,34-36} However, recent study has demonstrated that wound surface area has no association with flap-related reoperation rates.³⁷ In the present cases, only one case required re-exploration because of venous congestion, and all flaps survived. Therefore, this approach could be an alternative option for the reconstruction of complex soft-tissue defects in the hand and forearm.

Conclusion

Our experience showed that chain-linked bilateral ALTP flaps were an alternative option for one-stage reconstruction of complex soft-tissue defect in the hand and forearm. This flexible approach not only provided a large cutaneous area with primary closure of donor site, but also offered various flap designs, which allowed for more individualized treatment approaches. This technique further extended the range of applications and indications of the ALTP flap.

Declaration of Competing Interest

None declared.

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Ethical approval

Not required.

Supplementary materials

Supplementary material associated with this article can be found, in the online version, at doi:[10.1016/j.bjps.2019.08.004](https://doi.org/10.1016/j.bjps.2019.08.004).

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