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Original Article

Limb preservation with suprafascial and thin perforator flaps: salvaging osteomyelitis, Charcot collapse and critical limb ischemia

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Abstract

Aim: There are limited reports in the United States demonstrating outcomes of primarily thinned fasciocutaneous flaps in the setting of critical limb ischemia, Charcot collapse and osteomyelitis. We hope to determine patient and flap related outcomes in advanced lower extremity disease.

Methods: The authors conducted a retrospective review of fasciocutaneous free flaps of variable thickness for lower extremity salvage. Osteomyelitis and non-osteomyelitis patients were compared according to our primary outcome measures: functional ambulation, bone healing and complications to flap and patient. Subgroups with critical limb ischemia, Charcot collapse and diabetic foot were analyzed separately.

Results: Fifty-nine patients underwent free flap reconstruction: osteomyelitis (n = 20, 34%), Charcot collapse (n = 22, 37%), and/or critical limb ischemia (n = 12, 20%). All patients underwent anterolateral thigh flaps tailored for defect-specific thicknesses: 17 superthin, 25 suprafascial, 17 subfascial. There were no significant differences between groups in terms of partial and complete flap loss (P = 1.000 and P = 0.108). Ninety-one percent of patients were ambulatory at follow up. Eighty-five percent of individuals with osteomyelitis cleared their infection demonstrating radiographic bone healing. Two patients developed recalcitrant deep space infections ultimately requiring amputation. Subgroup analysis did not show any differences in flap related complications within the diabetic Charcot population. In multivariate regression, preoperative revascularization was independently associated with failure of limb salvage.

Conclusion: Primarily thinned perforator flaps performed well in the setting of lower extremity limb salvage, critical limb ischemia, osteomyelitis, and the Charcot foot - expanding their role in the armamentarium for lower extremity care.

Keywords: Perforator flap, diabetic foot, limb salvage

INTRODUCTION

Free microvascular tissue transfer in combination with aggressive debridement, targeted antimicrobial therapy, optimization of distal perfusion and boney stabilization remains a powerful tool to heal lower extremity wounds with osteomyelitis - restoring functional ambulation[1-3]. Godina along with Mathes described the role of muscle-flap coverage for high-energy wounds with infected bone almost 40 years ago. They achieved an 89% infection clearance rate[4]. Numerous authors have demonstrated similar results[1-7]. Lower extremity salvage in the setting of high-energy trauma, critical limb ischemia and the diabetic foot often includes management of denuded and dysvascular bone with variable degrees of osteomyelitis ranging from superficial contamination, to deeper medullary involvement, from localized to diffuse infections described by the four-tiered Cierny-Mader classification[8,9]. Traditionally muscle-bearing flaps were used to create a local tissue environment conducive to healing and fill-in tissue dead-space. Muscle has been thought of as more effective than fasciocutaneous flaps in overcoming bacterial colonization and infection due to improved oxygen delivery and restoration of wound bed perfusion[2,3,6,10]. However this has been refuted over the past decade by a number of authors[3,5,7,11].

Over time, a deeper understanding of perforasome anatomy[12], microsurgical technical refinements[13-16], perioperative protocols and improved instrumentation has empowered reconstructive surgeons to reliably utilize skin-only and fasciocutaneous flaps for coverage of lower extremity defects[17]. Nonetheless, challenges remain as traditional perforator-based flap thickness can interfere with post-operative function, particularly in the lower extremity, wherein bulky, thick, flaps can interfere with footwear, contour across joints, irregular weight bearing surface and can lead to flap breakdown[2,13,14]. Technical refinements in anterolateral thigh (ALT) harvest offer reliable methods to achieve thinner flaps, minimizing debulking procedures, improving contour and decreasing donor morbidity.

Recent reports consistently demonstrate that elevation of the ALT flap in different planes allow for the possibility of safe, consistent, and definitive distal extremity reconstruction in a single stage[15,18,19]. However, limited data exists for successful limb salvage with use of thin fasciocutaneous flaps in the setting of osteomyelitis, limb ischemia and the Charcot foot. Our goal is to describe the routine use of the primarily thinned ALT flap in varying thicknesses for lower limb salvage surgery, and to assess outcomes in patients at high risk for failure.

METHODS

Patient data

All lower extremity free flaps performed at a single, Level 1 medical center were entered into a prospectively maintained registry including patient demographic information, clinical history, radiographic imaging, procedural data, operative reports, postoperative care and long-term complications across 116 unique variables. A REDCap database was utilized as a secure web-based application for data maintenance. A trained member of the research team uploads data once monthly. Follow up radiographic reports and clinic visits are specifically analyzed to identify limb salvage failure, nonunion, malunion, osteomyelitis, flap failure, wound recurrence, patient ambulation, use of assistive devices, patient disposition and rates of amputation. The database is maintained via institutional review board approval.

Figure 1. Superficial osteomyelitis managed with suprafascial anterolateral thigh. A patient with Cierny-Mader Class 2 ostomyelitis of the calcaneus. A: A preoperative photo; B: immediate post flap phot; C: pre flap radiography with osteomyelitis; D: six-month follow up photo with clearance of osteomyelitis. The patient was weight bearing at time of follow up

For the purposes of this study, the database was queried in June 2018 for cases performed from January 2015 to December 2017. We excluded muscle flaps and skin-only or fasciocutaneous flaps other than ALT's. Of 84 patients who underwent lower extremity free-tissue with ALT flaps, we excluded 25 individuals without high risk factors. This left 59 patients selected for at least one of the following features: osteomyelitis, Charcot collapse, and critical limb ischemia.

For each patient, relevant demographic information, comorbidities, presence of peripheral vascular disease, revascularization, antibiotic use, anticoagulant use, wound etiology, pre-operative imaging, anatomical wound location, skeletal fixation, flap thickness, operative characteristics, complications and follow-up were reviewed.

Osteomyelitis was defined as tissue-proven boney infection via histological analysis and bony tissue culture obtained at the time of flap coverage in the case of single-staged reconstructions and or prior to reconstruction from bone biopsy. Clinical, radiographic, microbiological information was gathered.

Patients were separated based on the Cierny-Mader classification system defining the depth as well as diffusion of osteomyelitis[8,9,20]. Patients with Charcot collapse, critical limb ischemia (defined by vascular imaging proven: single vessel run-off, multi-level or multivessel arterial disease) and diabetes mellitus were separated into a subgroup for analysis of their unique pathophysiology.

Reconstructive technique
Patients were separated for analysis into groups based on flap thickness: periscarpal (superthin), suprafascial and subfascial (thick). During the period of study, no muscle-flaps were utilized. We relied uniformly on skin-only and fasciocutaneous flaps. Flap thickness was tailored to match defect surface contour and volume of dead space.

Figures 1-3 demonstrate case based examples of our reconstructive technique. ALT flap thickness for each case was determined by defect thickness, need to fill deadspace and correlates with Cierny classification of Osteomyelitis.
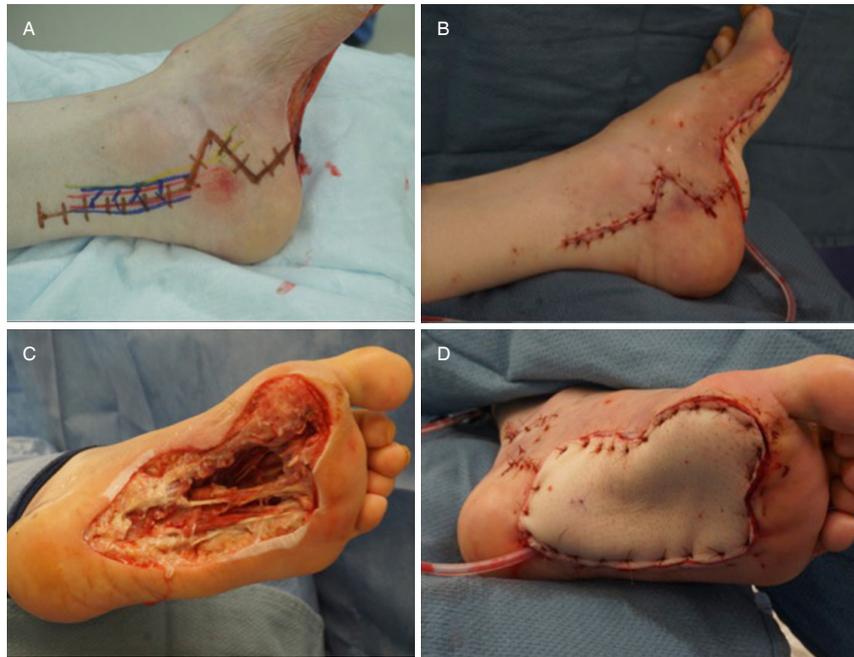
Figure 2. Deep Space Infection and Charcot Foot treated with Subfascial anterolateral thigh (ALT). A patient with plantar weight bearing soft tissue loss after deep space diabetic foot infection. A: Preoperative lateral view showing Bruner incision for tarsal tunnel release, vessel harvest and tibial neurolysis; B: lateral clinical photography after inset and closure of Bruner incision with mid-foot plantar arch contouring; C: preoperative view of the plantar surface; D: after subfascial ALT for coverage and lateral femoral cutaneous nerve coaptation to plantar branch of the tibial nerve. The crural fascia was inset well beyond the skin incision margin. The patient was successfully weight bearing 11 weeks post-operatively

Our technique for elevation in the desired plane has been previously described[15,16]. Superthin flaps were defined as those elevated at the superficial scarpal fascia within the subcutaneous fat. Suprafascial flaps were defined as flaps elevated just above the crural fascia and subfascial flaps were those elevated below the crural fascia and/or deep muscular fascia[2]. Defects with bone-loss requiring spacer placement and or bone grafting for management of later stage III, IV Cierny-Mader osteomyelitis often required thicker flaps to fill-in dead space. As such, subfascial ALT flaps were harvested to assist filling dead-space and or to contour deeper defects. However, we preferentially utilized a superthin elevation for reconstruction of weight bearing surfaces along the heal, mid-foot, dorsal-foot and ankle region. Earlier stage Cierny-Mader Osteomyelitis being cortical, focal medullary involvement resulted in superficial boney defects often amenable to coverage with super-thin flaps.

The major tenets of lower extremity salvage were regarded as appropriate debridement to perfused tissue, preservation of vital structure, muscle, nerve and tendon along with isolation and control of major vascular inflow. Wounds amenable to local tissue reconstruction with advancement flaps, skin-graft, regional pedicle flaps, freestyle propeller flaps were utilized when-able but were excluded from this study.

During free tissue transfer, we preferentially performed end-end anastomosis in patients with adequate runoff and normal vascular supply. However, in patients with peripheral vascular disease, single-vessel runoff, multi-vessel or multi-level flow limiting lesions, end to side anastomosis was performed to maintain in-line perfusion distal to the reconstruction. Venous outflow was preferentially based on the deep venous system with emphasis on vessel quality, size-match, lack of back-bleeding, avoidance of venous hypertension over absolute number of venous anastomosis.

An enhanced recovery protocol was utilized for the majority of our patients including the use of regional anesthetic block achieved via continuous peripheral nerve catheter placed in the popliteal region

Figure 3. A case of Calcaneal Osteomyelitis treated with superthin anterolateral thigh (ALT) flap. A patient with Cierny-Mader class 3 osteomyelitis with calcaneal and proximal mid-foot erosions seen on (A) preoperative radiography. This required boney debridement and soft tissue coverage with superthin ALT in single-stage; (B) shows postoperative radiography with clearance of osteomyelitis; (C) demonstrating superthin (periscarpal) ALT; (D) after final inset and small skin graft for coverage of the vascular pedicle. This resulted in full-ambulation in normal shoe gear

targeting the sciatic, tibial and peroneal nerves when appropriate. This achieved decreased rates of post-operative narcotic use and shorter post-anesthesia unit stays[21]. Additionally an early limb dependency program[22] helped patients dangle early in their post-operative course expediting hospital stay, discharge to rehabilitation facilities, and return toward functional ambulation.

Outcome measures
Outcomes pertaining to flap specific morbidity such as partial flap loss, microvascular collapse, vessel thrombosis, site infection and dehiscence were analyzed in addition to systemic complications.

With regard to osteomyelitis, discontinuation of antibiotic, achievement of boney union, return to weight bearing, exchange of external for internal hardware and radiography were analyzed. Return to functional ambulation, weight bearing and avoidance of amputation were compared across all groups.

Statistical analysis
Descriptive statistics were utilized to compare patient demographic information in regard to number, frequency, mean and standard deviation. Student *t*-test for continuous data and Fischer's exact test for categorical data were used for univariate analysis to determine significant differences in wound and flap characteristics along with donor site and flap complications between groups of patients. Those variables achieving significance P-value < 0.05 were entered into a multivariable regression model to identify independent risk factors associated with limb loss and osteomyelitis recurrence. Statistical significance was defined as a P-value < 0.05. The analysis was performed using IBM SPSS software by members of our research group within the institution (Version 3.154).

RESULTS
A total of 59 ALT flaps were performed from January 2015 to December 2017 for lower extremity salvage reconstruction. The mean follow-up time of our population was 13.8 months (2.24-39.2 months). Flaps

Table 1. Patient characteristics and univariate comparison based on the presence of osteomyelitis

	Osteomyelitis *n* = 20	No osteomyelitis *n* = 39	*P*-value
Age	51.95 ± 13.65	52.3 ± 13.44	0.918
Sex (%)			0.192
Male	18 (90)	29 (74.4)	
Female	2 (10)	10 (25.6)	
BMI	31.53 ± 6.80	28.10 ± 4.71	0.026
Smoking history (%)	6 (30.0)	17 (43.6)	0.311
Hypertension (%)	9 (45.0)	10 (25.6)	0.132
Diabetes (%)	9 (45.0)	13 (33.3)	0.380
Coronary artery disease (%)	5 (25.0)	3 (7.7)	0.106
Peripheral artery disease (%)	6 (30.0)	9 (23.1)	0.563
Renal disease (%)	1 (5.0)	3 (7.07)	1.000
Malnourished (Albumin < 3.5 g/dL) (%)	6 (30.0)	5 (12.8)	0.159
Multiple comorbidities (%)	10 (50.0)	23 59.0)	0.511
Preoperative antithrombotic use (%)	20 (100.0)	38 (97.4)	1.000
Preoperative antiplatelet use (%)	12 (60.0)	27 (69.2)	0.478
Chemotherapy (%)	1 (5.0)	3 (7.7)	1.000
Radiation (%)	1 (5.0)	3 (7.7)	1.000
Prior revascularization (open or endovascular) (%)	6 (30.0)	3 (7.7)	0.050
Vascular imaging (%)	13 (65.0)	22 (56.4)	0.525
Prior amputation level (%)	2 (10.0)	0 (0.0)	0.111

Table 2. Wound, flap and anastomotic characteristics with univariate comparison between groups of patients based on the presence of osteomyelitis

	No.	%	Osteomyelitis (*n* = 20)	No osteomyelitis (*n* = 39)	*P*-value
Type of wound (%)					
Traumatic	30	50.8	7 (35.0)	23 (59.0)	0.081
Malignant	5	8.5	0 (0.0)	5 (12.8)	0.156
Chronic (> 90-day)	24	40.7	13 (65.0)	11 (28.2)	0.006
Wound location					
Foot	24	40.7	8 (40.0)	16 (41.0)	0.939
Ankle	14	23.7	5 (25.0)	9 (23.1)	1.000
Calf	13	22.0	4 (20.0)	9 (23.1)	1.000
Shin	3	5.1	1 (5.0)	2 (5.1)	1.000
Knee	4	6.8	2 (10.0)	2 (5.1)	0.598
Thigh	1	1.7	0 (0.0)	1 (2.55)	0.544
Flap type					
Superthin	17	28.8	8 (40.0)	9 (23.1)	0.174
Suprafascial	25	42.4	8 (40.0)	17 (43.6)	0.792
Subfascial	17	28.8	4 (20.0)	13 (33.3)	0.284
Anastomosis					
End to End	42	76.4	15 (75.0)	27 (77.1)	1.000
End to Side	13	23.6	5 (25.0)	8 (22.9)	1.000

were elevated in three major planes: superthin (17 patients, 29%), suprafascial (25 patients, 42%) and subfascial (17 patients, 29%). Twenty patients (34%) had tissue-proven osteomyelitis. When separated into groups based on the presence of osteomyelitis, patients were well-matched across 116 variables. Select comparisons are shown in Table 1. Individuals with osteomyelitis had higher average BMI (*P* = 0.03) and a greater incidence of previous vascular interventions (*P* = 0.05).

Table 2 describes wound characteristics and locations. Traumatic injury was the most common type of wound etiology in both osteomyelitis and non-osteomyelitis groups (51%) followed by chronic wound and malignant wounds (40% and 9%, respectively). Chronic wounds were defined as an established wound despite attempts at local or surgical wound care, offloading, and medical comorbidity management past 90-days. The foot and ankle were the most common recipient site for the ALT flaps. The distributions of ALT thickness type across osteomyelitis as well as non-osteomyelitis groups were comparable.

Table 3. Flap complication and reported Limb salvage rates

	Total N N.59 = 59	Osteomyelitis N.20N = 20	CLI[1]N.12 = 12	Charcot N.22	*P*-value[2]
Ambulatory	54 (91%)	17 (85%)	10 (83%)	20 (90%)	0.110
Non-ambulatory	5 (9%)	3 (15%)	2 (17%)	2 (9.1%)	0.217
Amputation	2 (3.4%)	2 (10%)	2 (17%)	2 (9.1%)	0.252
Amputation free	57 (96.6%)	18 (90%)	10 (83%)	20 (90%)	
Osteomyelitis clearance		18 (90%)	10 (83%)	18 (81%)	
Flap complication	18 (30%)	8 (40%)	5 (42%)	7 (31.8%)	0.260
Complete flap loss	4 (6.8%)	1 (5%)	0 (0%)	0 (0%)	0.699
Partial flap loss	3 (5.1%)	1 (5%)	2 (17%)	2 (9.1%)	0.983
Flap infection	4 (6.8%)	2 (10%)	1 (8.3%)	1 (4.5%)	0.598
Dehiscence	6 (10.2%)	1 (5%)	1 (8.3%)	4 (18.2%)	0.653
Flap revision	9 (15%)	1 (5%)	1 (8.3%)	0 (0%)	0.841

[1]CLI: critical limb ischemia, defined as patients with at least one of the following: single-vessel runoff, severe peripheral vascular disease, multi-vessel arterial disease, multi-level arterial disease; [2]*P*-values reported after univariate comparison of patients with Osteomyelitis to those without across all outcomes

Overall donor site complication rates were as follows: seroma, 5% (n = 3); neuropathy, 5% (n = 3); contour irregularity, 3.4% (n = 2); and site infection, 3.8% (n = 2). No differences in donor site complication rates were noted between groups. Flap complication rates including complete flap loss, partial flap loss, wound dehiscence and flap infection were 6.8%, 5.1%, 10.2%, and 6.8%, respectively. Again, no significant differences between groups were noted. Table 3 demonstrates complication rates across high-risk individuals harboring critical limb ischemia, Charcot foot, and osteomyelitis. Eight flap revisions were needed, none of which were related to an osteomyelitis recurrence.

Sub-group analysis in the diabetic population revealed no cases of complete flap loss, two cases of partial flap loss, four cases of wound dehiscence and one of flap infection, complication rates of 0.0%, 9.1%, 18.2% and 4.5%, respectively [Table 3]. No differences between the osteomyelitis and non-osteomyelitis groups within the diabetic population were noted. Our sub-group analysis demonstrated comparable outcomes amongst a group of diabetic patients with osteomyelitis and Charcot foot.

Table 4 describes variegations in the osteomyelitis group and associated salvage rates. Cierny-Mader osteomyelitis class, flap type and presence of comorbidity did not significantly alter osteomyelitis clearance (P > 0.05) for each univariate comparison.

A multivariable regression was performed after stepwise entry of variables associated with limb-loss and amputation with (P < 0.1). Preoperative revascularization was independently associated with limb loss OR 6.1 (P < 0.05). Osteomyelitis, Charcot foot, diabetes, the presence of critical limb ischemia, and flap elevation plane were not in and of themselves independently associated with limb loss.

DISCUSSION

In this study of lower extremity free tissue transfers with ALT flaps, we compared complication rates and outcomes across three elevation planes in settings of osteomyelitis, charcot collapse and critical limb ischemia. We did not find any significant differences between the groups using either one of the three planes of elevation in terms of major complication as flap revision, flap infection; wound dehiscence, partial and complete flap loss. Important to note, the distribution of flap types between groups harboring osteomyelitis was comparable (superthin: P = 0.174; suprafascial: P = 0.792; and subfascial: P = 0.284). Interestingly, there were no differences between major flap complications within the diabetic population and Charcot foot. These findings further support the use of skin-only and fasciocutaneous flaps in the setting of osteomyelitis. We demonstrate that thin flaps can assist in boney healing and clearance of infection despite a lower metabolic demand compared to muscle flaps.

Table 4. Characteristics of 20 patients who underwent perforator based flaps for treatment of lower extremity osteomyelitis

	No.	(%)	Clearance[a]
Soft tissue defect location			
Calf/Knee	7	35	7 (100%)
Ankle	5	25	4 (80%)
Foot	8	40	7 (87.5%)
Bone involved			
Tibia	5	25	5 (100%)
Fibula	2	10	2 (100%)
Calcaneus	5	25	4 (80%)
Ankle mortis/carpus	6	30	6 (100%)
Metatarsal/phalangeal	2	10	1 (50%)
Tissue based diagnosis	20	100	
Cierney-Mader classification			
I - Superficial	12	60	12 (100%)
II - Medullary	3	15	2 (67%)
III - Isolated (Sequestrum)	1	5	1 (100%)
IV - Diffuse	4	20	1 (75%)
Hardware present and kept in place	(4/4)	100	4 (100%)
External fixator present	2	10	2 (100%)
Microorganism			
Staph epidermidus, coagulase negative staph. MSSA	13	65	12 (92%)
MRSA	1	5	1 (100%)
Enterobacter	2	10	2 (100%)
Streptococcal	1	5	1 (100%)
Corynebacterium	1	5	1 (100%)
Proteus sp.	1	5	0 (0%)
Stenotrophomonas	1	5	1 (100%)
Flap thickness			
Subfascial (Thick)	4	20	4 (100%)
Suprafascial	6	30	5 (83%)
Superthin (Periscarpal)	10	50	9 (90%)
Bone union achieved across fracture line	(8/9)	89%	
External fixator exchanged for internal hardware or removed	(2/2)	100%	
Amputation	2	10	
Radiographically healed compared to preoperative	(7/9)	78%	
Osteomyelitis recurrence	2	10%	

[a]Osteomyelitis clearance as defined by lack of local recurrence of boney osteomyelitis, discontinuation of antibiotic, healed soft-tissue envelope, clearance of deep-space infection

In subgroup analysis of our highest risk populations nine diabetic patients had osteomyelitis and three more had critical limb ischemia. Although this is a small sample size, outcomes in this population are mixed: none experienced recurrence of osteomyelitis defined as clinical evidence of bone infection by clinical exam, radiography or tissue pathology within the surgical site; five of our patients were fully weight-bearing in less than four months while three of them never fully ambulated due to conservative management of secondary ulcers in the same extremity, and one patient went on to amputation due to severe peripheral artery disease. Only one flap loss occurred due to extensive arterial thrombosis despite early intervention within the osteomyelitis group [Table 3].

Microvascular tissue transfer in high-risk individuals harboring vascular disease, osteomyelitis and the Charcot foot improves upon outcomes achieved with alternative standard of care pathways. Revascularization alone as demonstrated in the "Bypass versus Angioplasty in Severe Ischemia of the Leg Trial" (BASIL Trial)[23] offers limited salvage rates with shortened up overall amputation-free survival and mortality when compared to revascularization plus wound directed reconstructive surgery. Of 250 patients

enrolled and randomized with critical limb ischemia to either open or endovascular revascularization at a mean 3.1 year follow-up: the trial showed a 56% mortality rate, 38% amputation-free survival and thirty patients and (7%) living with an amputation. This of course represents a morbid group of individuals meeting particular selection criteria of the trial, many of whom may be precluded from the surgical stress of free tissue transfer. However, when wound-directed therapy with Integra Bilayer Wound Matrix (Integra Lifesciences, Plainsboro NJ) and skin graft was added to a similar group of individuals, Iorio *et al.*[24] improved limb salvage rates. Limb survival was compared across 105 individuals with 121 foot/ankle wounds according to tissue type exposed and presence of high-risk factors: 61% of those with bone exposure and osteomyelitis were salvaged, 71% of diabetic wounds were salvaged and 59% of diabetics with bone involvement avoided amputation. When provided with thin perforator flaps at our center (18/20) 90% of individuals avoided amputation with osteomyelitis, (21/22) 92%, of diabetics were salvaged, all of whom were high-risk for amputation, and 89% (8/9) of individuals with both diabetes and osteomyelitis avoided amputation.

Hong *et al.*[2] demonstrated a survival benefit over time in 2016 while utilizing the "Angiosome and Supermicrosurgery Concept" principle and techniques for the management of diabetic foot wounds. Hong *et al.*[2] salvaged 84.9% of individuals over five-year follow-up. However, Dr. Hong also noted limited success in those individuals requiring preoperative revascularization. During a regression analysis, revascularization was associated with limb-loss independent of other high-risk features similar to our findings. We came to similar findings as Dr. Hong's with regard to limb ischemia requiring revascularization-lending caution to future patient selection.

With regard to osteomyelitis, flap coverage has been widely studied by several groups over the last four decades[25,26]. In 1982, Chang and Mathes[10] described 21 patients with chronic osteomyelitis who underwent muscle flap coverage with a success rate of 90%, two patients (10%) developed recurrent infection postoperatively[11]. Then, in 1991 James *et al.* demonstrated the long term effect of muscle flap coverage in the management of 34 patients with chronic osteomyelitis with 89% of success rate over a long-term follow up (> 5 years, mean 7.4 years). Reconstructive surgeons readily accepted muscle flaps as a standard for management of Gustillo IIIB defects with osteomyelitis in the 1990's. Eventually fasciocutaneous flaps started to make a presence in the early 2000's. Salgado *et al.*[1] demonstrated in animal model that both muscle and non-muscle flaps provide a viable option for wound coverage of osteomyelitis defects. A recent publication by Hong *et al.*[3] assessed the efficacy of perforator flaps in the treatment of chronic osteomyelitis in a retrospective study including 120 patients who underwent reconstruction for chronic osteomyelitis of the lower extremity; their flap loss rate was 4.2% and partial flap loss rate of 8.3% with remission rate of 91.6% in one-stage reconstruction. These findings in line with ours in terms of 6.8% rate of flap loss overall and 5% rate of partial flap loss in the osteomyelitis group. Hong *et al.*[2] utilized 30 superficial circumflex iliac (SCIP) flaps, 1 thoracodorsal artery perforator (TDAP), and 41 ALT flaps but did not describe the plane of elevation. With our contribution of 16 superthin (N. 10) and suprafascial (N. 6) ALT's utilized for osteomyelitis, we estimate the number of published reports of utilizing superthin (periscarpal) and suprafascial flaps for the management of osteomyelitis is in the range of 50-100 worldwide to date.

Notable limitations of this study include our small sample size lending to type 1 error in the comparison of moderate-sized groups of patients with low overall complication rates - necessitating larger numbers to strongly power our conclusions over time. We uniformly relied on the ALT flap at our institution for wounds necessitating coverage by free tissue transfer, which assists in limiting selection biases but is of course a unique practice. The unique referral pattern from foot and ankle surgery, podiatry and vascular surgery along with availability to perform free-tissue transfer in this setting may also be difficult to repeat across centers. This study does not include a number of patients managed by local pedicled flaps, skin grafts, dermal substitutes and local tissue rearrangement. Our limited mean follow-up of 13.8 months

does not fully capture limb salvage rates particularly in individuals with osteomyelitis who can go on to recur after one year and or those with critical limb ischemia whose disease is not reversed by flap coverage. We also have not explored basic laboratory, animal research or clinical pathologic review facets of fasciocutaneous flaps that promote wound healing. Thus we can comment very little the physiologic basis of our findings. This certainly will be an avenue of further pursuit. Further, this nonrandomized single-site study carries potential selection and treatment biases inherent in unique to the surgeon and institutions practices. However, it is our hope that with further multi-institutional participation, presentation and publication, particularly to our podiatry, vascular surgery and orthopedic colleagues that we can expand our practice and move from small scale low-power studies to larger powered research - working toward prospective trial. This will be particularly helpful in those patients requiring revascularization by either open or endovascular means to delineate selection of patients fit for free tissue transfer and the timing of such interventions.

The superthin, suprafascial and subfascial variations of the ALT flap, are reliable, safe and effective options for lower limb salvage surgery in the setting of osteomyelitis, limb preservation and Charcot collapse. Incorporating these flaps widens the reconstructive surgeon's armamentarium to replace like tissue, avoid a muscle-flap donor, improve contour, shoe gear and allow bony healing - translating to healthy weight bearing limbs and restoring ambulation[27]. Limb ischemia necessitating revascularization prior to flap reconstruction remains a major risk factor for limb loss, particularly in the patient with concomitant osteomyelitis.

DECLARATIONS

Authors' contributions
Study design: Diamond S, Doval AF, Iorio ML
Manuscript preparation: Diamond S, Iorio ML
Data acquisition: Diamond S, Doval AF, Scott B
Data analysis: Scott B

Availability of data and materials
IRB approved retrospective study based on BIDMC hospital charted data.

Financial support and sponsorship
None.

Conflicts of interest
All authors declared that there are no conflicts of interest.

Ethical approval and consent to participate
IRB approval prior to data acquisition and study design.

Consent for publication
An informed consent for publication has been taken from the patients.

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