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ORIGINAL ARTICLE

Reconstruction of traumatic forefoot defects with free lateral arm flap

Kubilay Erol, MD, Can Yener, MD, Erdem Er, MD, Özgün Barış Güntürk, MD, Tulgar Toros, MD

Department of Orthopedics and Traumatology, Hand and Microsurgery, Orthopaedics and Traumatology (EMOT) Hospital, İzmir, Türkiye

ABSTRACT

Objectives: This study aims to evaluate the results of traumatic soft tissue defects of the forefoot reconstructed using the lateral arm flap and to examine the advantages and disadvantages of this flap.

Patients and methods: Between January 2007 and December 2023, a total of 25 patients (23 males, 2 females; median age: 35 years; range, 8 to 57 years) who underwent lateral arm free flap reconstruction for forefoot soft tissue defects were retrospectively analyzed. Age, sex, injury mechanism, flap size, anastomosis site, vascular complications, associated injuries, functional results, donor site coverage, and aesthetic results of the operation rated by the patient and surgeons were noted. The recovery of sensation at the reconstructed site was also evaluated.

Results: The median follow-up was 24.8 (range, 15 to 44) months. Only one total flap loss was encountered in this study, with an overall flap survival rate of 96%. Debulking of the flap was necessitated in four patients for comfortable shoe wear; those flaps were used to cover sizeable dorsal defects of the foot. The median European Foot and Ankle Society (EFAS) daily living score at the final evaluation was 18.2 (range, 17 to 21). All patients were able to wear regular shoes without modifications. All flaps regained protective sensation, although in none of them a neurography was performed. In the Semmes-Weinstein monofilament (SWM) testing, 18 patients could feel 4.56, four patients 6.65, and three patients 4.31. The patient-rated satisfaction score for reconstruction averaged 3,7 on a five-point scale.

Conclusion: Reconstruction of forefoot soft tissue defects using the lateral arm flap provided satisfactory results in terms of successful soft tissue coverage, function, and patient satisfaction, with good cosmetic appearance and unrestricted shoe wear. Based on these findings, this flap is a good alternative for forefoot reconstruction owing to its ease of dissection, constant vascular anatomy, rich blood supply, and limited thickness. In addition, it does not sacrifice a major artery, does not limit the function of the arm, and the donor site can be closed primarily in most cases. The main disadvantage of the flap seems to be the conspicuous scar it leaves on the lateral aspect of the arm.

Keywords: Foot reconstruction, forefoot, free lateral arm flap.

Reconstruction of traumatic soft tissue defects of the forefoot poses a challenge for orthopedic surgeons. This area has thin, yet durable and elastic soft-tissue coverage which can withstand prolonged pressure and impact forces. Due to the scarcity of neighboring soft tissues, local flaps have limited use in the foot and are mainly used to cover limited defects.[1,2] Although superficial soft tissue loss without bone and tendon exposure is amenable to secondary closure and skin grafting for certain injuries, deeper defects with exposed bones, tendons, nerves, and arteries necessitate flap coverage from distant donor sites for satisfactory results.[1-4]

Pedicled or local flaps harvested from the neighboring soft tissues are usually regarded as first-line flaps for reconstruction; however, due to the small size and limited reach of these flaps, sizeable defects cannot be reconstructed successfully using these alternatives.[1,5] In most injuries, the donor site of local flaps lies within the injury zone, increasing the complication rates and even flap failures compared to their free counterparts. In addition, sacrificing a feeder artery at the injury zone to harvest a local flap may increase the

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Correspondence: Kubilay Erol, MD. El ve Mikrocerrahi, Ortopedi ve Travmatoloji (EMOT) Hastanesi, Ortopedi ve Travmatoloji Kliniği, 35230 Konak, İzmir, Türkiye.

E-mail: kubilayerol89@gmail.com

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vascular compromise of the injured segment of the foot and endanger the viability of the traumatized tissues.[1]

The soft tissue coverage of the dorsal and distal sides of the foot is thin and pliable, which is an essential factor for function and ambulation. Reconstruction of forefoot necessitates thin flaps to achieve proper function and unrestricted shoe wearing.[1,2,6,7] Although modern supra fascial dissection techniques may decrease the soft tissue bulk of the majority of free flaps, this practice is not used commonly by many surgeons, since it endangers micro circulation within the flap in the acute phase and may decrease the rate of flap survival.[8] Due to the unmatched thickness of the proximally located flaps harvested from the lower extremities (such as the commonly used anterolateral thigh (ALT) flap or groin flap), these options are not regarded as perfect alternatives for coverage of the dorsal side and distal end of the injured foot.[9,10]

Recently, early flap coverage has become the gold standard in traumatic soft tissue reconstruction to limit scar tissue formation at the injury site, preserve the elastic properties of soft tissues, prevent infection and additional soft tissue necrosis.[11] Secondary coverage by regeneration of granulation tissue and skin grafting is prone to development of chronic infection at the reconstruction site and results with a fragile soft tissue coverage which is prone to ulceration that cannot tolerate prolonged stress imparted at the weight-bearing areas and distal end of the foot.[1,12] Secondary wound closure creates a non-elastic soft tissue coverage that limits the range of motion (ROM) of the metatarsophalangeal joints which is considered an essential factor for physiological ambulation. It may also cause adhesion of the tendons further limiting movement and physiological motion of the forefoot.[1]

At this point, the lateral arm flap becomes a prominent alternative for the reconstruction of sizeable forefoot soft tissue defects, fulfilling the major requirements of reconstruction that have been discussed previously. This flap is thin and pliable and can be harvested in dimensions of up to 6 × 12 cm. It has a constant and large pedicle, causes minimal donor site morbidity, does not sacrifice a major artery, its dissection is quick and straightforward and has a rich vascular supply.[13-15]

In the present study, we aimed to evaluate the results of traumatic soft tissue defects of the forefoot reconstructed using the lateral arm flap and to examine the advantages and disadvantages of this flap.

PATIENTS AND METHODS

This single-center, retrospective study was conducted at EMOT Hospital, Department of Orthopedics and Traumatology between January 2007 and December 2023. Our institution is a specialized center in microsurgery and traumatic extremity reconstruction. A total of 25 patients (23 males, 2 females; median age: 35 years; range, 8 to 57 years) who underwent lateral arm free flap reconstruction for forefoot soft tissue defects were included. Patients with defects at the midfoot, heel and ankle region were excluded from the study. Age, sex, injury mechanism, defect location, flap dimensions, anastomosis site, complications, donor site coverage, and associated injuries were recorded. Written informed consent was obtained from each patient. The study protocol was approved by the EMOT Hospital Ethics Committee (Date: 16.09.2024, No: 2024-08). The study was conducted in accordance with the principles of the Declaration of Helsinki.

Functional results of the patients were evaluated using the European Foot and Ankle Society (EFAS) daily living scoring system (up to 24 points) by patients. Cosmetic results were rated by the patients and the surgical team separately using a five-grade scale, where 0 represented the worst and 5 represented the best outcome. Shoe wearing and quality of ambulation were also evaluated. If present, pressure sores, location of pain, and callosities observed at the forefoot were assessed and recorded. Finally, two-point discrimination (PD) and Semmes-Weinstein monofilament (SWM) tests were performed to evaluate the quality of sensation at the reconstruction site.

Surgical technique

Following meticulous debridement and irrigation of the defect, the recipient artery and accompanying veins were dissected and prepared in all patients prior to flap dissection. A high arm tourniquet was used to facilitate dissection of the flap and enhance intraoperative visualization of the microvascular network in all patients. Wet gauze was used as a template to design the shape of the flap at the donor site. The non-dominant arms of all patients were used as the donor extremities. In 17 patients, distalization of the flap was preferred to extend the length of the pedicle and obtain a slender flap with thinner subcutaneous soft tissue (Figure 1). In the remaining patients, the flap

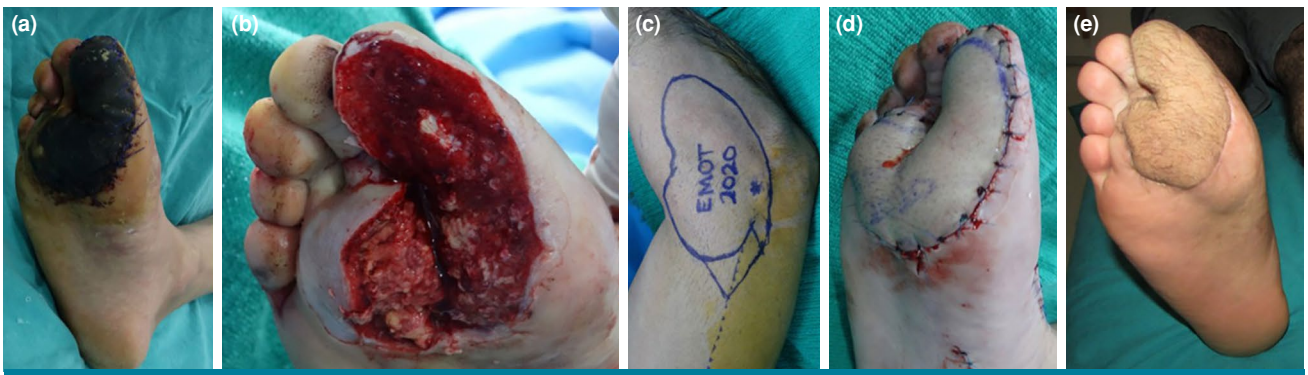


FIGURE 1. Thirty five years old patient had an avulsion injury of the soft tissues at the plantar side of the forefoot which was debrided and repaired during the initial operation. **(a)** Wide soft tissue necrosis was developed after 14 days after the initial operation. **(b-d)** The necrotic tissue was debrided, preserving the bony architecture of the foot, and the defect was reconstructed with a distalized lateral arm flap during the same operation. **(e)** Two years postoperatively, there was no pressure sore (SWM test: 4.31), and the thickness of the flap matched that of the native soft tissue. There was no contracture or limitation of joint motion in the area involved.
SWM, Semmes-Weinstein monofilament.

was harvested from the original site as described in the literature.[15] Dissection of the flap was performed beginning from the posterior side of the lateral intermuscular septum,[13,14] followed by exposure and dissection of the posterior radial collateral artery (PRCA), anterior side dissection, and careful mobilization of the flap to avoid injury to the pedicle. When the pedicle dissection was completed, the tourniquet was deflated, and the flap was perfused for 20 min before dividing the pedicle and transferring to the recipient site. Primary closure of the donor site was possible in 21 cases. In four patients, the defect was partially closed, and a split-thickness skin graft was applied to the remaining area. In none of the cases, a neurotization to increase the sensibility of the flap was performed.

The flap was, then, located and secured to the defect using superficial skin stitches. Vascular anastomoses were performed under microscopic magnification. In 17 cases, the artery of the flap was anastomosed to the dorsalis pedis artery. If the distal extension of the artery was irreparably damaged, end-to-end arterial anastomosis was performed (n = 6); if it was intact, end-to-side anastomosis was preferred to preserve the microcirculation of the damaged area as much as possible (n = 11). In three cases, end-to-side anastomosis of the flap artery to the anterior tibial artery was performed. In the remaining five cases, end-to-side anastomoses were performed at the level of the extensor retinaculum which is the area of transition between the anterior tibialis and dorsalis pedis arteries.

Venous anastomoses were performed in an end-to-end fashion using vena concomitants in 22 cases. In the remaining three patients, the diameter of the accompanying veins was too small; therefore, larger subcutaneous veins were used as donor site vessels. All anastomoses were performed under calf tourniquet to facilitate exposure and the quality of the repair. At the end of the operation, all damaged lower extremities were protected with a below-knee cast brace for three weeks, and the patients were hospitalized for seven days under close surveillance of trained staff for flap monitoring.

Statistical analysis

Statistical analysis was performed using the IBM SPSS version 25.0 software (IBM Corp., Armonk, NY, USA). Descriptive data were presented in median (min-max) or number and frequency, where applicable. The distribution of the ROM measurements from the operated fingers was assessed for normality using the Kolmogorov-Smirnov test. To determine whether there were differences between the concomitant metatarsal fracture group and other group for EFAS score, the Mann-Whitney U test was applied. The relationship between the patient's and physician's cosmetic evaluation scores was assessed using the Spearman's correlation analysis. A p value of < 0.05 was considered statistically significant.

RESULTS

Successful initial coverage of all defects was achieved with satisfactory contours and thicknesses

TABLE I
Demographic and clinical characteristic of patients

Patient No.	Age/Sex	Etiology	Flap size (cm)	EFAS score	Follow-up (mo)	Associated procedure
1	32/M	Hallux crush injury	8 x 6	19	15	Hallux amputation (base of proximal phalanx preserved)
2	8/F	Traffic accident	8 x 5	20	39	Hallux amputation through IP joint
3	35/M	Foot crush injury	7 x 6	18	18	Multiple metatarsal fx
4	34/M	Traffic accident	6 x 5	17	43	Multiple metatarsal fx
5	28/M	Power saw injury	8 x 6	17	40	Multiple metatarsal fx and extensor tendon lacerations of the toes
6	50/M	Hallux crush injury	8 x 6	18	16	Hallux amputation (base of proximal phalanx preserved)
7	51/M	Foot crush injury	12 x 5	20	17	Multiple metatarsal fx
8	17/M	Escalator injury	7 x 6	20	22	5th toe traumatic total amputation through MTP joint
9	26/M	Gunshot injury	10 x 5	17	19	Multiple metatarsal fx, 4th and 5th toe amputation through MTP joint
10	52/M	Toes crush injury	6 x 5	19	44	2nd and 5th toe amputation (proximal phalanx base preserved) 3rd and 4th toe amputation through MTP joint
11	47/M	Foot crush injury	11 x 6	19	33	Multiple metatarsal fx 2nd ray amputation
12	44/M	Traffic accident	11 x 5	17	18	2nd and 3rd toe amputation through MTP joint. 1st metatarsal fx
13	57/M	Foot crush injury	12 x 5	19	15	Hallux and 2nd toe amputation (base of proximal phalanx preserved)
14	44/M	Foot crush injury	12 x 5	17	16	Hallux and 2nd toe amputation through MTP joint
15	41/M	Foot crush injury	12 x 6	17	18	Hallux amputation through 1st metatarsal diaphysis
16	38/F	Traffic accident	13 x 6	18	18	Hallux amputation through MTP joint Total flap necrosis bone shortening and skin graft
17	38/M	Foot crush injury	10 x 5	18	16	Amputations of all toes (base of proximal phalanx preserved)
18	42/M	Foot crush injury	7 x 5	21	24	None
19	30/M	Foot crush injury	8 x 5	17	28	Amputations of all toes (base of proximal phalanx preserved)
20	42/M	Foot crush injury	7 x 5	19	17	Hallux amputation (base of proximal phalanx preserved)
21	21/M	Foot crush injury	8 x 5	17	15	Hallux amputation (base of proximal phalanx preserved)
22	22/M	Foot crush injury	7 x 5	19	36	Lisfranc injury
23	24/M	Foot crush injury	9 x 5	17	15	Multiple metatarsal fx 2nd ray amputation
24	22/M	Foot crush injury	10 x 5	20	38	Multiple metatarsal fx
25	30/M	Foot crush injury	11 x 5	17	40	Hallux amputation (base of proximal phalanx preserved) Multiple metatarsal fx

EFAS, The European Foot and Ankle Society; MTP, metatarsophalangeal; IP, interphalangeal; fx, fracture.

of the reconstruction site. The median follow-up was 24.8 (range, 15 to 44) months. The mechanism of injury, demographic data, flap size, and associated procedures are presented in Table I. The median flap size was 5.3 × 9.1 cm (range: 5 × 13 cm). The smallest flap measured 5×6 cm, whereas the largest was 6 × 13 cm. Acute circulatory compromise was observed in three patients during the first three postoperative days. These patients were urgently readmitted to the operating room for exploration. Arterial thrombosis at the repair site was observed in one case and venous thrombosis in the remaining two patients; re-anastomosis of the compromised vessels was performed. Flap loss was observed in one patient in the study. This patient had a severe soft tissue crush injury, including the cruris and foot. The flap was revascularized using long vein grafts to span the crushing zone and reach an uninjured area for safer anastomosis. However, early venous thrombosis occurred, endangering flap survival. The patient underwent two additional surgeries due to venous thrombosis, but flap loss occurred after four days. Due to the wide crushing zone on the cruris, another flap surgery was not performed. Stump revision, vacuum-assisted closure (VAC) application three times, and skin grafting were used to close the stump in this case. The healing time (graft epithelization) was 44 days after the initial surgery. The overall flap survival rate was 96%. The median soft tissue healing (epithelialization time) following reconstruction was 15 (range, 12 to 21) days. Three patients already had an infection at the time of initial admission to our hospital. Flap surgery was performed after meticulous debridement in these patients at the same session. After flap reconstruction, three patients developed infections. In two of them, local infection persisted following flap healing; these patients underwent re-debridement, and definitive cure of the infection was achieved. In the remaining patient, who was one of the preoperatively infected cases, the infection was eliminated after removing the Kirschner wires. Four patients required flap debulking during the follow-up period for proper shoe-wearing. All these reconstructions were dorsal side reconstructions of the forefoot.

The final sensory evaluation revealed that all patients had a two PD greater than 15 mm. The SWM testing demonstrated that 18 patients sensed 4.56, four patients sensed 6.65, and three patients sensed 4.31. The median EFAS daily living score was 18.2. In 12 patients, the soft tissue defect was accompanied by multiple metatarsal fractures. There was no significant difference in the EFAS scores between patients with and without multiple metatarsal fractures ($p = 0.186$). All patients were able to wear regular shoes; however, 11 patients preferred to wear larger-sized shoes compared to their pre-injury foot size, and five patients preferred to use soft insoles. The median cosmetic satisfaction score based on patient evaluation was 3.7, whereas the score was 3.1 based on physician evaluation. No significant correlation was found between the cosmetic results evaluated by the patient and those assessed by a physician ($p = 0.616$). One patient was a child; another one was a retired worker. Of the remaining 23 patients, 16 returned to their previous jobs, and seven changed their jobs.

DISCUSSION

In the present study, we evaluated the results of traumatic soft tissue defects of the forefoot reconstructed using the lateral arm flap. Our study demonstrated that reconstruction of forefoot soft tissue defects using a lateral arm flap provided both functional and cosmetic success, with high patient and physician satisfaction.

Reconstruction of soft tissue defects of the foot necessitates thin yet durable soft tissue capable of withstanding the prolonged pressure exerted on the foot. The reconstructed forefoot should enable regular shoe wearing, and whenever possible, scar-free healing should be provided to permit physiologic movements of the foot during walking, eliminate pain, and prevent ulceration at the reconstruction site.

The distal end of the foot is exposed to cyclic loading and impact forces during walking and constant pressure caused by wearing shoes. Durable soft tissue reconstruction should be achieved to prevent pressure ulcers in this region (Figures 1 and 2). In addition, reconstruction of the forefoot with elastic soft tissue should be aimed whenever possible, since unrestricted dorsiflexion of the metatarsophalangeal joints during the terminal stance phase is necessary for a normal gait. Similarly, the metatarsophalangeal joints and proximal part of the proximal phalanges should be preserved for proper ambulation.[16,17]

The application of VAC therapy to generate granulation tissue at the defect site and skin grafting is a commonly encountered solution for the reconstruction of soft tissue defects in common practice. This type of treatment may succeed in superficial soft tissue losses; however in complex

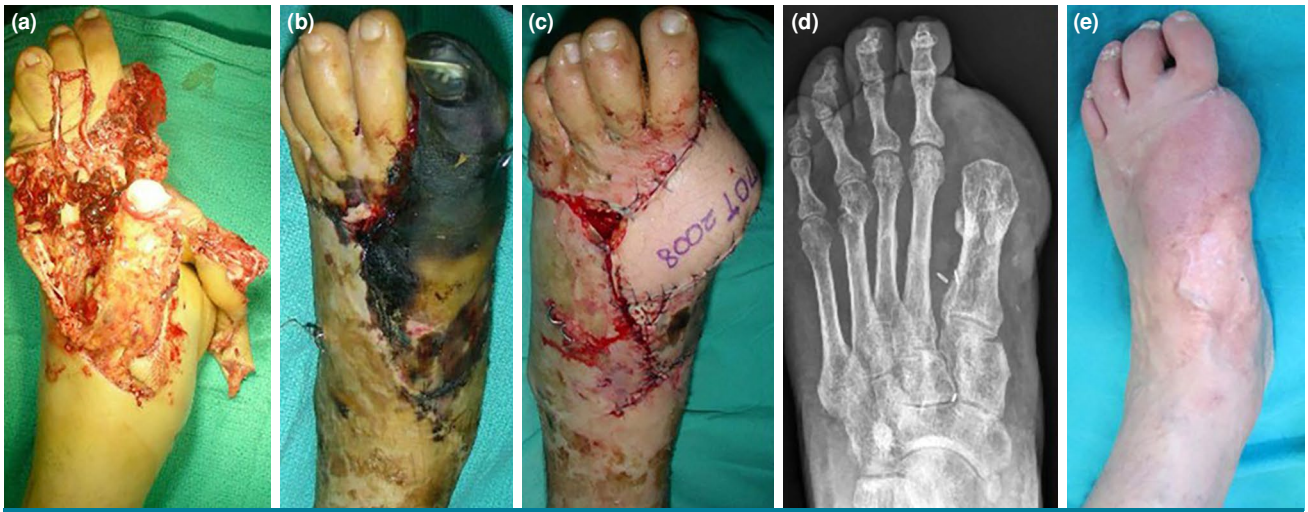


FIGURE 2. (a) Crushing injury of the foot. **(b)** Despite all efforts to save the forefoot, soft tissue necrosis involving the medial side of the forefoot, including the first toe, was unavoidable. **(c)** After debridement, a lateral arm flap was used to cover the soft tissue defect. **(d)** Medial ray including the first metatarsal was salvaged. **(e)** Three years postoperatively, the patient could walk without pain, had a 4.56 in SWM test, and used regular shoes of the same size as the opposite foot.
SWM, Semmes-Weinstein monofilament.

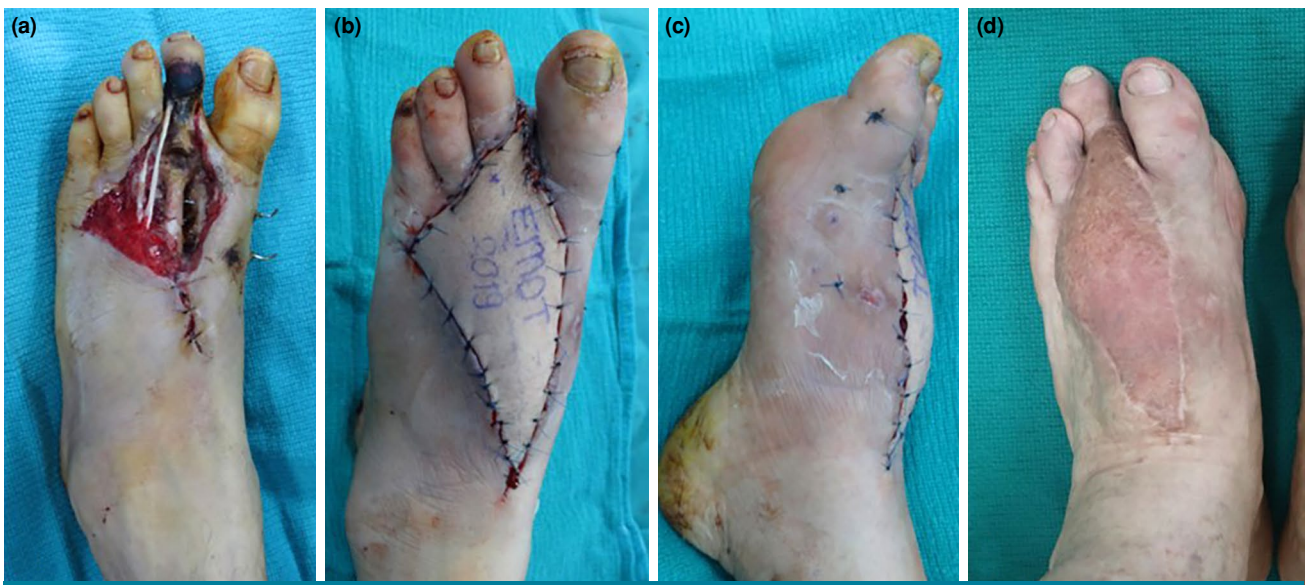


FIGURE 3. (a) Crush injury of the foot treated with debridement and VAC application for two months. **(b, c)** Debridement and reconstruction with lateral arm flap were performed. **(d)** Two years after the operation, there were no pressure sores (SWM test: 4.56), and the patient used regular shoes.
VAC, vacuum-assisted closure; SWM, Semmes-Weinstein monofilament.

injuries where bones, tendons, arteries and nerves are exposed, it fails to achieve a satisfactory result in most cases (Figure 3).[1] In addition, the newly formed granulation tissue usually contains bacteria and is prone to develop chronic infection, lacks elasticity necessary for proper joint motion and cannot tolerate prolonged pressure or impact forces exerted on the forefoot.[1,4] It has been shown that reconstructive ladder may not be applied to all injuries in the weight bearing areas of the foot and areas where impact forces are unavoidable.[7,15] Godina et al.[11] showed that early flap coverage has more successful results compared to late reconstructions both in terms of function, cosmesis and in decreasing the rate of complications. Timely soft tissue reconstruction increases the success of

treatment and prevents deep tissue infection and additional soft tissue loss.

Currently, there is no consensus on flap selection that provides the most optimal results for forefoot reconstruction. As stated previously, local flaps have limited value in the reconstruction of sizeable defects in the foot owing to their small size and limited reach.[1,5] In most injuries, the donor site for local flaps lies within the injury site, which endangers flap survival and decreases the success rate of the operations. Cross-leg flaps may also be used in order to avoid this disadvantage.[18] However, the cross-leg flap procedure limits the mobilization of the patient and the extremities for a prolonged period and reduces the patient's quality of life. Furthermore, positioning the legs and extending the flap to the defect site may be challenging in forefoot defects. In complex injuries spanning more than two zones, free flaps performed in the early period of the injury are demonstrated to provide the most optimal results.[4,5] In sizeable defects of the foot, the ALT flap is regarded as the workhorse among the numerous flap options with its long pedicle that enables arterial anastomosis outside the trauma zone and its extended size capable of covering large defects.[2,19] However, this flap involves thick subcutaneous fat tissue in most patients which causes a disadvantage when reconstructing the thin dorsal and distal soft tissue defects of the foot.[9]

With limited subcutaneous tissue compared to the ALT flap, the radial forearm flap was a commonly utilized alternative for reconstruction of the foot in the past as a thinner flap.[10,20] However, it sacrifices one of the two main arteries of the forearm, may cause adhesion of the flexor tendons at the donor site, and leaves a conspicuous scar on the forearm which limits its use in modern flap surgery.

The superficial circumflex iliac artery perforator (SCIP) flap is another good alternative for soft tissue reconstruction of the injured forefoot. However, the limited length of its pedicle and its thin and slender structure, which is prone to anatomic variations, limit its use in common practice.[21-23] The groin flap on the other side has a larger and more constant pedicle than the SCIP flap; however, this flap also has very thick subcutaneous fat tissue, causing an apparent size mismatch in forefoot reconstruction. The limited pedicle length of this flap is also another serious concern in injuries with a wide traumatic zone.[21,22]

The lateral arm flap has a constant and thick vascular pedicle, patent vascular anatomy, and does not sacrifice a major artery. Its dissection is easy and straightforward, the thin nature of this flap almost perfectly matches the thickness of the soft tissues on the dorsal and distal sides of the foot, and its elasticity is advantageous for preserving the physiological ROM of the metatarsophalangeal joints. Distalization of the flap may easily be performed without complications when thinner flap versions are required, this practice also helps to lengthen the pedicle of the flap up to 14 cm.[13,14]

In the literature, large series indicating the results of lower extremity flap surgery report flap survival rates between 93% and 98%.[24,25] Despite the most distal location of the foot with relatively long pedicles, the survival rate of lateral arm flaps in this series was 96%, which is similar to the reported free flap survival rate for lower extremity reconstruction. Jeng et al.[26] recently reported a large series regarding forefoot reconstruction, and they favored free flaps in very large defects and presented their 31 cases. However, they did not perform any lateral arm flaps in their series. In another recent report, Mayr-Riedler et al.[27] presented the results of free flaps in the forefoot reconstruction. Thirty of their cases were traumatic cases and they also did not perform any lateral arm flaps. With 25 traumatic cases our series is one of the large series in the literature and we believe the lateral arm flap is a versatile and useful option for forefoot reconstruction, along with the other workhorse flaps in the literature.

Although it has been documented in the literature that values greater than 4.56 in the SWM test are associated with decreased protective sensation,[28] in our study, four patients with a SWM test of 6.65 on the flap experienced no chronic ulcers in the long term. We attribute this to the development of protective sensation over time in fasciocutaneous flaps, as shown in previous studies.[6,29]

Nonetheless, the single-center and retrospective design are the main limitations to this study. In addition, the number of patients enrolled is also limited, and there is no control group for comparisons with other types of pedicled or free flaps. Further multi-center, large-scale, prospective studies are warranted to confirm these findings.

In conclusion, the lateral arm flap appears to be a reasonable option for forefoot reconstruction owing to its limited thickness, ease of dissection,

and constant and robust vascular supply. In addition, dissection of this flap avoids major artery scarification and early cosmetic and functional results of forefoot reconstruction via the lateral arm flap are satisfactory, and it does not preclude regular shoe wear. Utilization of this flap does not restrain the function of the donor extremity, although it leaves a conspicuous scar on the lateral side of the arm.

Data Sharing Statement: The data that support the findings of this study are available from the corresponding author upon reasonable request.

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