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SUPPLEMENT ARTICLE

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Surgery for the diabetic foot: A key component of care

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Abstract

Surgery for acute and chronic diabetic foot problems has long been an integral component of care. While partial foot amputations remain as important diabetic limb-salvaging operations, foot-sparing reconstructive procedures have become equally important strategies to preserve the functional anatomy of the foot while addressing infection, chronic deformities, and ulcerations. A classification of types of diabetic foot surgery is discussed in accordance with the soft tissue status and acuity of the presenting foot problem. This brief overview from the Association for Diabetic Foot Surgeons describes common conditions best treated by surgical interventions, as well as specific indications. While techniques and indications continue to evolve, effective surgical management of the diabetic foot remains an integral component of care as well as for the prevention of recurrent ulceration.

KEYWORDS

Charcot, diabetic foot, infection, surgery, ulcers

1 | INTRODUCTION

Surgical management for diabetic foot disorders and complications is not a new concept born out of an enhanced understanding of underlying pathophysiology or of recent technological advancements. To the contrary, the medical literature is replete with such reports going back at least 70 years. While our understanding of the diabetic foot 'syndrome' has certainly improved and our surgical techniques and instrumentation have similarly advanced, surgeons of the mid-20th century recognized the importance of appropriate surgical interventions as alternatives to major lower extremity amputation.

McKittrick and associates from the Deaconess Hospital in Boston, Massachusetts, United States published the first large series of transmetatarsal amputations in 1949.[1] They were applauded for their 67% success rate and low in-hospital mortality in an era where major lower extremity amputation was more the norm for even gangrene of the toes. In the 1950s, 1960s, and 1970s interest developed in foot sparing operations focusing on local resections of infected underlying bone and metatarsal heads for neuropathic ulcers in both the United Kingdom and the United States.[2-5] It was even recognized in that era that the diabetic Charcot foot was also amenable to surgical reconstruction when accompanied by chronic ulceration or severe deformity.[6-8] Such procedures are now rather commonplace in multidisciplinary diabetic foot teams and are frequently recommended in clinical practice guidelines and protocols.[9-12]

Structural deformity with attendant high plantar pressures is a predisposing risk factor to diabetic foot ulceration (DFU) development and recalcitrance in the neuropathic foot.[13-15] Furthermore, feet with deformities that cannot be adequately offloaded by footwear therapies are at high risk for DFU recurrence.[16] Common deformities contributing to development of DFU include hammertoes, prominent metatarsal heads, hallux limitus, gastrocnemius-soleus equinus, Charcot foot, and partial foot amputations.[17] Each leads to high plantar or in-shoe pressures that contribute to tissue inflammation and subsequent break-down. Ameliorating these high pressures by structurally realigning or removing underlying bony prominences is the underlying rationale for foot surgery. In the presence of infection and/or osteomyelitis, surgery frequently becomes a critical component of care.[18] Although the current Guideline on interventions to enhance the healing of diabetic foot ulcers concentrates primarily on *non-surgical* modalities,[19] our premise remains that surgery generally plays a key role in the overall management of DFU.

Accordingly, several authors have proposed a risk-based scheme for classifying the types of foot surgery performed in diabetic patients largely depending upon the presence of open wounds and their acuity.[20,21] Each class of foot surgery is distinguished not only by its wound status but also by its risk for subsequent amputation[22] (Table 1). *Elective surgery* (Class I) refers to reconstructive procedures performed to correct deformities or high plantar pressures in persons *without* neuropathy and generally in those without prior history of ulceration. *Prophylactic* (Class II) procedures are those performed in neuropathic patients to reduce the risk of ulceration or recurrent ulceration in the absence of open wounds. When open wounds are present, *Curative surgery* (Class III) is often performed to provide a cure by joint resection, removing underlying bony prominences (surgical decompression), osteomyelitis, or by draining underlying abscesses. (Figure 1) Obviously, such procedures are at higher risk for non-healing or infection than are the former two classes. *Emergent* procedures (Class IV) are performed for severe or ascending infections (wet gangrene, necrotizing fasciitis, etc.) to control the progression of infection. As the name implies, these procedures are performed emergently and usually consist of open amputations at the foot level with attendant fasciotomies of the leg.[17,23]

TABLE 1 Classification of diabetic foot surgery

Class I	Elective	Reconstructive procedures on patients without neuropathy. Examples: Hammertoe, bunion, osteotomy, Achilles lengthening (TAL), etc.
Class II	Prophylactic	Reconstructive procedures performed to reduce the risk of ulceration or re-ulceration in neuropathic patients who do not have a wound present. Examples: Keller arthroplasty, TAL, Exostectomy, Charcot reconstruction, etc.
Class III	Curative	Procedures performed to assist in healing of open wounds. Examples: Metatarsal head resection, Keller arthroplasty, toe amputation, etc.
Class IV	Emergent	Procedures performed to arrest or limit progression of infection. Examples: Incision & drainage, Guillotine/open amputation, fasciotomy, etc.

1.1 | Surgical management of diabetic foot attack

Most infected DFUs respond well to local debridement, administration of culture specific antibiotics and offloading of the foot in a brace or cast. Some develop rapid spread of infection along the tissue planes and tendon sheaths and present with local tissue necrosis, spreading cellulitis and systemic inflammatory response. These can potentially be limb threatening without timely intervention as delay will lead to further tissue loss. The concept of 'time is tissue' is applicable to such infection, which is labelled as a 'Diabetic Foot Attack'.[23]

The management of diabetic foot attack is best delivered in a multidisciplinary setting using a structured approach. The management principles are as follows:

1.1.1 | Diagnose infection rapidly

A thorough clinical assessment, including the vascular examination and routine investigations often help achieve the diagnosis. The serum

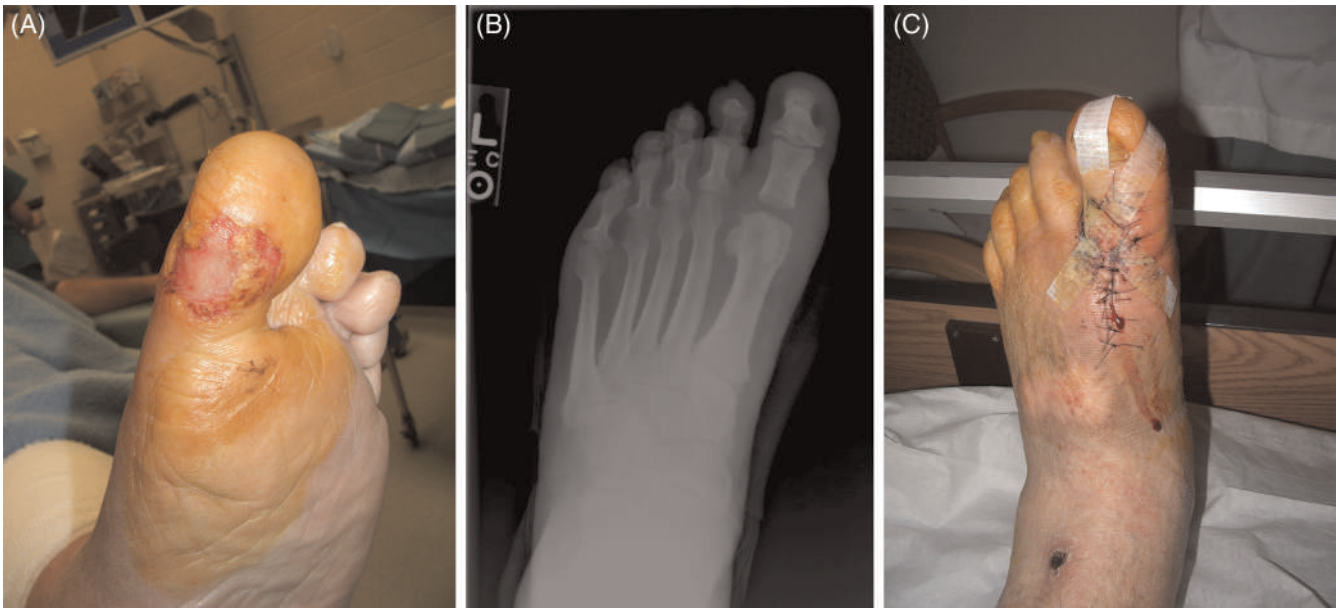

FIGURE 1 Keller arthroplasty performed for hallux limitus with plantar hallux ulcer to reduce plantar pressure. A, Pre-operative chronic hallux ulcer. B, Post-operative X-ray showing resection of hallux proximal phalangeal base. C, Post-operative image showing the typical dorsal incision

C-reactive protein level is frequently elevated to greater than 100 mg/L. Ultrasound examination can immediately assess the presence of deep soft tissue fluid collections and osteomyelitis. Plain radiographs, magnetic resonance imaging (MRI), computed tomography or bone scintigraphy can also determine presence of osteomyelitis and/or soft tissue infection spread along the tissue planes.

1.1.2 | Identify bacteria responsible

Obtain deep tissue specimens for aerobic and anaerobic microbiological cultures prior to starting intravenous antibiotics.[24] Ultrasound guided aspiration can be considered for microbiological cultures if there is any clinical or MRI evidence of deep collection and if this does not lead to any further delay in surgical debridement.

1.1.3 | Aggressive antibiotic therapy

Initiate appropriate empirical intravenous antibiotic therapy soon after obtaining tissue samples, based on the previous microbiological cultures on the same patient if available or as per the local hospital protocols. The antibiotics are then changed further, if required, based on the microbiological sensitivities of deep tissue cultures.

1.1.4 | Emergent surgical debridement

Surgery for diabetic foot attack is a Class IV procedure. Aggressive and radical surgical debridement consisting of exposing all infected tissue planes and removal of infected and necrotic bone and soft tissues should be performed soon after the diagnosis. Any associated instability due to bone resections can be managed with a temporary stabilization using threaded wires passed across the bones, external fixator, or a windowed cast. Deep soft tissue and bone specimens are obtained for microbiology cultures. Repeat surgical debridement is performed if there is progressive tissue necrosis or further deep infection.

Targeted intravenous antibiotics are continued until complete infection clearance is achieved. The multidisciplinary team (MDT) should aim to achieve complete healing of the wound in a timely manner and various methods can be used to achieve this; including negative pressure wound therapy (NPWT), followed by skin grafting or a similar form of plastic surgical procedure, depending on the extent of the wound and its location. Any subsequent instability or deformity in the foot and ankle can be managed with a brace, cast or surgical stabilization procedure.

1.2 | Charcot foot

The surgical management of diabetic Charcot neuroarthropathy continues to evolve.[25,26] The indications for surgery include deformities that cannot be accommodated in a brace, non-healing wounds, recurrent wounds, pain and gross instability. The traditional dogma of not performing surgery during the active phase of Charcot has been challenged by a number of surgeons over the past several years. Historically, high failure rates of early surgical intervention were attributed to the acute inflammatory response, manifesting in edema and hyperemia. Over the past several decades, advancement in methods of fixation has resulted in improved outcomes and some experienced surgeons advocate early stabilization. These improvements have been developed in both internal and external fixation techniques. Several Charcot specific implants have been developed, and while long term results are not available, short term results are promising. External fixation can be applied in a static or dynamic method, offering the opportunity for gradual correction if needed. The optimal method of surgical fixation remains inconclusive, especially in patients without wounds or a history of infection. Some experienced authors use only internal fixation, others use only external fixation while others use a combination of fixation methods. Regardless of the specific method, surgical treatment generally utilizes realignment arthrodesis incorporating soft tissue releases, osteotomies and partial ostectomies as needed.[27] In addition, fixation needs to be more robust to withstand the stresses unknowingly applied by neuropathic patients. There does not seem to be much debate in the face of active infection, albeit soft tissue or osteomyelitis. In this situation, the stabilization method of choice is external fixation, and most authors recommend avoiding any permanent type of internal fixation. There is also a debate as to whether to perform a single stage correction vs two stage correction in patients with infection. A systematic review published in 2016 demonstrated improvement in the quality of evidence regarding surgery and Charcot, and now more evidence from controlled studies is available for guidance.[27,28]

The ideal perioperative care of the Charcot patient should include an MDT due to the comorbidities commonly associated with Charcot. Patients often have concurrent coronary artery disease, poor glycemic control, diabetic nephropathy and neuropathy (motor, sensory and autonomic). There appears to be increasing evidence that Charcot patients may have subclinical peripheral artery disease and this is important to recognize prior to intervention.[29] Appropriate nutritional assessments and assessment of bone health is essential. Patients with diabetes in general often have vitamin D deficiency that should be corrected prior to surgery. Preoperative and postoperative outcomes should be assessed.

Attendance at a pre-surgery educational class is also of great help in order to establish appropriate expectations. This has been extremely effective in other areas of surgery, such as patients who undergo total joint arthroplasty. In addition, preoperative rehabilitation is beneficial to strengthen core muscle groups and teach the optimal methods of gait training in patients who are going to be non-weight bearing for a protracted period. This can be especially challenging in obese patients who have balance issues due to motor and sensory neuropathy. In summary, medical optimization, education and realistic outcomes should be addressed prior to embarking on this complex patient population.

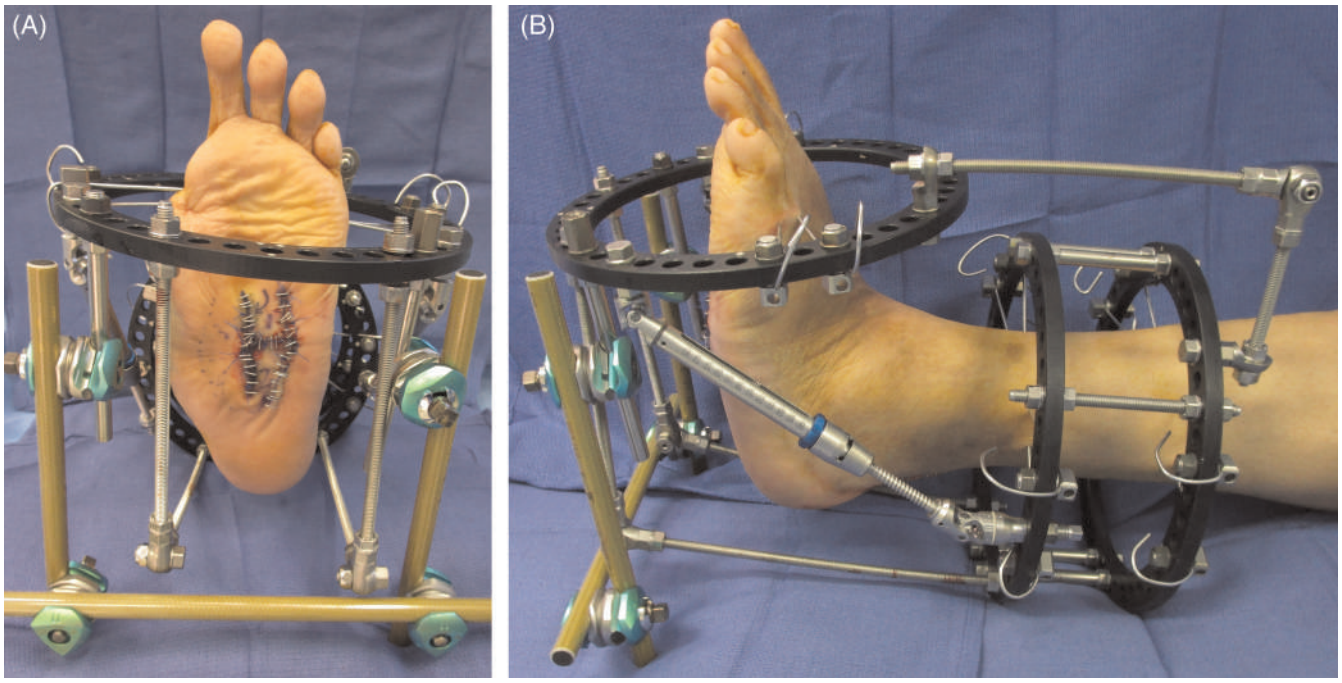

FIGURE 2 Intraoperative clinical pictures demonstrating the podoplastic approach by combining an open tendo-Achilles lengthening, double local random rhomboid flap closure, and circular external fixation for the treatment of a chronic non-healing wound in a patient with diabetic Charcot neuroarthropathy. A, Plantar view. B, Lateral view

1.3 | Podoplastic procedures for addressing diabetic Charcot soft tissue and/or Osseous defects and deformities

Untreated acute or chronic diabetic foot wounds can lead into soft tissue and osseous infections, necrotizing fasciitis, gas gangrene with systemic manifestations, amputation, and cardiovascular complications. Early and prompt medical and surgical treatment in the presence of a moderate and/or severe diabetic foot infection is paramount for the overall patient's successful outcome. Medical optimization and consultation to the appropriate specialties with an interest in the diabetic foot followed by diabetic limb salvage procedures are best performed in a large healthcare and/or academic centre. Surgical treatment of diabetic foot infections and osteomyelitis may lead into major resected soft tissue and/or osseous defects that need further staged reconstruction for definitive wound closure. Staged surgical interventions in the setting of acute or chronic diabetic foot complications are not uncommon and are performed within the setting of an MDT approach.

Various wound closure procedures in the soft tissue reconstructive pyramid for the treatment of the diabetic foot include NPWT, allogeneic skin graft substitutes, autogenous skin grafting, local random, muscle, pedicle/perforator and free flaps.[30] In cases of diabetic foot osteomyelitis with or without Charcot neuroarthropathy, osseous resection of the infected bone and/or joints can lead to large osseous defects that might require staged treatment with or without local antibiotic beads/spacers, bone grafting and circular external fixation.

The podoplastic approach describes the combined method of utilizing the circular external fixation system with plastic surgical closure techniques in the diabetic Charcot neuroarthropathy.[31] Such foot and ankle deformities with concomitant osteomyelitis are best managed in a staged surgical approach by first eradicating the presence of any soft tissue and/or osseous infection and followed by the definitive surgical reconstruction. Circular external fixation can be ideal for surgical treatment by providing the necessary stabilization, compression, deformity correction and surgical offloading.

In the podoplastic approach for diabetic foot wounds, circular external fixation can also play an important role as an adjunct to surgical equinus correction (tendo-Achilles lengthening or Gastrocnemius recession). Furthermore, the utilization of circular external fixation becomes exemplary in the setting of major plastic surgical closure techniques in the diabetic foot and ankle by surgically offloading the extremity throughout the postoperative period (Figure 2).

Finally, circular external fixation application in the setting of plastic surgical closure in the diabetic foot, allows for elevation and stabilization of the lower extremity with less movement around the flap. It also provides for direct visualization and monitoring of the flap closure, decreases lower extremity edema while offloading the extremity without any weight-bearing.

2 | CONCLUSIONS

The surgical management of diabetic foot disorders ranges from minor procedures to address foot ulcers, to major reconstructive procedures

which address Charcot deformities and associated soft tissue defects. Paramount in this decision tree is to recognize and treat soft tissue and bone infections at their earliest presentation. Successful outcomes of surgery require an MDT to holistically manage the entire patient. Providers who are not surgeons play an important role in managing glycemic control, cardiovascular disease, nutrition, renal disease, and wound care. Ideally, specialists in orthotics and prosthetics should collaborate with surgeons to provide optimal footwear, bracing, and offloading after healing has occurred. Equally important, these patients are at high risk for subsequent ulcerations or other pedal complications and require ongoing surveillance at regular intervals by the MDT as part of an integrated prevention-oriented program.

CONFLICT OF INTEREST

All authors report no conflicts of interest in the writing of this manuscript.

AUTHOR CONTRIBUTIONS

R.G.F., D.K.W., V.K., and T.Z. wrote and edited the manuscript. L.D.P. provided guidance in the concept of this review and made critical edits to the manuscript. All authors have read and approved the final manuscript.

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