Optimal Timing and Duration of Flap-Frame Immobilization

A Podoplastic Case Series

Craig J. Verdin, DPM*
Holly D. Shan, BS†
Thomas Milisits, DPM, MPH*
Karen K. Evans, MD*
Christopher E. Attinger, MD*
John S. Steinberg, DPM*
Jayson N. Atves, DPM*

Background: Flap-based and podoplastic limb salvage in the foot and ankle is difficult due to the presence of biomechanical forces that can impact flap healing and complication rates and, in turn, limb salvage rates. For this reason, external fixation is indicated to neutralize forces across the flap interface and allow for optimal flap take and healing. Although external fixation for flap immobilization is the current standard of care, not much is known about how duration and timing may impact complication and salvage rates.

Methods: We retrospectively identified and analyzed complication and limb salvage rates in 18 patients who underwent flap-frame immobilization with a multiplanar external fixator during a 4.75-year period.

Results: Patients ranged in age from 40 to 75 years (mean, 55.5 years). Sixteen patients (88.9%) had diabetes mellitus, and all had defects that were a mean of 110.9 cm^2 (range, 36–500 cm^2) and required the use of a local or free flap. Thirteen defects (72.2%) were in the plantar region, with the remaining five (27.8%) in nonplantar regions. Eleven flaps (61.1%) were fasciocutaneous, and the remaining seven (38.9%) were vascularized muscle flaps. All of the flaps were immobilized with either a three- or four-ring circular external fixator. Overall, a 66.7% limb salvage rate (12 of 18) was observed with mean follow-up of 2.4 years, or 892.6 days (range, 222–1,555 days). Seven minor flap complications (38.9%) required a return to the operating room.

Conclusions: External fixation is an essential tool in flap-based limb salvage. These findings hint that the "Goldilocks zone" of duration is approximately 28 to 35 days. Furthermore, we believe that risk factors such as open amputation, increased defect size, and presence of Charcot's neuroarthropathy impact limb salvage rates regardless of duration and timing of flap-frame immobilization. (J Am Podiatr Med Assoc 115(5), 2025; doi:10.7547/23-140)

Infection of the foot and ankle places patients at risk for amputation, which then places patients at risk for increased morbidity and mortality.[1] Although major amputation does have some functional benefits in certain patient populations, limb salvage in comorbid populations should be attempted when reasonable, especially given underwhelming ambulatory and mortality data.[2,3] In recent years, orthoplastic and podoplastic reconstruction has seen an increase in use and value for limb salvage in the diabetic population.[4,5] Through the use of osseous and soft-tissue reconstruction, lower-extremity surgeons can reduce the morbidity and mortality associated with limb loss. Common tools that are used in the orthoplastic/podoplastic approach include the flap (locoregional and free) and osseous stabilization through amputation or use of fixation, internal or external. The tissue flap is

*Department of Plastic and Reconstructive Surgery, MedStar Georgetown University Hospital, Washington, DC.

†Georgetown University School of Medicine, Washington, DC.

Corresponding author: Craig J. Verdin, DPM, Department of Plastic and Reconstructive Surgery, MedStar Georgetown University Hospital, 3800 Reservoir Rd NW, Washington, DC 20007. (E-mail: cverdin@kent.edu)

the workhorse for orthoplastic/podoplastic intervention that allows clinicians to create an environment conducive to healing and provide a predictable level of soft-tissue coverage.[6-14] Despite the improved outcomes associated with flap use, flaps in the foot and ankle are often at risk for failure due to increased exposure to biomechanical forces secondary to the numerous mobile structures, such as joints and tendons, that are found in the region.[15-17] Consequently, the protection of soft-tissue reconstruction with the use of external fixators was first described by Nappi and Drabyn[18] in 1983 and is recommended for all transarticular flaps, free or local, for the purpose of immobilizing the targeted joint and, in turn, preventing biomechanical forces across the flap interface to allow for a static environment that optimizes flap take.[16,18-20] Ever since, flap-frame immobilization (FFI) with the use of an external fixator has become the standard of care for flap immobilization, shear force reduction, and off-loading; however, not much is known about the effect that FFI duration and timing may have on outcomes. Furthermore, there is a significant need for information because a great deal of the current literature focuses on the use of external fixation for the purpose of orthoplastic reconstruction in the setting of trauma as originally described by Levin[21] as opposed to the diabetic population that requires podoplastic reconstruction, which are two drastically different populations. When evaluating the literature, there seems to be a significant amount of heterogeneity in terms of timing of FFI, which ranged from 3 weeks as described by Sagebien et al[22] in 2007 to as high as 9.5 months as described by Lowenberg et al.[23]

Given that there are no data describing the optimal duration and timing of FFI in patients who undergo flap reconstruction, we sought to provide preliminary data on outcomes and complications. Given the potential for increased morbidity and mortality associated with failed limb salvage along with the clinical importance of limb preservation, obtaining a better understanding of and optimizing the limb salvaging intervention is paramount. We suspected that increased immobilization would result in the increased opportunity for flap maturation and healing, which, in turn, would result in increased rates of limb salvage and a reduction in complications.

Patients and Methods

After attaining institutional review board approval, we retrospectively identified a single-surgeon convenience sample of patients who underwent external fixator application for the purpose of flap off-loading and immobilization performed by a fellowship-trained podiatric surgeon (J.N.A.) at Georgetown University Hospital (Baltimore, Maryland). All of the patients had lower-extremity wounds that required a combination of surgical intervention for infection management and definitive closure, which was performed using a muscle or fasciocutaneous flap. All of the patients underwent serial debridement and antibiotic coverage as recommended by infectious disease consultation before flap creation and inset. All of the flaps were performed by two plastic surgeons in our department (K.K.E. and C.E.A.), both with a minimum of 10 years of experience. Inclusion criteria included patients older than 18 years who had a minimum 6-month follow-up at the time of analysis, underwent a locoregional or free flap, and were subsequently treated with external fixation. Patients who underwent limb salvage without the use of flaps or who did not undergo external fixation for the purpose of flap immobilization were excluded. In addition, delta or monoplanar external fixators were excluded because their use is not common in our practice. Primary outcomes were defined as rates of complications, major and minor, and rates of limb salvage over the duration of FFI and follow-up. Limb salvage success was defined as limb retention without further amputation, and failure was defined as progression to below-the-knee amputation (BKA). Major flap complications were defined as total flap loss, which required removal of the nonviable flap, or any other complication that threatened the viability of the entirety of the flap, such as thrombus formation in the pedicle. Minor flap–related complications were defined as any complications that required a return to the operating room, such as dehiscence, necrosis, hematoma or seroma formation, and recurrent infection. Dehiscence is defined as visible separation of the flap from the epidermal margins without regard to depth, and necrosis is the presence of visibly ischemic changes at the graft-flap interface. Partial necrosis was defined as any necrosis less than 60% of the total flap/graft surface area, and total necrosis was anything greater than 60%.[24] Secondary outcomes were defined as frame-related complications, which included pin-site infections, hardware breakage, or removal due to intolerance of frame therapy. All of the operative notes were used to identify specifics related to wound type and location and flap type and location. Postoperative notes were used to identify postoperative complications requiring return to the operating room, flap failure, and loss of limb. All of the patients were treated with

a multiplanar circular external fixator consisting of optional use of half pins as well as a varying number of skinny wires, which was determined by the performing surgeon based on need and space availability without violation of the flap. The duration of FFI was determined arbitrarily based on surgeon availability and the patient's clinical progress. Postoperative instructions involved weight-bearing only for the purpose of transfer for the entirety of the FFI duration.

Results

Initial medical record review identified 20 consecutive patients who underwent flap-frame reconstruction and were treated by the podiatric and plastic surgeons at Georgetown University Hospital over a targeted period from August 1, 2018, to March 31, 2023. Subsequent review revealed that 18 of the medical records met the inclusion criteria and two were excluded because of the lack of a targeted follow-up duration. The two medical records that were excluded were locoregional flaps; however, the patients had follow-up of 69 and 97 days.

With respect to the 18 remaining medical records (15 males, three females) that met the inclusion criteria, the mean patient age was 55.5 years (range, 40–75 years) and the mean body mass index (the weight in kilograms divided by the square of the height in meters) was 29.6 (range, 20.2–43.3). Sixteen of the 18 patients (88.9%) were diabetic; six (33.3%) had chronic kidney disease, with half undergoing dialysis; and seven (38.9%) had peripheral vascular disease. The mean Charlson Comorbidity Index was 4.7 (range, 1–7), and one mortality occurred 643 days after FFI due to unrelated causes. The mean defect size at the time of flap inset was 110.9 cm^2 (range, 36–500 cm^2). Thirteen feet (72.2%) had wounds that were plantar, and the remaining five were in the nonplantar region. Eleven of the wounds (61.1%) were in the midfoot region, and seven (38.9%) were in the rearfoot region (all of the heel wounds). Three patients had an antecedent guillotine/open midfoot amputation (two transmetatarsal and one Chopart) that required flap coverage, and the remaining four amputations were fifth-ray resections. Three patients (16.7%) had Charcot's neuroarthropathy that required surgical intervention at the time of flap-frame intervention.

Regarding hematologic data, the average hemoglobin A_{1c} level at the time of flap inset was 7.9% (range, 5%–14%), and the average albumin level was 3.3 g/dL (range, 2.0–3.9 g/dL). Eight of 16 patients (50%) had angiographically evident three-vessel, six (37.5%) had two-vessel, and two (12.5%) had one-vessel runoff, which was determined by a single vascular surgeon in our department. Two patients did not have a recorded angiogram that allowed for the characterization of inflow patterns.

All of the patients were treated with a multiplanar circular external fixator for a mean of 39.4 days (range, 20–77 days). No instances of frame- or flap-related complications requiring premature removal of external fixator were noted. Seventeen of the circular frames (94.4%) were static, with no plans for gradual correction, and one construct was dynamic, with gradual compression achieved through the frame due to the presence of concomitant Charcot's neuroarthropathy before staged and eventual internal fixation (5.6%). Of note, 66.7% of Charcot's reconstructions had internal fixation placed at the time of FFI. The mean time between flap inset and subsequent application of the external fixator was 8.2 days (range, 0–48 days). Sixteen limbs (88.9%) were treated with a four-ring construct (Fig. 1), and the remaining two (11.1%) with a three-ring construct (Fig. 2). The average ring diameter was 159.7 mm (range, 140–180 mm), an average of 8.7 skinny wires were used (range, 7–9), along with an average of 2.2 olive wires (range, 0–4) and 0.5 half pins (range, 0–4). In total, seven frame-related complications occurred in four patients (22.2%). Five instances of pin-site infections were observed in three patients (16.7%), equating to a 1.7% pin-site infection rate relative to the overall number of pin sites (n = 302). One instance of wire breakage was noted, and the wire was subsequently removed without compromising the overall construct stability, and, last, there was one case of chronic sinus

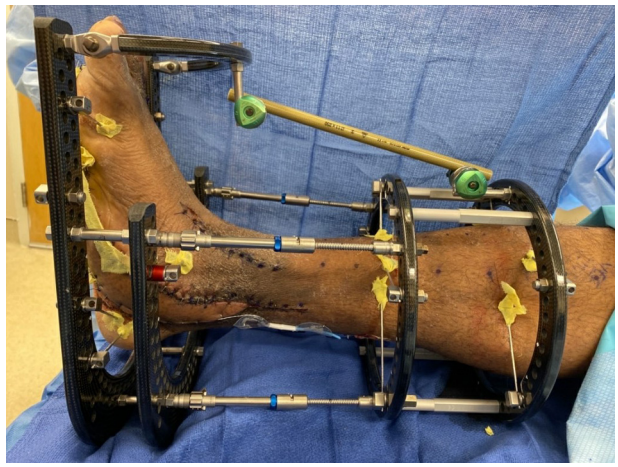


Figure 1. Intraoperative photograph demonstrating a four-ring external fixator construct for the purpose of off-loading an anterolateral thigh flap.

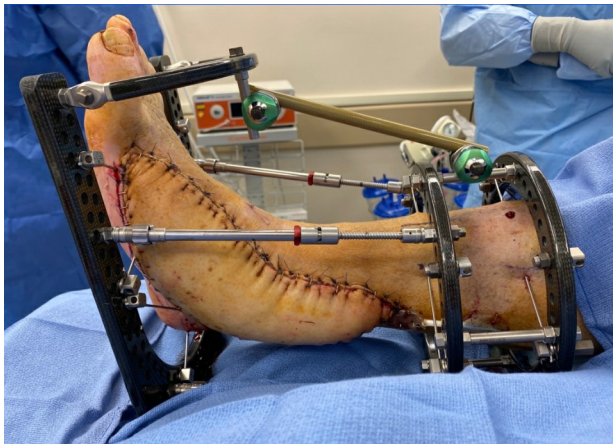


Figure 2. Intraoperative photograph demonstrating a three-ring external fixator construct for the purpose of off-loading an anterolateral thigh flap.

tract formation where a previous fixator half pin was placed that was subsequently treated with operative debridement and local wound care.

Eleven flaps (61.1%) were fasciocutaneous, and the remaining seven (38.9%) were vascularized muscle flaps (MFs). Overall, the most common flap was the anterolateral thigh flap, which was the only type of fasciocutaneous flap used (Figs. 1 and 2). The most common MF was the vastus lateralis MF (Fig. 3), which was used in 22.2% of the cases (n = 4). Other MFs that were used were the latissimus dorsi MF (n = 2) and the abductor hallucis MF (n = 1). All of the MFs required subsequent skin grafting that was performed at a mean of 9 days (range, 0–49 days) after flap inset.

Overall, a 66.7% limb salvage rate (12 of 18 patients) was observed, with mean follow-up of 2.4 years, or 892.6 days (range, 222–1,555 days). All of the failures resulting in a BKA were attributed to recurrent infection (three of six patients) or hardware complications (three of six patients), which resulted in a BKA a mean of 123 days (range, 33–227 days) after external fixator removal. No instances of major flap complications resulting in total flap loss were observed, resulting in 100% flap survival; however, there was a 38.9% rate of minor flap complications (seven of 18 patients) requiring a return to the operating room. The most common minor flap complication was dehiscence of the flap margins, which occurred in six flaps (33.3%); however, all were managed with operative debridement or local wound care, and one complication was partial split-thickness skin graft necrosis (80% graft take) in the MF group that required reapplication of a split-thickness skin graft without incident.



Figure 3. Clinical photograph showing a free vastus lateralis muscle flap, the most common muscle flap in the cohort, to cover an open Chopart amputation.

The data set was divided into two groups based on successful limb salvage and failed limb salvage resulting in a BKA. In addition, the data were chronologically subdivided into equal tertiles (six patients per tertile) based on time spent in the external fixator. The mean duration of FFI in the successful limb salvage group was 40.6 days (range, 20–77 days), and 37.2 days (range, 22–56 days) for the failed limb salvage group, with an average delay between flap and frame application of 9.7 days (range, 0–48 days) and 5.3 days (range, 0–10 days), respectively. The mean defect size at the time of flap inset for the limb salvage group was 70.4 cm^2 (range, 36–120 cm^2) and for the failure group was 191.8 cm^2 (range, 40–500 cm^2). When evaluating the tertiles, there was a 50% failure rate (three of six patients) in the upper tertile, a 100% success rate in the middle tertile, and, again, a 50% failure rate (three of six patients) in the bottom tertile. The mean defect size was 127.7 cm^2 (range, 42–322 cm^2) in the upper tertile, 63.8 cm^2 (range, 36–108 cm^2) in the middle tertile, and 141.2 cm^2 (range, 40–500 cm^2) in the lower tertile. The mean duration of FFI in the upper tertile was 58.3 days (range, 44–77 days), in the middle tertile was 35.8 days

(range, 29–44), and in the lowest tertile was 24.2 days (range, 20–28 days). The time between flap inset and frame application was 5.67 days (range, 0–9 days) in the upper tertile, 11.8 days (range, 0–48 days) in the middle tertile, and 7.2 days (range, 0–13 days) in the bottom tertile. Regarding the number of minor flap–related complications (N = 7), 0%, 57.1% (n = 4), and 42.9% (n = 3) complication rates were observed in the upper, middle, and lower tertile, respectively. Last, frame-related complications occurred at a rate of 5.6% (n = 1), 5.6% (n = 1), and 11.1% (n = 2) in the upper, middle, and lower tertiles, respectively.

Discussion

External fixation has proved itself to be a valuable asset in podoplastic reconstruction because of its ease of use and inherent stability, which is advantageous when used in combination with soft-tissue reconstruction in regions of increased biomechanical forces. Despite the literature being plentiful about the use of free and locoregional flaps for the purpose of flap-based limb salvage, the literature is nonexistent on the purposeful examination of the timing that FFI may have on outcomes and complications, and in many instances, complications are not mentioned at all.[25-31]

In 2008, Lowenberg et al[19] evaluated ten patients who spent a mean of 12 weeks in a circular external fixator and demonstrated a 20% complication rate. Again, in 2008, Clemens et al[16] described the use of FFI with the use of multiplanar external fixation in 12 patients who were off-loaded for a mean of 66 days and reported a 50% complication rate. In 2022, Jafari Kafiabadi et al[30] conducted a pilot study in 26 patients who underwent FFI with the use of a circular external fixator and concluded that the use of an Ilizarov external fixator resulted in a 0% total flap failure rate, but there was no mention of minor flap complications outside of swelling.[30] The largest cohort to date describing FFI secondary to trauma requiring orthoplastic reconstruction is an article by Hollenbeck et al[32] in which the average time spent in a frame across 62 patients was 6.9 months, and a 24% complication rate was noted; however, it is not clear whether outcomes in relatively healthy trauma patients can be translated to comorbid diabetic patients.[32] Overall, we reported a flap complication rate of 38.9% and a limb salvage rate of 66.7% in patients who were immobilized for a mean of 39.4 days, which is relatively comparable with the wide range of reported complication rates in the scant literature in which complications and timing were both reported.[16,19,32]

Interestingly, when the data were chronologically divided, we observed a bimodal distribution of failures and a unimodal distribution of flap complications, which could be an argument for a potential "Goldilocks zone" of duration of FFI when it comes to reducing flap-related complications. The upper tertile, or the group with the longest duration of FFI, demonstrated a 0% flap-related complication rate but a 50% limb salvage rate. This counterintuitive increase in failures with increased time spent in an external fixator is likely related to the increased complexity and locoregional trauma associated with the type of cases that required an increased amount of time in the frame, such as concurrent osseous reconstruction or open amputation, which consisted of one open midfoot amputation, one concurrent midfoot Charcot's reconstruction, and a previous partial calcanectomy that occurred before free flap inset for the treatment of calcaneal osteomyelitis. The middle tertile demonstrated a limb salvage rate of 100% and a flap-related complication rate of 57.1%, which is most comparable with the findings by Clemens et al.[16] Although it is not clear why the middle tertile demonstrated the largest number of complications, we posit that this trend may be related to the timing between flap inset and frame application as the average time between these two critical events was 1.5 times longer than the time between events compared with the upper and lower tertiles. Consequently, it is likely that the delayed elimination or neutralization of biomechanical forces across the flap interface during the acute phases of healing may negatively impact healing and result in a higher rate of flap complications.[33,34] In the lower tertile, the limb salvage rate was 50%, along with a 42.9% flap-related complication rate after a mean duration of FFI of 24.2 days. As was the case in the upper tertile, the failures were cases that required increased metabolic demand for healing, with one open midfoot amputation, one concurrent ankle Charcot's reconstruction via internal fixation, and a non-Charcot's ankle arthrodesis with the use of internal fixation.

Although external fixation is certainly useful for podoplastic intervention, it is not without inherent morbidity. We reported a frame-related complication rate of 22.2%. The use of an external fixator has inherent disadvantages and can result in pin-site infection rates as high as 38%, as demonstrated by Gopal et al[35]; however, the use of external fixation, or more specifically, a circular external fixator, is advantageous because it allows for increased rates

of ambulation during treatment and increased visibility of the flap for observation and monitoring.[30,35] Aside from the articles by Clemens et al,[16] Jafari Kafiabadi et al,[30] and Lowenberg et al,[19] we found it difficult to effectively compare the present results with the literature because almost all of the flap-frame literature describes the use of FFI in the setting of traumatic open fractures and wounds, and the literature that does discuss the use of FFI in a comparable diabetic cohort often describes the use of a delta external fixator for strict off-loading, which does not have the inherent benefits of a circular external fixator in terms of possible ambulation and overall construct stability.[36-38]

Overall, the present findings hint that the use of external fixation should be considered especially when a flap is placed in the foot and ankle region. Historically, external fixation is considered when a flap crosses major joints (ie, the ankle joint), but we posit that the effects of tendinous structures and multiple smaller joints are additive and should be immobilized in any circumstances, especially if the flap is on the plantar foot. The result of our observation hints that failure of podoplastic intervention may likely be related to the size of the targeted defect and the magnitude of concurrent reconstruction, both soft tissue and osseous, as opposed to FFI duration, which results in an increased metabolic demand for sufficient healing in a comorbid population that may not be able to meet those requirements for healing, as evidenced by a mean Charlson Comorbidity Index score of 4.7. Furthermore, the presence of Charcot's neuroarthropathy and open amputation seems to have an effect on the podoplastic limb salvage rate. In the present study, 66.7% of the cases (four of six) that resulted in a BKA were in the setting of Charcot's neuroarthropathy (two of six) that required osseous intervention or open amputation (two of six). In the absence of open amputation or Charcot's neuroarthropathy, the limb salvage rate was noted to be 85.7% (12 of 14 patients). It is well documented that the presence of Charcot's neuroarthropathy places patients at increased risk for proximal amputation, as demonstrated by Elmarsafi et al[39] in 2019, and findings by Berceli et al[40] support the conclusion that open amputation is a potential risk factor for limb salvage failure in podoplastic intervention.

Despite an interesting bimodal distribution of failures that does not seem to be related to the use of external fixation, we believe that the timing and duration of FFI is most impactful on the rate of complications as opposed to limb salvage rates. The reduction of time spent in an external fixator may likely result in an increased rate of complications secondary to the reduced time for flap neovascularization. According to the literature, neovascularization peaks in healthy tissue 7 to 10 days after flap inset, and it is reasonable to assume that the neovascularization in diabetic patients occurs well after the first week and may reach a stable plateau at an average of 35 days, further explaining the drastic drop in flap-related complications in the upper tertile.[33,34] As a result, we believe that immobilization with an external fixator should optimally occur simultaneously or within 7 to 10 days to allow for maximization of neovascularization through the reduction of biomechanical forces and, in turn, the reduction of dehiscence complications. If simultaneous application of the external fixator is not possible, then we recommend placement of a splint or immobilizing dressing with strict nonweightbearing until a frame is applied. This conclusion is largely supported by the rate of complications in patients who underwent same-day flap and frame application as one of the flap-related complications (14.3%) was in a patient who underwent simultaneous flap and frame application within the same day, whereas the average delay between flap and frame application for the remaining 85.7% of complications (six of seven) was 16 days. Even more, based on our observation, when possible, a longer duration of FFI seems to be most beneficial for flap healing because flap healing and revascularization can take up to 1 year to allow full incorporation free of any dependence of the vascular pedicle and anastomosis.[41-43] Given the small sample size and retrospective nature of this observational case series, generalizable conclusions are weaker in strength, and it is unclear whether the conclusions are significant from a statistical perspective, which we regrettably were not able to achieve due to low power. Also note that the purpose of this evaluation was to generate hypotheses for which future studies of larger volume may lend statistical strength to our observations. Regardless, we believe that this attempt to establish a preliminary relationship between timing and duration of FFI will benefit future studies and can impact clinical decision making. As a result of these preliminary findings, at Georgetown University Hospital, the targeted duration of FFI is typically around the 28- to 35-day mark. Future studies of greater size and volume are needed to help clinicians better understand the effectiveness of FFI in the hopes of increasing the rates of limb preservation and preventing the morbidity associated with major lower-extremity amputation.

In conclusion, based on these findings and the current literature, we believe that knowledge of the effect of external fixator timing is imperative to optimize outcomes in podoplastic and flap-based limb salvage. Regardless, we conclude that timing and duration of FFI is impactful, especially considering the well-documented morbidity that is associated with free flap failure and subsequent limb loss.

Financial Disclosure: None reported.
Conflict of Interest: None reported.

References

1. Armstrong DG, Swerdlow MA, Armstrong AA, et al: Five year mortality and direct costs of care for people with diabetic foot complications are comparable to cancer. J Foot Ankle Res **13:** 16, 2020.
2. Zolper EG, Deldar R, Haffner ZK, et al: Effect of function-based approach to nontraumatic major lower extremity amputation on 5-year mortality. J Am Coll Surg **235:** 438, 2022.
3. Ordaz A, Trimm C, Pedowitz J, et al: Transmetatarsal amputation results in higher frequency of revision surgery and higher ambulation rates than below-knee amputation. Foot Ankle Orthop **7:** 24730114221112938, 2022.
4. Naga HI, Azoury SC, Othman S, et al: Short- and long-term outcomes following severe traumatic lower extremity reconstruction: the value of an orthoplastic limb salvage center to racially underserved communities. Plast Reconstr Surg **148:** 646, 2021.
5. Hoyt BW, Wade SM, Harrington CJ, et al: Institutional experience and orthoplastic collaboration associated with improved flap-based limb salvage outcomes. Clin Orthop Relat Res **479:** 2388, 2021.
6. Lee ZH, Daar DA, Stranix JT, et al: Free-flap reconstruction for diabetic lower extremity limb salvage. J Surg Res **248:** 165, 2020.
7. Bekeny JC, Zolper EG, Steinberg JS, et al: Free tissue transfer for patients with chronic lower extremity wounds. Clin Plast Surg **48:** 321, 2021.
8. Kotha VS, Fan KL, Schwitzer JA, et al: Amputation versus free flap: long-term outcomes of microsurgical limb salvage and risk factors for amputation in the diabetic population. Plast Reconstr Surg **147:** 742, 2021.
9. Lu J, DeFazio MV, Lakhiani C, et al: Limb salvage and functional outcomes following free tissue transfer for the treatment of recalcitrant diabetic foot ulcers. J Reconstr Microsurg **35:** 117, 2019.
10. Zhang W, Li X, Li X: A systematic review and meta-analysis of perforator flaps in plantar defects: risk analysis of complications. Int Wound J **18:** 525, 2021.
11. Ramanujam CL, Stuto AC, Zgonis T: Use of local intrinsic muscle flaps for diabetic foot and ankle reconstruction: a systematic review. J Wound Care **27**(suppl 9): S22, 2018.
12. Ramanujam CL, Zgonis T: Versatility of intrinsic muscle flaps for the diabetic Charcot foot. Clin Podiatr Med Surg **29:** 323, 2012.
13. Capobianco CM, Stapleton JJ, Zgonis T: Soft tissue reconstruction pyramid in the diabetic foot. Foot Ankle Spec **3:** 241, 2010.
14. Short DJ, Zgonis T: Circular external fixation as a primary or adjunctive therapy for the podoplastic approach of the diabetic Charcot foot. Clin Podiatr Med Surg **34:** 93, 2017.
15. Mooney V, Ferguson AB Jr: The influence of immobilization and motion on the formation of fibrocartilage in the repair granuloma after joint resection in the rabbit. J Bone Joint Surg Am **48:** 1145, 1966.
16. Clemens MW, Parikh P, Hall MM, et al: External fixators as an adjunct to wound healing. Foot Ankle Clin **13:** 145, 2008.
17. Kim SW, Choi SM, Kim MB, et al: The effects of tibialis anterior tenotomy on wound complications and functional outcomes after anterior fusion plating for severe ankle arthritis. J Foot Ankle Surg **62:** 237, 2023.
18. Nappi JF, Drabyn GA: External fixation for pedicle-flap immobilization: a new method providing limited motion. Plast Reconstr Surg **72:** 243, 1983.
19. Lowenberg DW, Sadeghi C, Brooks D, et al: Use of circular external fixation to maintain foot position during free tissue transfer to the foot and ankle. Microsurgery **28:** 623, 2008.
20. Parikh PM, Hall MM, Attinger CE, et al: External fixation: indications in lower extremity reconstruction and limb salvage. Plast Reconstr Surg **123:** 160e, 2009.
21. Levin LS: The reconstructive ladder: an orthoplastic approach. Orthop Clin North Am **24:** 393, 1993.
22. Sagebien CA, Rodriguez ED, Turen CH: The soft-tissue frame. Plast Reconstr Surg **119:** 2137, 2007.
23. Lowenberg DW, Feibel RJ, Louie KW, et al: Combined muscle flap and Ilizarov reconstruction for bone and soft tissue defects. Clin Orthop Relat Res **332:** 37, 1996.
24. Gupta A, Lakhiani C, Lim BH, et al: Free tissue transfer to the traumatized upper extremity: risk factors for postoperative complications in 282 cases. J Plast Reconstr Aesthet Surg **68:** 1184, 2015.
25. Castro-Aragon OE, Rapley JH, Trevino SG: The use of a kickstand modification for the prevention of heel decubitus ulcers in trauma patients with lower extremity external fixation. J Orthop Trauma **23:** 145, 2009.
26. Ting BL, Abousayed MM, Holzer P, et al: External fixator kickstands for free soft tissue flap protection: case series and description of technique. Foot Ankle Int **34:** 1695, 2013.
27. Kachare SD, Vivace BJ, Henderson JT, et al: Kickstand external fixator for immobilization following free flap plantar calcaneal reconstruction. Eplasty **19:** e11, 2019.
28. Berkowitz MJ, Kim DH: Using an external fixation "kickstand" to prevent soft-tissue complications and facilitate wound management in traumatized extremities. Am J Orthop (Belle Mead NJ) **37:** 162, 2008.

29. Roukis TS, Landsman AS, Weinberg SA, et al: Use of a hybrid "kickstand" external fixator for pressure relief after soft-tissue reconstruction of heel defects. J Foot Ankle Surg **42:** 240, 2003.
30. Jafari Kafiabadi M, Biglari F, Sadighi M, et al: Pilot study of additive effect of "offloading Ilizarov frame" to reduce "reverse sural flap" surgery complications: a clinical trial. World J Plast Surg **11:** 38, 2022.
31. Bibbo C: Reverse sural flap with bifocal Ilizarov technique for tibial osteomyelitis with bone and soft tissue defects. J Foot Ankle Surg **53:** 344, 2014.
32. Hollenbeck ST, Woo S, Ong S, et al: The combined use of the Ilizarov method and microsurgical techniques for limb salvage. Ann Plast Surg **62:** 486, 2009.
33. Klingenström P, Nylén B: Timing of transfer of tubed pedicles and cross-flaps. Plast Reconstr Surg **37:** 1, 1966.
34. Young CM: The revascularization of pedicle skin flaps in pigs: a functional and morphologic study. Plast Reconstr Surg **70:** 455, 1982.
35. Gopal S, Majumder S, Batchelor AG, et al: Fix and flap: the radical orthopaedic and plastic treatment of severe open fractures of the tibia. J Bone Joint Surg Br **82:** 959, 2000.
36. Morandi MM, Simoncini A, Hays C, et al: Optimal configuration for stability and magnetic resonance imaging quality in temporary external fixation of tibial plateau fractures. Orthop Traumatol Surg Res **106:** 1405, 2020.
37. Ramlee MH, Kadir MR, Murali MR, et al: Biomechanical evaluation of two commonly used external fixators in the treatment of open subtalar dislocation: a finite element analysis. Med Eng Phys **36:** 1358, 2014.
38. Ramlee MH, Kadir MR, Murali MR, et al: Finite element analysis of three commonly used external fixation devices for treating type III pilon fractures. Med Eng Phys **36:** 1322, 2014.
39. Elmarsafi T, Anghel EL, Sinkin J, et al: Risk factors associated with major lower extremity amputation after osseous diabetic Charcot reconstruction. J Foot Ankle Surg **58:** 295, 2019.
40. Berceli SA, Brown JE, Irwin PB, et al: Clinical outcomes after closed, staged, and open forefoot amputations. J Vasc Surg **44:** 347, 2006.
41. Bhat W, Wiper JD, Platt AJ: Delayed autologous free anterolateral thigh flap failure. J Plast Reconstr Aesthet Surg **64:** 420, 2011.
42. Kumar K, Jaffe W, London NJ, et al: Free flap neovascularization: myth or reality? J Reconstr Microsurg **20:** 31, 2004.
43. Kim SW, Kwon YH, Kim YH: Incidental total necrosis of a successful flap due to a secondary operation after one year. Arch Plast Surg **41:** 294, 2014.