Operative Debridement of Diabetic Foot Ulcers

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Every year, the incidence of diabetes increases, and an estimated 366 million people worldwide will be affected by 2030.[1] Because of multiple physiologic impairments[2] such as decreased angiogenesis or other microcirculatory conditions[3,4] and neuropathy, routinely treatable wounds in patients without diabetes often become chronic, nonhealing wounds in patients with diabetes, posing serious risk for infection, sepsis, and amputation.[5] Diabetic foot ulcers (DFUs) occur in approximately 15% of patients with diabetes, and of these, 14% to 24% of ulcers will end in amputation.[6] Amputations in patients with diabetes are associated with a high morbidity and a 5-year survival rate of 31%.[7]

Sharp debridement of the diabetic foot ulcer stimulates the nonmigratory edge epithelium, releases growth factors, and reduces the local inflammatory and proteolytic environment.[8-10] The goal of operative debridement is to remove all hyperkeratotic tissue (ie, callus), necrotic tissue, functionally abnormal senescent cells, and infected tissue, all of which inhibit wound healing.[10-12] In this manner, the remaining tissue, although physiologically impaired, can respond to exogenous topical treatment, (ie, growth factors or cell therapy).

Debridement is widely accepted as the most definitive treatment for the diabetic foot ulcer,[13,14] and although it is mentioned in guidelines, protocols, and consensus statements,[13,15-17] there remain few established descriptions of the procedure.[18-20] Inadequate debridement may lead to prolonged infection, increasing risk for limb amputation. The objective of this study and accompanying video was to detail an operative procedure for debridement of diabetic foot ulcers based on biologic principles.

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METHODS

The technique described represents the key steps we found after reviewing 280 operative debridements, which were performed on 178 consecutive patients. Once a patient is admitted for surgery, an interdisciplinary team of surgeons, primary care physicians, nurses, social workers, nurse practitioners, and physician assistants implement published protocols and guidelines.[15,16,21-25] The wounds are also examined, photographed, measured, and documented in the Wound Electronic Medical Record (WEMR) database. Patients were identified using the Wound Electronic Medical Record and operative notes for each operation reviewed.

RESULTS

Operative technique

Excision of callus and skin edge, routine pathology

Callus refers to nonviable, hyperkeratotic tissue, and is common to diabetic foot ulcers. The presence of callus can prevent healing and can also create increased pressure from footwear or improper gait in the neuropathic diabetic foot, ultimately leading to further ulceration.[26] The entire callus is resected with a sharp scalpel and further debridement should extend to the soft tissue adjacent to the callus (Fig. 1A). The clinical margin of debridement should be confirmed by pathology and should not include epidermis with significant hyperkeratosis or parakeratosis as is seen in Figure 1B. The solid line in Figure 1E represents the margin of callus, but debridement should extend to the dashed line, soft normal appearing skin.

Assessment of undermining and removal of the overlying tissue

Although most commonly associated with pressure ulcers, undermining may also occur in diabetic foot ulcers. Although assessment for undermining before debridement is usually done, occasionally undermining is not apparent until after the initial callus has been removed. Undermining is the destruction of tissue or ulceration extending under the skin edges so that the ulcer is larger at its base than at the skin surface. A sterile cotton swab can be used to gently examine the wound for evidence of undermining (Fig. 1C). Undermining should be exposed by surgically

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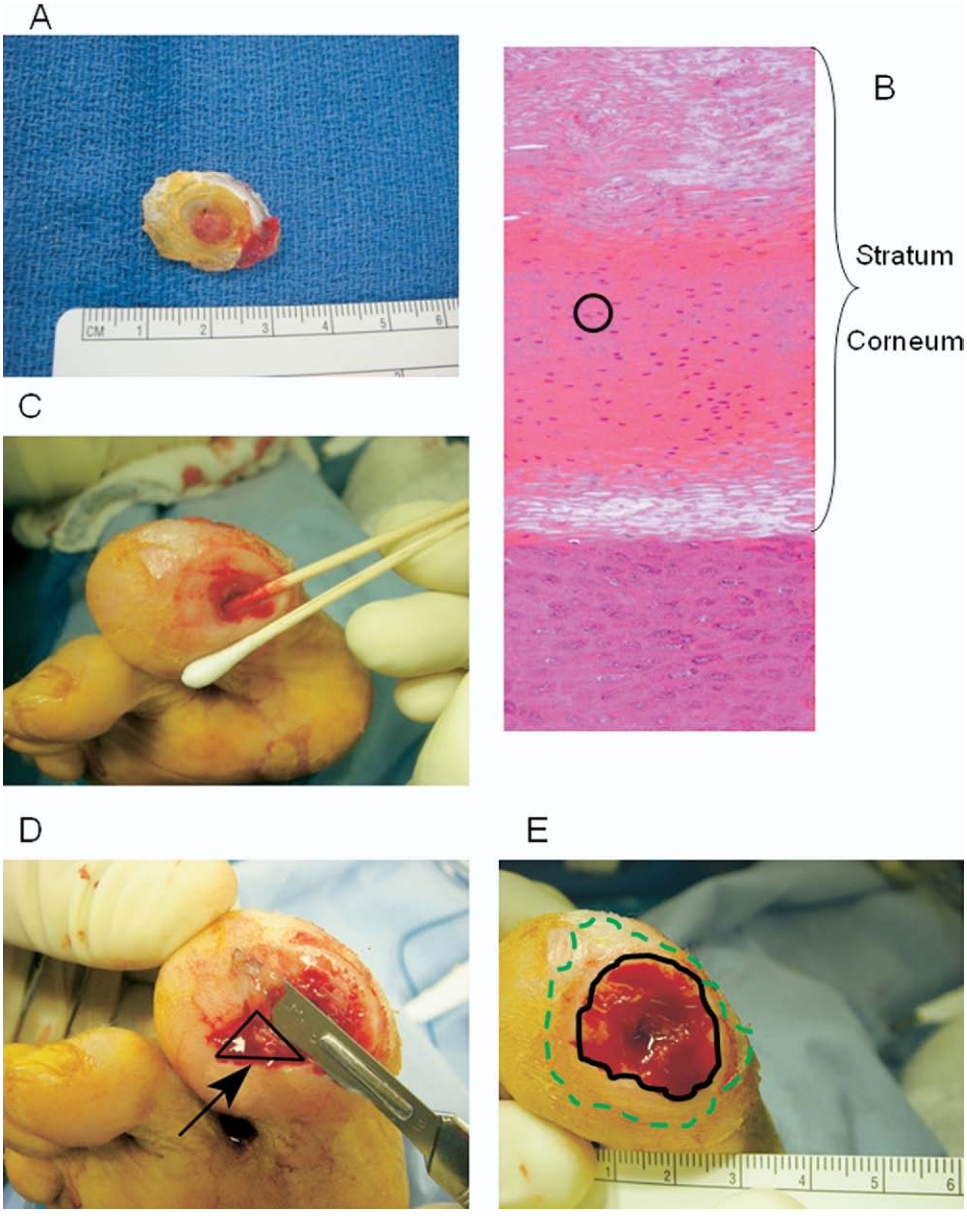

Figure 1. (A) The gross appearance of the callus after excision using the technique demonstrated in Video 1. (B) A routine hematoxylin and eosin stain of the callus, which is histologic, thickened stratum corneum. Parakeratosis is noted by the presence of nuclei (small purple dots) in the stratum corneum. (C) After removal of the callus, 2 cm of undermining was discovered in the operating room, as indicated by the depth of the cotton swabs. (D) Preparation for excision of undermined tissue. (E) The wound after excision of a triangular portion of undermined tissue. The base of the triangle is toward the center of the ulcer and the apex, toward the normal appearing tissue. The solid lines represent the border of callus; debridement should be extended to soft epidermis, just beyond this border, represented by the dashed line.

resecting the overlying tissue. It is important to remove the least amount of healthy tissue needed to expose the underlying wound bed (Fig. 1D). By using a triangular incision, with the apex of the triangle at the deepest point of undermining, the entire wound bed can be exposed.

Removal of clinically infected soft tissue and bone from the wound and routine pathology

Debridement of the wound should proceed from superficial to deep in a fashion parallel to the wound bed. First, the necrotic skin should be removed. Next is the

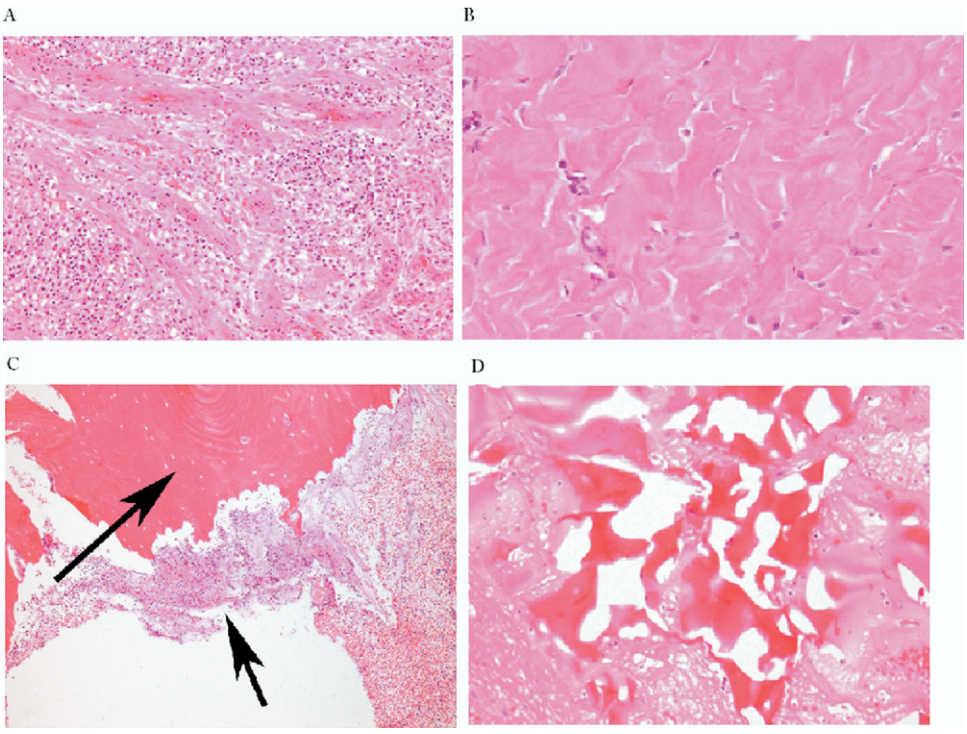

Figure 2. (A) Hematoxylin and eosin (H&E) stain of the wound bed showing granulation tissue as evidenced by numerous cells in addition to newly formed blood vessels. (B) H&E stain of the same patient's wound at a different level showing fibrosis, characterized by acellular woven strands of collagen. This tissue should be surgically removed, with the goal of reaching and stimulating granulation tissue seen in Figure 2A. (C) Acute osteomyelitis: H&E stain of bone from the metatarsal region on a previous debridement. The top arrow points to viable bone; the lower arrow points to exudate of inflammatory cells, including neutrophils, lymphocytes, and plasma cells. Treatment should include further debridement after antibiotic treatment to ensure that either healthy or reactive bone is confirmed by pathologic analysis. (D) Reactive bone, which is characterized histologically by woven bone with osteoclastic or osteoblastic activity, depending on the stage of the remodeling and is considered healing bone.

subcutaneous layer, including fat and connective tissue. Adjacent fascia, tendon, and muscle should be examined for any evidence of spreading disease and infection, and can be easily excised, as demonstrated in Video 1. A biopsy of the tissue left after this primary debridement is sent for both pathologic and microbiologic analysis. The optimal margin of debridement is where the tissue left behind after removal of all clinically infected and necrotic tissue is free of infection and scar. Routine hematoxylin and eosin (H&E) staining of wound specimens is useful to identify cellular granulation tissue (Fig. 2A) versus the acellular, woven collagen fibers typical of fibrosis (Fig. 2B). Debridement should go down to bone if necessary, as Video 2 demonstrates in the metatarsal wound. A earlier debridement on the patient had shown acute osteomyelitis (Fig. 2C), but after further treatment with antibiotics and sharp debridement, noninfected bone, ie, reactive bone, was seen (Fig. 2D).

Dressing and postoperative followup

The remaining wound bed is treated with a primary hemostatic agent, such as fibrin sealant and collagen, which has been shown to reduce intraoperative and postoperative bleeding.[31] Because minimal drainage is expected, the wound is dressed in Kerlix gauze (Covidien), which is left up to 7 days. In the presence of infection (ie, increased white blood cell count, cellulitis, or drainage), the patient is treated with broad spectrum systemic antibiotics, which are then tailored to the microbiology results. Once discharged, the patient is followed weekly in the outpatient setting to assess healing rates.

In preliminary studies, we found a generalized decrease in wound area and amputation rate in our case series of 178 patients. These data endpoints are currently the subject of a multicenter study and further review will be needed to determine if the data will indeed significantly reflect the trends we have seen so far at our institution.

DISCUSSION

Clinical judgment in itself is often not sufficient to determine if all abnormal tissue has been removed from a foot ulcer in a person with diabetes. The margin of debridement of the skin edge should extend to the soft tissue beyond the callus. The depth of debridement of the wound bed should extend to tissue that is free of fibrosis and infection, eg, osteomyelitis, as confirmed by pathology and microbiology.

The accompanying figures and video illustrate the key portions of operative debridement of diabetic foot ulcers. Although the concept of debridement of a wound until only normal, soft tissue remains and culture and pathology analysis has been advocated,[13] precisely how this is achieved has not been described exclusively in foot ulcers in persons with diabetes. Saap and Falanga[12] developed a debridement performance index that includes callus, undermining, and wound bed necrotic tissue. Falanga[27] noted the importance of the goal of debridement down to well-vascularized tissue free of scar. In this report, we have built on these ideas to present practical, biologically based techniques of diabetic foot ulcer debridement.

Clinical judgment has traditionally defined the margin of debridement, which is recognized as tissue with punctuate bleeding.[13] Although pathology has been advocated in wound care,[28] specific abnormal histopathologic findings have not been a focus of intensive discussion.

Excision of the skin edge to the point where clinically viable tissue is reached should be confirmed by routine H&E staining. Figure 1 highlights Mr X, a 74-year-old man with type 2 diabetes, coronary artery disease, and hypertension. He presented with nonpurulent drainage of a right great toe ulcer, had chronic osteomyelitis based on MRI and x-ray findings, and was growing methicillin-resistant *Staphylococcus aureus* on culture, so operative debridement was indicated. The technique described for callus removal is regularly included in protocols as a measure of adequate debridement.[12] The excised callus revealed hyperkeratotic squamous epithelium with mildly inflamed dermal tissue (Fig. 2). The outer edge, clinically normal appearing skin, was sent for pathologic analysis, revealing benign squamous epithelium and underlying dermal tissue. Any area of tissue that contains hyperkeratosis or parakeratosis likely represents incomplete keratinocyte differentiation, so is pathologic and should be excised.[29] Pathologically, hyperkeratosis is defined as an increase in the thickness of the stratum corneum. Hyperkeratosis may be either orthokeratotic or parakeratotic in nature. Orthokeratotic hyperkeratosis is an exaggeration of the normal pattern of keratinization (ie, no nuclei are seen in the stratum corneum). In parakeratotic hyperkeratosis, nuclei are pathologically retained in the stratum corneum.[30] Examples of parakeratosis are visible in Figure 1B.

Pathologic specimens are examined by the surgeon to allow correlation between clinically appearing negative margin and definitive pathologic analysis. To gain the proficiency necessary to differentiate between parakeratosis, hyperkeratosis, and normal epithelium, a strong relationship between the surgeon and the pathology department is essential. Repetition of this correlation will allow surgeons to more adequately assess the margins of resection clinically, with anticipation that this will allow definitive debridement in one operation. Secondarily, analysis of the pathologic specimens does provide the necessary information to define an adequate debridement and allow the surgeon to determine if a second debridement is necessary. But the primary objective is to gain the experience to provide a complete debridement in one operation using a combination of pathologic analysis and clinical judgment. In our experience, it is estimated that for a surgeon with no experience in skin pathology, it would be necessary to perform approximately 50 procedures and pathologic analyses before gaining clinical proficiency. Once attained, the surgeon will gain the ability to perform a thorough and adequate debridement with fewer operative interventions.

Although assessment of undermining may be clinically encountered more often in pressure ulcers and is part of routine physical examination, it can be occasionally encountered in diabetic foot ulcers, particularly if clinical suspicion is high for osteomyelitis. Armstrong and colleagues[18,19] stress the importance of removing undermined tissue, and they describe a circumferential technique of excision. Although this technique certainly removes skin over undermining, it may also remove excess normal tissue. The case of Mr X illustrates the triangular technique of removal of undermining. He had an area of undermining along the wound edge of the right toe, extending approximately 2 cm. A triangular excision planned with the base of the triangle on the wound edge and the apex extending into normal tissue, is useful to minimize the amount of normal tissue resected, but at the same time expose any undermined area (Fig. 1C). Without excising this overlying skin, access to the wound bed is limited, so healing may be delayed. Further study is needed to evaluate the efficacy of this technique.

It is apparent that there are several clinical scenarios in which such an operative technique may appear to be less desirable, such as in patients with severe peripheral vascular disease. This technique of operative debridement would be contraindicated without evaluation by a vascular surgeon and assessment for possible intervention. In such cases, it is important to note that there is not only one specific defin-

itive debridement, and this technique can be tailored to the patients' medical condition while still removing all pathologic tissue. As previously noted, by removing all pathologic tissue, the wound is increasingly stimulated to heal. To perform a lesser debridement and leave pathologic tissue would only further impair an already susceptible patient's ability to heal a very complex wound. A key to this technique is first identifying patients with ischemia or otherwise complicating medical factors and discussing with them in detail the risks associated with such a procedure. The primary risk with this technique is postoperative bleeding. Although potential complications in addition to bleeding, such as risk of infection or progression to amputation, are always present, especially with a larger wound, it is our experience that providing these patients with a wide and deep debridement will give them the best possible chance of healing.

Soft tissue and bone debridement techniques are featured in the video. Mrs Y is a 46-year-old woman with type 2 diabetes mellitus who presented with bilateral large blistering plantar ulcers. Her past medical history was relevant for congestive heart failure, hypertension, and chronic renal insufficiency. Her initial wounds each measured more than 12 cm^2 in area. Her wounds were debrided in the operating room on multiple occasions using the techniques described earlier, until complete closure was achieved. Soft tissue cultures from the right foot grew *Proteus mirabilis*, *Staphylococcus aureus*, and *Morganella morganii.* Quantitative cultures of the right fifth metatarsal bone revealed more than 10 million gram-negative rods and more than 10 million gram-positive cocci in clusters.

Mr Y's pathology illustrates two key findings in the bone. Normally, bone is surrounded by adipose and connective tissue. Osteomyelitis should be distinguished clinically from reactive bone. Histologically and microscopically, osteomyelitis is characterized by an admixture of inflammatory cells (including neutrophils, lymphocytes, and plasma cells surrounding what is often viable bone. The term *reactive bone* pertains to new bone formation or bone remodeling, which histologically is characterized by woven bone with osteoclastic or osteoblastic activity depending on the stage of the remodeling.[30] Bone debridement should extend until there is an absence of infection and fibrosis as confirmed by pathology.

In the field of surgical oncology, surgeons have traditionally used multiple histopathologic and molecular markers to identify a "negative margin." In the future, surgeons may be able to use molecular markers of chronic wounds such as the oncogenes c-myc and β-catenin to identify impaired cells and guide debridement.[29] Because the goal of debridement is to remove physiologically impaired cells, an assay similar to a frozen section to define the extent of debridement could accelerate healing. Similar to a Moh's procedure, wound surgery may one day be guided by the regulation of genes at the wound edge.

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