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Original Article

"Saving the crippled foot" – a study on diabetic foot ulcers and its salvage using flap surgeries

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Abstract

Objective: Emphasize the importance of a comprehensive and aggressive management with surgical debridement and flap-based reconstruction of defects in patients with diabetic foot ulcers (Ganga Class 3), and in turn, focusing on limb salvage.

Methods: A retrospective cohort analysis was conducted on 40 patients with Ganga Class 3 diabetic foot submitted to flap surgeries between 2019 and 2022. These surgeries included both free and local flaps, and patients were followed postoperatively to monitor complications such as flap necrosis, infection, and the need for amputation. A pedobarogram was performed after wound healing to assess the risk of ulcer recurrence.

Results: The mean age of the study population was 58.5 years, with 75% being male. Most ulcers (60%) were located in the hindfoot, with large hindfoot ulcers often requiring anterolateral thigh-free flaps, which showed excellent long-term outcomes. While effective for smaller defects, local flaps demonstrated higher complication rates, particularly flap necrosis in reverse sural artery flaps. Despite these complications, flap surgeries were largely successful, with only one patient requiring amputation, achieving significant success in limb salvage.

Conclusion: Given that India is considered the diabetic capital of the world, with 85% of amputations preceded by foot ulcers, this study highlights the potential for surgical management of diabetic foot ulcers, regardless of size or location, emphasizing the importance of limb salvage in improving patient outcomes.

Level of evidence: Level IV.

Keywords: Diabetic foot; Amputation, surgical; Limb salvage; Surgical flaps.

Introduction

The prevalence of diabetes mellitus in India stands at 8.8%(1). The diabetic foot has become one of the most common and serious complications of diabetes mellitus and is a frequent cause of hospitalization and disability. Diabetic foot ulcers were found in 4.54% of patients newly diagnosed with type 2 diabetes mellitus in India; of these, 46.1% had neuropathic, 19.7% ischemic, and 34.2% had neuro-ischemic foot ulcers(2).

Advancements in diagnosing and treating diabetes and its complications, including retinopathy, nephropathy, neuropathy, and foot ulcers, have significantly extended patient's lifespans and improved their quality of life. One of the most severe complications, however, is diabetic gangrene. While the causes of diabetic wounds typically involve both angiopathy and neuropathy, often due to reduced sensation and, at times, impaired blood flow, the underlying mechanisms of neuropathy, ischemia, and microangiopathy play varying roles in hindering healing. These factors contribute to complex tissue damage and make wounds highly vulnerable to persistent, hard-to-treat infections(3-5).

Patients with diabetes who develop foot ulcers have increased mortality(6) compared with those who have intact feet (15% lower survival at 3 years), reduced quality of life, and are more likely to require amputation(7,8). Several studies have shown that an amputation affects the quality of life only

Study performed at the Father Muller Medical College, Mangalore, Karnataka, India.

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a minority of patients regain independent walking capacity[7], and the direct and indirect costs are much higher than limb salvage procedures[8,9].

First, all patients underwent a radical debridement of the infected/necrotic area, followed by vacuum-assisted closure (VAC) application for 3-5 days. After this period, the wound was reassessed, and an appropriate flap was planned. The patients then underwent a secondary debridement, and an appropriate flap surgery was performed. Larger size wounds and wounds enveloping the joints were planned for microvascular free tissue transfer, while local skin or muscle-based flaps were planned for coverage of smaller-sized defects.

This study aims to emphasize the importance of comprehensive and aggressive management with surgical debridement and flap-based reconstruction of defects in patients with diabetic foot ulcers (Ganga Class 3) and, in turn, focusing on limb salvage. By prioritizing limb preservation, the study seeks to explore and validate various surgical techniques that minimize the need for amputation, regardless of the severity of the condition, thereby improving patient outcomes and quality of life. We hypothesize that a thorough debridement of infected and devitalized tissue, irrespective of the size and site of the ulcer, along with an adequate vascularized flap cover, can help not only arrest and reverse the progression of disease but also save the foot from the need for amputation and improve the quality of life in such patients.

Materials and methods

Study design

In a retrospective cohort, 40 patients with diabetic feet were classified based on Ganga classification for diabetic feet – pre-ulcerative changes (Ganga Class 1), chronic uncomplicated non-healing ulcer (Ganga Class 2), complicated ulcer and extensive skin and soft tissue loss (Ganga Class 3) and neglected ulcers which have progressed to limb- or life-threatening situations necessitating urgent amputation (Ganga Class 4). Patients with (Ganga Class 3) who were operated on between 2019 and 2022 were selected for the outcome of subsequent flap surgeries. Flaps of two categories were included – free and local flaps. The free flaps comprised anterolateral thigh free flaps and radial forearm free flaps, and the local flaps comprised transposition flaps, reverse sural artery flaps, and flexor digitorum brevis flaps. After obtaining necessary institutional ethical clearance, patients satisfying the inclusion criteria of (1) 18 years and above and (2) patients with Ganga Class 3 diabetic feet were included, and patients were excluded if they (1) had a concomitant peripheral vascular disease, and (2) patients lost to follow-up. Patients were then evaluated on routine follow-ups for complications such as (1) flap necrosis (2) infections, and (3) need for amputation. The inclusion-exclusion criteria were identified based on previous medical records. A pedobarogram was performed on subsequent follow-ups at six and 12 months for all patients after complete wound healing to assess the potential risk of developing another ulcer. The study protocol was approved by the institutional review board. After explaining the study, all patients signed the informed consent form.

Surgical techniques

All patients were evaluated for size and site of ulcers, and a vascular evaluation was performed using a computed tomography angiogram. After confirming adequate vascularity, patients first underwent a preliminary wound debridement, followed by VAC application for 3-5 days. After this period, the wound was reassessed, and an appropriate flap was planned. Smaller defects with an adequate soft-tissue bed required only a local flap rotated around an existing vascular pedicle, whereas larger defects or defects over bony prominences and joints required free flaps with vascular anastomosis. Amongst the local flaps, based on the location of the ulcer over the foot, the nearest local flap that could be elevated to cover the defect while maintaining the native vascular supply was chosen. The patients then underwent a secondary debridement and an appropriate flap surgery was performed. Our study involved free microvascular anterolateral thigh flap transfer, harvested from the contralateral thigh outlined along the axis of the anterior superior iliac spine and superolateral corner of the patella, with the identification of vascular pedicle consisting of the descending branch of the lateral circumflex femoral artery and its accompanying veins, present along the axis of vastus lateralis and rectus femoris. Radial forearm free flaps with a pedicle consisting of the radial artery with its perforators to the overlying skin and its accompanying vena commitans and cephalic vein for venous drainage was used, and the donor sites in these microvascular free flap cases were partially closed while the remaining area, grafted with a split-thickness skin graft. Patients underwent local transposition or rotation of skin flaps, which were rotated around the native pedicle, supplying the flap locally. Reverse sural artery flap (a distally based fasciocutaneous flap consisting of skin, superficial and deep fascia, sural nerve, short saphenous vein, and superficial dual artery) and peroneus brevis muscle flap were used to cover critical raw areas.

Postoperative evaluation

Patients received routine postoperative care, limbs were immobilized using off-loaded plaster-of-Paris slabs, and anti-coagulant therapy was initiated for the patients who underwent free flaps. Regular dressings were performed, and flaps were monitored for any signs of necrosis or repeat infection. Patients were discharged with instructions to continue wound dressings at home and were scheduled for regular follow-up on an outpatient basis. After wound healing, a pedobarogram was conducted for all patients, and appropriate off-loading footwear was prescribed. Patients who developed complications such as flap necrosis or infection underwent further debridement with a repeat flap cover using the same flap selection protocol used in the index surgery. If vascularity to the distal extremity was found to be compromised with no other alternative, such patients underwent amputation.

Statistical analysis

Data were collected and subjected to both descriptive and inferential statistical analysis. Continuous variables such as patient age, ulcer size, and HbA1c levels were expressed as mean ± standard deviation (SD). Logistic regression was used to assess the association between continuous variables and the risk of developing postoperative complications. A logistic regression model was created for each complication, using the continuous variables as predictors. The significance of each predictor was evaluated using p-values, and a threshold of 0.05 was set for statistical significance. Fisher's exact test was applied to assess the relationship between different flap types and postoperative complications due to its suitability for small sample sizes and categorical data. Contingency tables were constructed for each flap type and complication pair, and Fisher's exact test was used to compute p-values. A p-value of less than 0.05 was considered statistically significant. Data analysis was performed using SPSS version 29.

Results

The mean age of our patient population was 58.5 years and was predominantly male (75%). The mean HbA1c was 8.3, the mean ulcer duration was two months, and the mean size was 49.67 cm^2. Out of 40 patients with Ganga Class 3 diabetic feet, 19 underwent local flaps – transposition flap (11), flexor digitorum brevis flap (5), and reverse sural artery flap (3), 15 underwent anterolateral free flaps, and six underwent radial forearm free flaps. Most ulcers were in the hindfoot (24) followed by the forefoot (10) and midfoot (6) respectively (Figure 1). Nineteen ulcers were found to be over a weight-bearing area, while 21 were over a non-weight-bearing area. Hindfoot ulcers were primarily covered using anterolateral free flaps (41%), midfoot ulcers using radial forearm free flaps, and forefoot ulcers using transposition flaps (Figure 2). The mean area of ulcers requiring anterolateral free flaps was 186 cms^2, ranging from 150-300 cms^2. Radial forearm free flaps, which were primarily used to cover defects in the midfoot and forefoot, were used for defects from 40 cms^2 up to 90 cms^2, with a mean size of 58.3 cms^2. The local flaps, namely transpositional flaps, reverse sural artery flaps, and flexor digitorum brevis flap, were used for smaller defects with a mean size of 27.6 cms^2, 28 cms^2, and 36.6 cms^2 respectively (Figure 3). Complications such as flap necrosis were seen in 3(7.5%) patients, with two in reverse sural artery flaps and one in a flexor digitorum brevis flap; repeat infection and the need for amputation were seen in one patient (2.5%) (Figure 4).

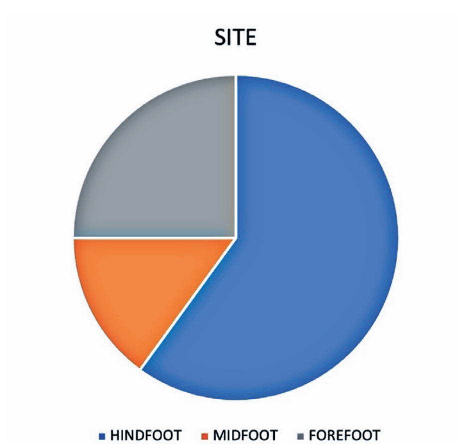

Figure 1. Site of involvement in diabetic feet.

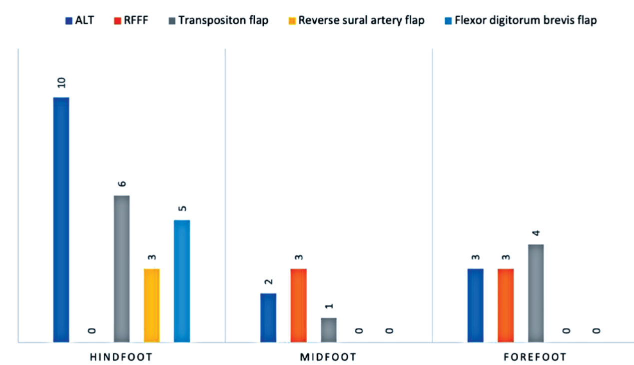

Figure 2. Types of flaps used over different parts of the foot.

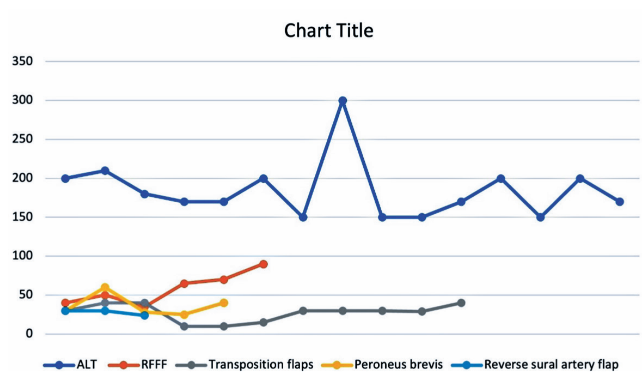

Figure 3. Surface area (cms^2) of ulcers covered using different flaps.

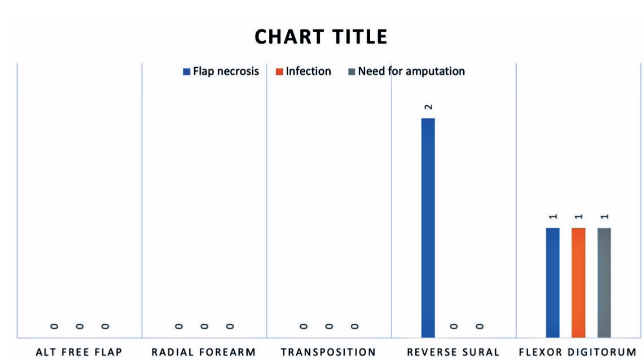

Figure 4. Complications associated with various flap surgeries.

A logistic regression analysis for factors affecting flap complications showed no statistical significance as a causal factor (Table 1).

Discussion

Diabetes affects an estimated 463 million adults worldwide, with India being home to over 70 million diabetics, earning the title of the diabetic capital of the world[2]. Diabetic foot complications, especially foot ulcers, are a significant burden on the healthcare system, being the primary cause of hospitalization in about 30% of diabetic patients[4]. Treating diabetic foot ulcers accounts for 20% of healthcare costs for diabetics[4]. Foot ulcers precede 85% of amputations, with 75% occurring on neuropathic feet with secondary infections, which are potentially preventable[5]. In India alone, around 100,000 legs are amputated annually due to diabetes, with the numbers rising[4].

Our study evaluated the outcomes of flap surgeries in patients with Ganga Class 3 diabetic feet. The ulcers were most commonly located in the hindfoot, followed by the forefoot and midfoot, with a majority in non-weight-bearing areas. Complications were minimal, with flap necrosis occurring in only three patients and one infection requiring amputation.

Three key factors contribute to diabetic foot ulcers: neuropathy, limited joint mobility, and ischemia. High blood sugar levels disrupt the myoinositol sorbitol pathways in neurons, causing nerve dysfunction[10]. Neuropathy affects motor, sensory, and autonomic components, with motor neuropathy leading to deformities due to intrinsic muscle atrophy. These deformities result in focal areas of high pressure on the plantar aspect of the foot. Sensory neuropathy diminishes protective mechanisms, while autonomic neuropathy reduces skin moisturization, leading to cracks and delayed wound healing[11]. Chronic uncontrolled diabetes also leads to the deposition of advanced glycation end products (AGE) in soft tissues, altering collagen and elastin properties, limiting joint mobility, and causing high plantar pressures[6]. Callosities increase pressure, leading to sub-callus ulcers, which can develop into deep tissue abscesses or osteomyelitis, spreading infection along soft tissue and tendon planes[11]. Additionally, vascular complications in diabetic patients can result in gangrenous ulcers due to thickened capillary walls and endothelial cell proliferation. Surgical bypass may sometimes be required to revascularize affected areas[7].

Table 1. Logistic regression analysis relationship between various continuous predictors (age, duration of diabetes, HbA1c, and ulcer area) and the development of postoperative complications (flap necrosis, infection, sepsis, and death).

	Flap necrosis	Infection	Sepsis	Death
Age	0.228287393	0.228287	0.228287	0.228287
Duration	0.774801616	0.774802	0.774802	0.774802
HbA1c	0.788224193	0.788224	0.788224	0.788224
Area	0.977747577	0.977748	0.977748	0.977748

Although ulcers are generally known to be more prevalent in weight-bearing areas, most of the ulcers in our study were found to be in non-weight-bearing areas. This highlights the importance of recognizing diabetic ulcers as not just a mere chronic pressure-sore but a complex issue with various confounding factors like loading of bony prominences from altered biomechanics in diabetic neuropathy, poor wound healing of small but otherwise unrecognized injuries of the foot due to uncontrolled sugars, and skin breakdown from poor vascularity resulting from diabetic microangiopathy. Thus, treating these ulcers requires offloading footwear, strict diabetic control, revascularization of the local soft tissue by debridement and flaps, and in some cases, even reconstruction of the bony architecture of the foot.

Diabetic wounds, even small ones, often mask the extent of the underlying infection. Superficial ulcers may be accompanied by tracking infections along soft tissue planes, leading to chronic osteomyelitis. Wound care in such cases must focus on removing all infected and necrotic tissue. In this study, patients underwent primary debridement with VAC therapy for a mean of 4-5 days, followed by secondary debridement before flap cover surgery. This approach improved wound prognosis and increased the success of reconstructive procedures. The suppressed immune system in people with diabetes further accelerates wound infections, making patients susceptible to resistant infections, particularly in bones[8,12]. Treating osteomyelitis requires aggressive management, including complete removal of necrotic tissue, decompression of infected compartments, filling dead spaces with vascularized tissues, and appropriate antibiotic therapy.

In the past, primary major amputations were common for large soft tissue deficits in diabetic feet, particularly on weight-bearing surfaces. However, only a small percentage of amputees regained full mobility, and limb loss had significant physical, mental, and financial consequences. A review of 45 studies including 419 patients, 149 patients who underwent amputation between 1948 and 2010 reported 30-day mortality rates of 16.45% and one-year mortality rates of 33.49%, emphasizing the need for combined interventions over early amputation in patients with viable outflow vessels[13,14].

Local random flaps have been used in reconstructive surgery for centuries, with the first use in diabetic foot wounds documented by Colen et al. in 1988[15]. These flaps are ideal for certain wounds that cannot be closed primarily or treated with skin grafts. Local random flaps, including advancement, rotational, and transpositional flaps, replace soft tissue defects with adjacent tissues, preserving the site's structure and function[16]. Free-tissue transfer offers effective solutions for more complex defects, especially in limb salvage. Studies have shown that free flaps can promote revascularization in ischemic limbs by forming vascular connections between the flap and surrounding tissue. This technique has proven successful in treating large diabetic ulcers that would otherwise lead to amputation(17-22). The best flaps for diabetic foot reconstruction provide well-vascularized tissue to combat infection, structural support for durability, and resistance to mechanical stress(23). Muscle flaps are preferred over fasciocutaneous flaps for their adaptability to the foot’s irregular surfaces and superior infection control, especially in cases of osteomyelitis. Muscle flaps provide cushioning to prevent further tissue breakdown, but the lack of sensation can increase the risk of recurrent complications(24-26). Despite this, muscle flaps are favored for managing complex defects, improving wound healing, and preserving the limb.

Our study examined the outcomes of local flaps in treating diabetic ulcers in various parts of the foot. Local transposition flaps, flexor digitorum brevis flaps, and reverse sural artery flaps were used, mainly for hindfoot ulcers, with some transposition flaps for forefoot and midfoot ulcers (Figures 5-7). While effective for smaller defects, local flaps showed higher rates of necrosis and repeat infections, particularly with reverse sural artery flaps. For larger ulcers, we employed anterolateral thigh free flaps (Figure 8-11) and radial artery forearm free flaps (Figure 12), both commonly used in our institution. Anterolateral flaps were used for hindfoot and large midfoot and forefoot defects, showing excellent results with no long-term complications. Some patients later required secondary procedures to debulk the flaps. Radial forearm flaps were used for medium-sized wounds in the midfoot, offering reliable coverage due to their larger, more

Figure 6. Postoperative follow-up cases of healed reverse sural artery flap.

Figure 5. (A) Forefoot ulcer (B) Post preliminary debridement (C) Medial plantar artery-based local transposition flap elevation (D) Flap onset (E) One-month follow-up (F) One-year follow-up showing complete wound healing.

Figure 7. (A) Forefoot ulcer (B) Post-wound debridement with flexor digitorum brevis muscle cover (C) Skin grafting over muscle flap (D) Two-month follow-up showing complete healing of plantar ulcer.

Figure 8. (A) Hindfoot ulcer (B) Post preliminary debridement (C) Anterolateral thigh free flap onset (D, E, and F) One-year follow-up, with complete recovery and independent ambulation.

Figure 9. (A, B, and C) Midfoot ulcer (D) Post preliminary debridement with harvested anterolateral free flap (E, F) Anterolateral thigh free flap onset.

Figure 10. (A, B) Forefoot ulcer (C) Post preliminary debridement (D) Post-secondary debridement (E, F) Anterolateral thigh free flap inset.

Figure 11. (A) Massive anterolateral flap (B) Post-debridement (C) Flap inset (D) One-month follow-up (E) One-year follow-up with complete wound healing and ambulation using modified footwear.

Figure 12. (A) Forefoot ulcer (B) Two-week follow-up post-radial artery forearm free flap onset.

reliable pedicles, which minimize vessel mismatch and allow for easy microsurgical anastomoses. The radial forearm flap also provides thin, pliable tissue that adapts well to the foot contour, allowing patients to wear normal footwear without needing secondary surgeries. All patients with radial forearm flaps completely recovered with good flap uptake and no complications[27].

The existing literature showed results comparable to our study on diabetic foot ulcers and flap surgeries. An algorithm-based approach described by Armstrong et al.[28] incorporated debridement, infection control, vascular assessment, and reconstruction, achieving a 96% limb salvage rate, emphasizing a comprehensive management protocol with multidisciplinary care being integral to improving patient outcomes. While we excluded cases with peripheral vascular disease due to its confounding effect on flap survival, Randon et al.[29] examined 55 patients undergoing combined arterial reconstruction and free flap transfers with a limb salvage rate of 80%, lower than our current study's 97.5%. Similarly, a prospective study by Azhar et al.[30] highlighted the impact of peripheral arterial disease (PAD) on limb salvage, with amputation rates reaching 53.8% in PAD-associated diabetic ulcers and highlighting the possible context of PAD that may account for this discrepancy.

Although many flaps are available for lower limb defects, several factors influence the outcome, including lower limb vascularity, bony deformities, and diabetic control. Our study demonstrated the potential to salvage diabetic feet using appropriate soft tissue procedures. Successful ambulation was defined as the ability to walk independently or with assistance. All our patients achieved independent ambulation within 3-6 months postoperatively. While our study showed successful flap outcomes with minimal complications, wound management does not end with surgery. We successfully converted Ganga Class 3 diabetic feet to class 1, as evidenced by postoperative pedobarograms. Patients were prescribed off-loading modified footwear and taught proper foot care to prevent ulcer recurrence.

Limitations of our study included a small patient population and a selection bias due to the retrospective study design. Although we assessed flap outcome and disease progression, we did not include quality of life measures on long-term follow-up, which can be a potential study area in the future. Strengths of the study include cases involving a wide spectrum of disease severity, from small ulcers to large soft tissue defects, and diverse surgical approaches that can be performed for each type of ulcer based on its location and size. Additionally, surgeries performed by a single senior specialist remove any confounding factors that may have caused the difference in surgical quality. Lastly, the long-term follow-up with a subsequent pedobarogram completes the follow-through of the surgical procedure.

Conclusion

Our study highlights the spectrum of the diabetic foot that can be effectively managed surgically, regardless of ulcer location or size. Diabetic feet can—and must—be salvaged. However, surgery is one of many challenges in the broader fight against this condition. A holistic approach is essential, encompassing strict diabetic control and adherence to postoperative modified footwear to ensure optimal long-term outcomes.

Authors' contributions: Each author contributed individually and significantly to the development of this article: LL *(https://orcid.org/0009-0005-2213-8988) Conceived and planned the activities that led to the study, interpreted the results of the study, performed the surgeries, data collection, statistical analysis, survey of the medical records, approved the final version and wrote the article; AXJ *(https://orcid.org/0000-0002-3604-5863) Conceived and planned the activities that led to the study, interpreted the results of the study, data collection, statistical analysis, survey of the medical records, approved the final version and wrote the article; MMA *(https://orcid.org/0009-0003-6554-6370) Conceived and planned the activities that led to the study, interpreted the results of the study, performed the surgeries, data collection, statistical analysis, survey of the medical records, approved the final version and wrote the article; TM *(https://orcid.org/0009-0001-4417-4454) Data collection, statistical analysis, survey of the medical records; VA *(https://orcid.org/0009-0008-1839-6118) Conceived and planned the activities that led to the study, interpreted the results of the study, approved the final version and wrote the article. All authors read and approved the final manuscript. *ORCID (Open Researcher and Contributor ID) iD.

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