Wound Care Center of Excellence: Guide to Operative Technique for Chronic Wounds

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Wound surgery is a well-established modality for the treatment of chronic wounds. Surgical debridement is an essential, integral part of wound care management[1-4] and the wound service is often an appendage of other departments, such as surgery, nursing, or geriatrics. However, the specifics of surgical management of chronic wounds are often not well-defined. To have a full-time practice of 4 wound surgeons, we found it necessary for the sake of continuity of care to use agreed-on techniques for goal-directed therapy. We have built a dedicated wound surgery service and, in this article, we discuss the operative techniques used by 4 specialized wound physicians in 3,717 consecutive operations from 2012 to 2016 for the management of chronic wounds at a tertiary care facility. Table 1 is a summary of our wound practice.

OPERATIVE PRINCIPLES, INDICATIONS, AND RATIONALE

The general principles of debridement are centered around the maintenance of a healthy wound bed, for example, removal of necrotic tissue and callus (Fig. 1). Many patients can undergo debridement in the office, such as those with small wounds, well-controlled or no comorbidities, minimal pain, and who are non-anticoagulated. However, we believe that there are several indications for performing wound procedures in the operating suite and only a few contraindications (eg not medically optimized, patient declines consent). Frequently, the pain associated with debridement is not tolerated by patients if performed in the office. However, in the operating suite, anesthesiologists are available to provide monitored IV pain relief. The operating suite is also a safer option for patients who are taking anticoagulation therapy and might have uncontrollable bleeding in the office. In the operating suite, the anticoagulant might not have to be held before the procedure, and the surgeon has more options available for obtaining hemostasis of the wound bed. Another indication for operative debridement is infection. Patients with a local or systemic infection from a wound source that is not controlled with office-based wound debridements should undergo additional debridement in the operating suite, along with administration of IV antibiotics. Concurrent imaging can also identify an underlying infection (eg osteomyelitis) that is preventing the wound from healing. The operating suite setting allows for thorough debridement and procurement of deep pathologic specimens of the remaining tissue, which helps target future therapy. In addition, an adequate, sterile, deep-tissue culture is facilitated during the procedure for micro-organism-specific antibiotic therapy.

Before undergoing operation, all patients are optimized, which includes correction of metabolic perturbations.[5,6] We emphasize that in the critically ill patient (eg the septic patient with diabetes), source control in the operating suite is often the most effective technique for medical optimization. When ischemia is suspected in lower-extremity ulceration, patients with risk factors such as diabetes, hyperlipidemia, hypertension, and obesity are assessed using ankle-brachial index and pulse volume recording, noninvasive tests that help identify significant peripheral arterial disease. An ankle-brachial index <0.9 or >1.3,[7,8] or pulse volume recording waveforms with a loss of the dicrotic notch, decreased amplitude, dampened contour with broad, rounded peaks, and equal upstroke and downstroke times,[9,10] are indicative of lower-extremity ischemia. Patients are then referred to vascular surgery for evaluation and possible intervention.

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Table 1. Wound Service Overview

Variable	Data
Visits in wound clinic, n	38,756
Admissions to wound service, n	1,081
Total inpatient consults, n	2,151
Mean length of stay, d	
Wound service patients	6.5
Consult patients	11.8
Mean cost of hospital admission, $	25,570
5 most common primary ICD-9 codes for patients admitted to the wound service	682, 707, 250, 785, 459*
30-d readmission rate, %	19.3
Operating suite, n	
Total cases performed by all departments	114,099
Total cases performed by wound service	3,717
Total debrided in wound clinic, n	6,021

Summary of patients seen by the Wound Service from January 1, 2012 to December 31, 2016.

*682, other cellulitis and abscess; 707, chronic ulcer of skin; 250, diabetes mellitus; 785, symptoms involving cardiovascular system (eg gangrene); 459, other disorders of circulatory system (eg venous stasis ulcers).

In our practice, goal-directed therapy included provider credentialing, recommending debridement depth, and reviewing cases at a weekly conference. Each member of the group was credentialed by performing 10 proctored cases before independent operation on wounds (eFig. 1 illustrates the credentialing sheet used at our institution). Credentialing was not an institutional requirement. Other providers (eg podiatrists, general surgeons) also performed debridements; however, we believe that optimization of patient outcomes on the wound service is improved with targeted, goal-directed therapy. Wound procedures performed by other providers at our institution without this specific credentialing were not included in these data.

ANESTHESIA

Depending on patient status and wound location, surgical cases are booked for roughly 1 to 3 hours. Relatively uncomplicated patients presenting for elective debridement of a small wound might require less time compared with patients presenting emergently with sepsis or complex wounds that might require more time in the operating suite. Discussions are held among the anesthesia provider, surgeon, and patient to determine the appropriate type of anesthesia that will be used. Physician avoidance of more aggressive operative debridements in high-risk patients can be offset by an experienced anesthesiologist-surgeon team. This wound service was served by a subset of anesthesiologists who were familiar with our patient population (eg chronic wounds and multiple comorbidities). We have previously reported on the safety of using IV sedation (ie ketamine, fentanyl, midazolam, and propofol) for patients with wounds,[11] and we encourage the use of regional and monitored anesthesia care. Local anesthesia is also infiltrated into the wound; a 1:1 mixture of 1% lidocaine and 0.5% bupivacaine has the best outcomes and fewest side effects for our patient population. Lidocaine with epinephrine

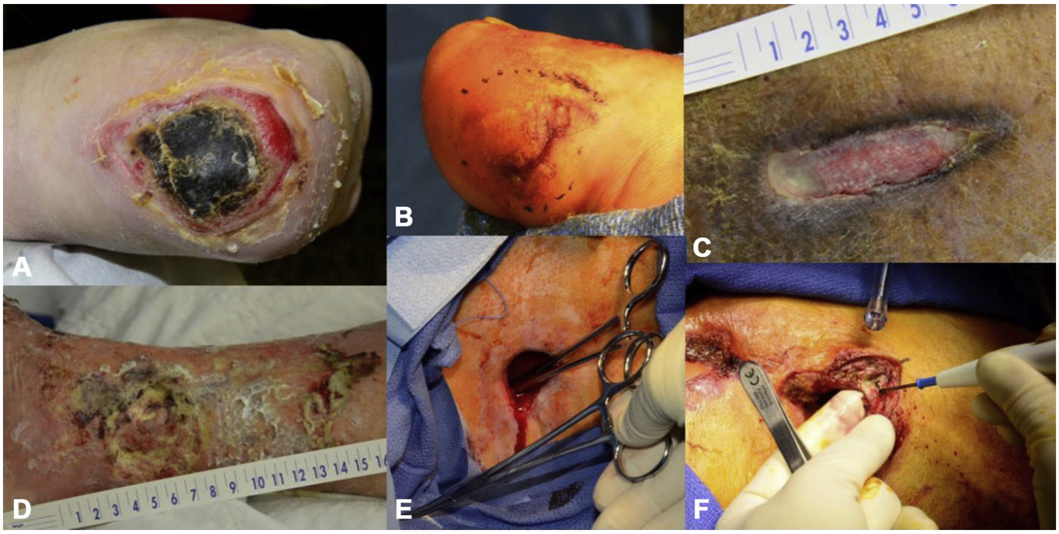

Figure 1. General principles of debridement. Wounds exhibiting features necessitating debridement: (A) nonviable/necrotic tissue, (B) callus, (C) nonmigratory heaped or rolled skin edges, (D) exudate, (E) tunneling, and (F) undermining.

is not used, as it has been shown to be associated with higher incidences of wound infection.[12] General anesthesia is used for septic patients, when a second operation is anticipated within the next 24 to 48 hours (eg necrotizing fasciitis cases), or when the maximum dose of local anesthesia would be exceeded due to wound size or the patient's sensitivity to pain. General anesthesia can also be used for patients with spinal cord injuries, as many have autonomic dysreflexia resulting in either hypotension/tachycardia or hypertension/bradycardia after stimulation below the level of spinal cord injury. Caution must be exercised if succinylcholine is used for neuromuscular blockade due to the risk of hyperkalemia-induced cardiac arrest.[13] Regional anesthetic blocks are an option for wounds: sural nerve block for a pedal plantar surface ulcer, digital block for paronychia or distal phalanx amputation, or an ankle block for a transmetatarsal amputation.

PATIENT POSITIONING

In the operating suite, patients are positioned to achieve optimal exposure of the wound for debridement. Prone position and general anesthesia are usually avoided due to the limited ability to manage the airway and potential respiratory compromise, but can be used with caution when other positions do not provide adequate exposure. For wounds located between the back and the posterior proximal thigh, patients are placed in the lateral decubitus position and stabilized using a flat-bottom gel roll, gel pads, tape, and safety belt (Fig. 2). Care is taken to pad all potential pressure points, including arms, knees, and ankles. Also, upper extremities are not abducted >90 degrees to prevent nerve and muscle trauma. Wounds located on the lower extremities entail positioning of the appropriate leg and might require the use of ankle or boot stirrups to provide the best exposure to the surgical site.

Figure 2. Patient positioning. The patient is in a right lateral decubitus position with a pillow between the lower extremities for cushioning and a safety belt (not seen). A flat-bottom gel roll (A) is placed behind the patient's back for added support.

INSTRUMENTS

The instruments used most frequently by our wound surgeons include: scalpel (10-, 15-, and 20-blade), Metzenbaum scissors, curettes, rongeurs, electrocautery, osteotomes, pulse lavage, smoke evacuator, and sagittal saw. The 10-blade scalpel is used frequently for tangential shaving of long wounds, and the 15-blade scalpel is used for general debriding. It is imperative to change the blade often to maintain a sharp and accurate cutting edge. This will eliminate tissue shearing and damage of surrounding tissue (Fig. 3).

TECHNIQUES

Various instruments and techniques are used, depending on the wound etiology, size, and location. Venous ulceration generally occurs on the lower extremities, starting at the medial malleolus, with larger wounds circumferentially involving the entire lower leg and can often extend to involve the feet and down to the bone. Goals of debridement include removal of hemosiderin deposits and fibrotic and infected tissue. Often, these wounds are covered by biofilm, which can only be seen with electron microscopy[14] and must be removed for topical antimicrobials to be effective. After adequate anesthesia, necrotic tissue is sharply removed using a 15- or 20-blade scalpel. A curette is used to grossly remove slough and exudate and a 10-blade scalpel is then used to tangentially remove layers of unhealthy tissue[15] (Fig. 4). Hydrosurgical

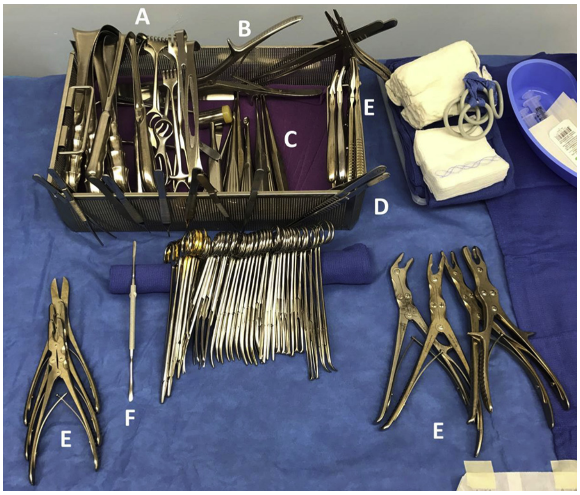

Figure 3. Instrument tray. The wound tray that we have developed includes: (A) retractors, (B) bone cutters, (C) curettes, (D) forceps, (E) rongeurs, and (F) elevators.

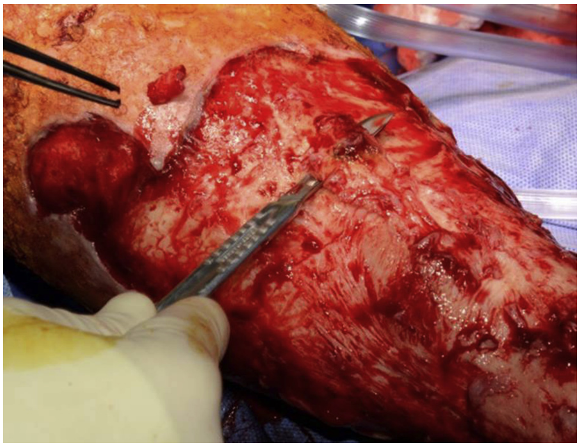

Figure 4. Debridement of venous ulcer. Venous wounds are vigorously scrubbed with a surgical chlorhexidine brush to remove biofilm, coupled with tangential shaving of the ulcer down to a layer of viable-appearing tissue.

debridement can also be performed to remove nonviable tissue (Video 1). This technique provides the surgeon with the ability to excise and evacuate nonviable tissue with simultaneous normal saline irrigation to reduce wound bioburden. Antibiotic-impregnated solution was found to clog the hydrosurgical tubing; therefore, normal saline is used. Perforating veins are often encountered during debridement of venous ulcers and adequate hemostasis is imperative to minimize blood loss and blood pooling in the wound, which would create a favorable environment for bacterial growth (Fig. 5). Hemostatic options are included in Table 2. Hemostasis can also be achieved using ace compression and leg elevation for lower-extremity wounds.

Debridement of pressure ulcers includes special attention to removal of nonviable tissue and undermining or tunneling down to the level of grossly viable tissue.[16,17] This can include removal of underlying periosteum or bone (Figs. 6A, B). The entire wound is thoroughly probed and irrigated to ensure removal of purulent pockets. Areas of tunneling or undermining are unroofed by triangulation (Figs. 6C, D) to stimulate healing of the wound bed from the base and decrease epithelialization forming over dead space with the potential to become infected. It is particularly important to consider the home care or facility nurse and their ability to pragmatically apply the secondary dressing. For example, if the patient will receive negative pressure therapy, the wound would be extended to accommodate the vacuum sponge. In our experience, the application of a vacuum-assisted wound closure device was performed 2 to 3 days postoperatively instead of at the time of operation to decrease bleeding occurrences.

In patients with diabetes, ulceration typically occurs on insensate pedal locations, including the phalanges, plantar surface, and heels. Often coupled with neuropathy and repeated trauma of ambulation or unrecognized irritants,

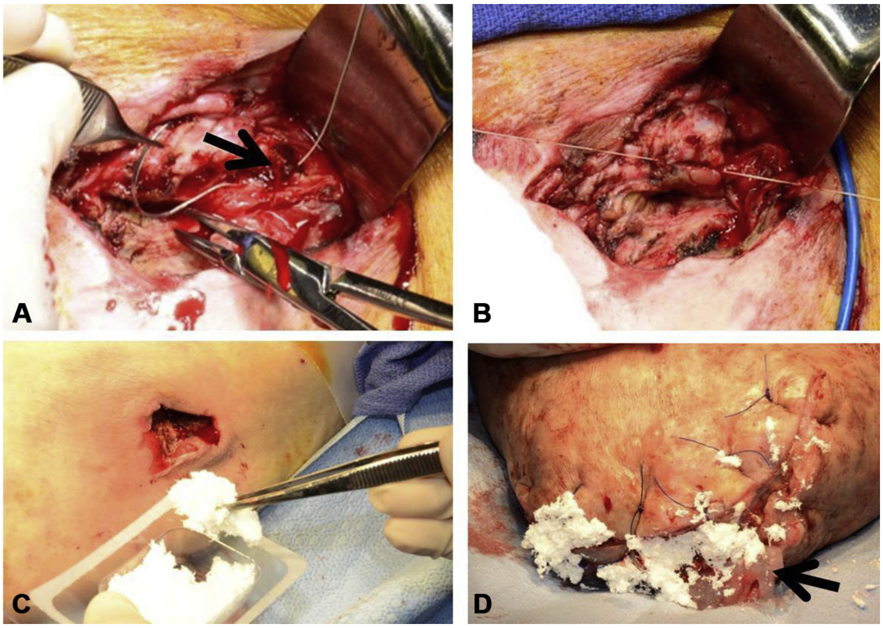

Figure 5. Intraoperative hemostasis. (A, B) An actively bleeding vessel (arrow) is sutured. (C) Fibrillar collagen is applied to a pressure wound. (D) Fibrin sealant (arrow) is applied to a surgical amputation site, followed by fibrillar collagen.

Table 2. Intraoperative Hemostasis

Hemostatic options
Electrocautery
Thrombin/fibrin spray
Suture ligation
Clips
Bone wax
Fibrin sealant; fibrillar collagen
Compression wrap; pressure dressing

patients present with a spectrum of ulceration, from superficial Wagner grade 1 through extensive, gangrenous grade 5 (Fig. 7). A protocol for the debridement of these ulcers has been reported previously,[18,19] with an emphasis on a combination of debridement with appropriate offloading.

PATHOLOGY AND CULTURE

Skin-edge and wound-base specimens are taken during each debridement to evaluate viability of deep-tissue margins and to rule out pathology such as carcinoma, necrosis, osteomyelitis, and active infection, as evidenced by inflammatory cell infiltrates (Fig. 8). These specimens are transported to pathology in formalin. When infection is suspected, aerobic and anaerobic wound cultures are obtained to tailor antibiotic therapy. Unused sterile instruments are used to collect cultures, which are sent fresh in a sterile cup. Cultures are sent in thioglycolate broth when anaerobic pathogens are suspected. When vasculitis or pyoderma is suspected, a specimen is collected from the nearby healthy-appearing skin that is not part of the gross wound and sent in Michel's transport medium to allow for immunofluorescent-based analysis (Fig. 9).

As part of our goal-directed therapy, pathology results were reviewed at our weekly, multidisciplinary, continuing medical education wound conferences. The review included a discussion of the debridement adequacy, microbiology results, and antibiotic use (ie targeted coverage, appropriate course length).

OPERATING SUITE USE AND SCHEDULING

We arranged two, 13-hour days per week of operative suite block time with dedicated operating staff for scheduled, elective wound service cases. Patients presenting to the emergency department at any time with sepsis or severely infected wounds, such as necrotizing fasciitis, are taken to the operating suite urgently or semi-urgently as add-on

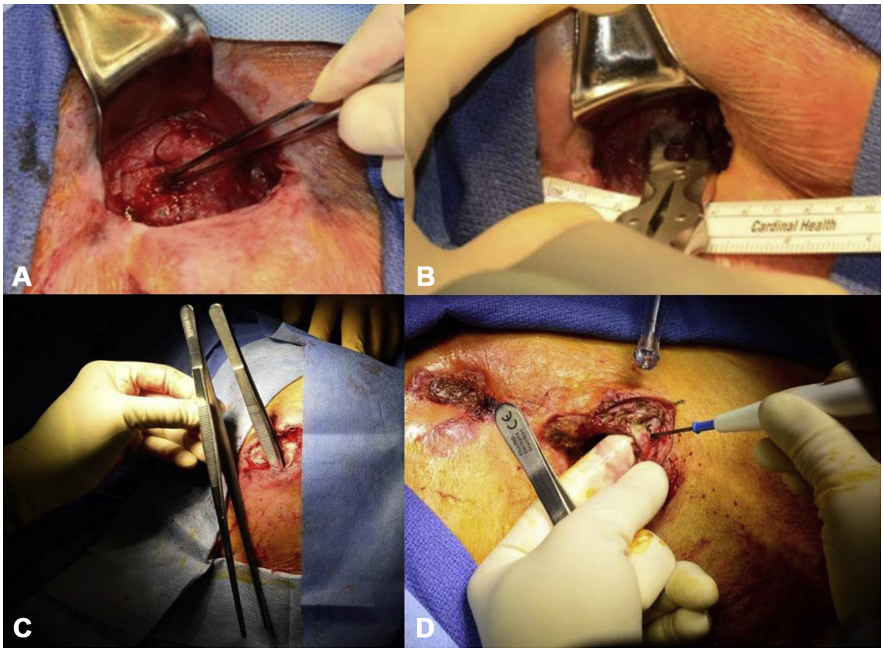

Figure 6. Debridement of a pressure wound. (A) A stage IV sacral pressure wound with necrotic sacrum indicated by the forceps. (B) A rongeur is used to debride the necrotic bone and the specimen is sent to microbiology and pathology for analysis. (C) Extensive tunneling is demonstrated with the use of DeBakey forceps. (D) Undermining is removed by triangulation of the skin overlying the wound.

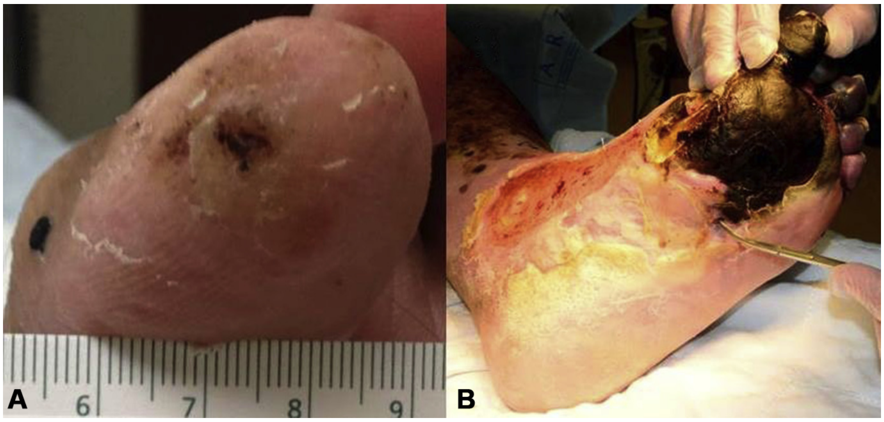

Figure 7. Grades of diabetic foot ulceration. (A) Grade 1 diabetic ulcer in a patient, which subsequently healed. (B) Grade 5 diabetic ulcer in a patient that underwent a below-knee amputation.

cases and are simultaneously booked for a second operation occurring 24 to 48 hours later (Fig. 10). Comparatively, patients who present to the outpatient office are scheduled electively within the weekly wound surgery operating room block time. Once the decision is made to perform the debridement in the operating suite, debridements are scheduled at regular intervals until clinical signs of healing are noted (ie decreased exudate and wound size).

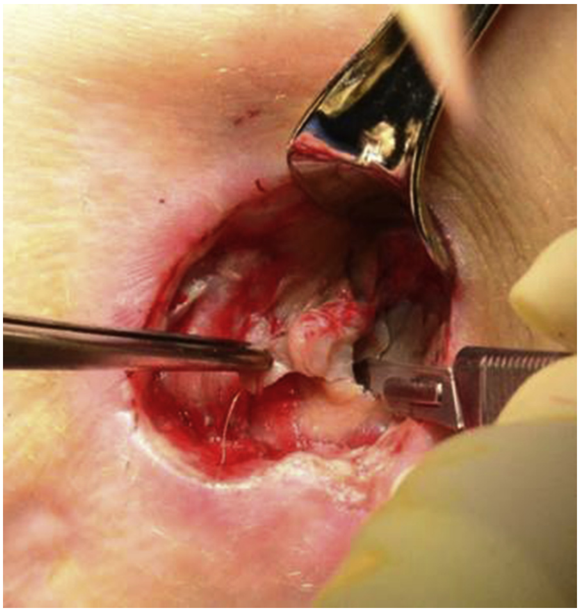

Figure 8. Deep-tissue specimen. An unused, sterile scalpel and forceps are used to obtain a deep specimen. The specimen can be cut in half with one half sent for pathology and the other half sent for culture and sensitivities.

REGENERATIVE MEDICINE IN THE OPERATING SUITE

Regenerative biologic products can be used to facilitate additional healing if deemed medically necessary. They are placed once the wound has been adequately debrided, has healthy granulation tissue, and lack of exudates, and the patient has no clinical signs of infection. At our institution, these advanced products include granulocyte-macrophage colony-stimulating factor; bilayered neonatal fibroblasts and epidermal keratinocytes on a bovine type I collagen; acellular matrix scaffold from porcine small intestine mucosa; purified type I collagen with antimicrobial; dehydrated human amnion/chorion membrane allograft; and cross-linked bovine tendon collagen on a semi-permeable silicone layer (Table 3). Application of these regenerative medicine products can be performed in the office or operating suite (Fig. 11). Regularly scheduled surveillance and dressing changes are important for many regenerative medicine therapies, therefore, it was uncommon to place any of these therapies on the inpatient floors due to difficulty of surveillance after discharge and lack of reimbursement.

As we have reported previously, a bilayered, bioengineered living skin substitute is used for both diabetic and venous ulcers.[26] The product is moistened with sterile saline and applied with the dermal fibroblast layer directly in contact with the wound. It can be passed through a meshing device before application, as seen in Figure 11C. Meshing is performed to increase the available surface area in contact with the wound. Other products, such as the porcine urinary bladder matrix, cryopreserved placental membrane, acellular matrix scaffold, dehydrated human amnion/chorion membrane allograft, and purified type I collagen with polyhexamethylenebiguanide, are applied

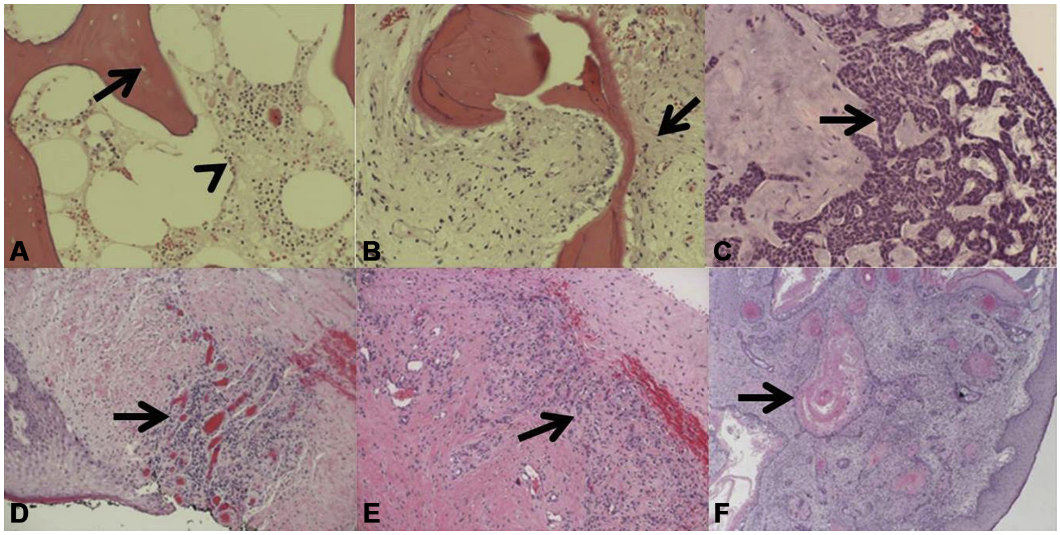

Figure 9. Pathology of deep specimens. (A) Acute osteomyelitis with empty lacunae (arrow) and inflammatory cells in the marrow space (arrowhead). (B) Chronic osteomyelitis with a mix of viable and nonviable bone, bone remodeling, and fibrosis (arrow). (C) Basal cell carcinoma with characteristic basal clue cells (arrow). (D) Venous ulceration with granulation tissue (arrow). (E) Charcot arthropathy with inflamed dense fibrous connective tissue (arrow) and granulation tissue. (F) Keratinizing squamous cell carcinoma with characteristic keratin pearls (arrow) in a bleeding exophytic back mass.

directly to the wound with no specific orientation required. These products can be secured using staples, glue, sutures, Steri-Strips (3M), or overlying dressings and are reapplied during subsequent scheduled visits until healing occurs (Fig. 12).

Split-thickness skin grafting (STSG) is an additional modality available for wound closure. STSG was used commonly when the patient had a large wound ($\geq$10 cm^2) that was contracting, well-vascularized, granulating, and free of infection. Split-thickness skin grafting has the inherent

Figure 10. Emergency wound. A 53-year-old male presented with right lower-extremity necrotizing fasciitis with group A *Streptococcus* identified on wound culture. (A) Preoperative right lower extremity with blistering and erythema extending from the proximal thigh to the ankle. (B) Fasciotomy revealed gray discharge, friable fascia, and healthy-appearing muscle. (C) Healed fasciotomy site 3 months after operation.

Table 3. Intraoperative Regenerative Medicine: Description and Mechanism of Action of Therapies Used in Our Operating Room

Generic name	Description	Mechanism of action	Trade name
Porcine urinary bladder matrix	Lyophilized sheet of intact basement membrane and subadjacent lamina propria of the porcine urinary bladder ECM	Guides wound healing response by providing a complex molecular architecture that aids in biologic tissue repair[20]	MatriStem Burn Matrix and MicroMatrix
Granulocyte-macrophage colony-stimulating factor	Pleiotropic cytokine	Promotes proliferation and differentiation of bone marrow-derived monocyte precursors into macrophages[21]	Leukine
Cryopreserved placental membrane	Source of MSCs, collagen matrix, growth factors (preserved structural and cellular integrity)	Anti-inflammatory, antimicrobial, angiogenic activities Create a moist environment[22,23]	Grafix
Bilayered bioengineered living skin substitute	Type I bovine collagen dermal layer fibroblasts with overlying epidermal layer keratinocytes	Produces a great number of cytokines and growth factors that stimulate differentiation and proliferation in the nonhealing wound bed[24-26]	Apligraf
Acellular matrix scaffold	Porcine small intestine submucosa ECM	Contains collagen, elastin, glycosaminoglycans, proteoglycans, and growth factors Numerous cell types attach and migrate into the matrix Reduces level of MMPs[27]	Oasis
Dehydrated human amnion/chorion membrane allograft	Dehydrated human amnion/chorion membrane allograft	Provides matrix, nonimmunogenic, reduces inflammation/scar tissue/pain, antibacterial, contains GF and cytokines[28,29]	Epifix
Bilayered cross-linked type I bovine tendon collagen combined with chondroitin-6-sulfate and a semi-permeable silicone membrane	Bilayered cross-linked type I bovine tendon collagen combined with chondroitin-6-sulfate and a semi-permeable silicone membrane	Guides growth of the neo-dermis with silicone as a temporary epidermal barrier[30-32]	Integra
Purified type I collagen with polyhexamethylenebiguanide	Purified type I collagen with polyhexamethylenebiguanide	Selectively binds and condenses bacterial DNA chromosomes[33-35]	Puraply

ECM, extracellular matrix; GF, growth factor; MSC, mesenchymal stem cell; MMP, matrix metalloproteinase.

downside of creating an additional wound; however, in our experience, STSG has a low complication rate and the majority of donor sites heal within 4 weeks. We also use epidermal grafting, which does not create a full-thickness wound.

After application of a regenerative medicine therapy or STSG, wounds are covered with appropriate nonadherent, sterile dressings including gauze, abdominal pads, and bandage rolls, taking care to avoid the use of concurrent toxic antiseptics (eg sodium hypochlorite). A vacuum-assisted wound closure device was also placed with or without regenerative medicine therapies for certain indications, such as stimulation of contraction of deep or large wounds, control of drainage, and treatment of abdominal wound dehiscence. A vacuum-assisted wound closure device with instillation of topical solution was used for inpatients with contaminated wounds, and has been shown to decrease length of stay and improve healing.[36]

DISCUSSION

In this report, we described surgical techniques performed by a team of wound surgeons at our facility. In our center, we have agreed-on targets of goal-directed therapy, including specifying the tools and procedures used to manage patients with nonhealing wounds. Agreed-on targets of the operative technique in any program with a wound center are critically important for efficiency, patient safety, and team uniformity. Similar work done in Denmark also found that an optimal wound care model includes an outpatient clinic joined with an inpatient ward within a departmental structure, with surgery as a vital component.[37] This organizational structure and surgical emphasis provides optimal benefits to patients and society.[37] We believe that, similar to trauma patients,[38,39] patients with wounds are best served on a dedicated surgical team. Our team is available around the clock to

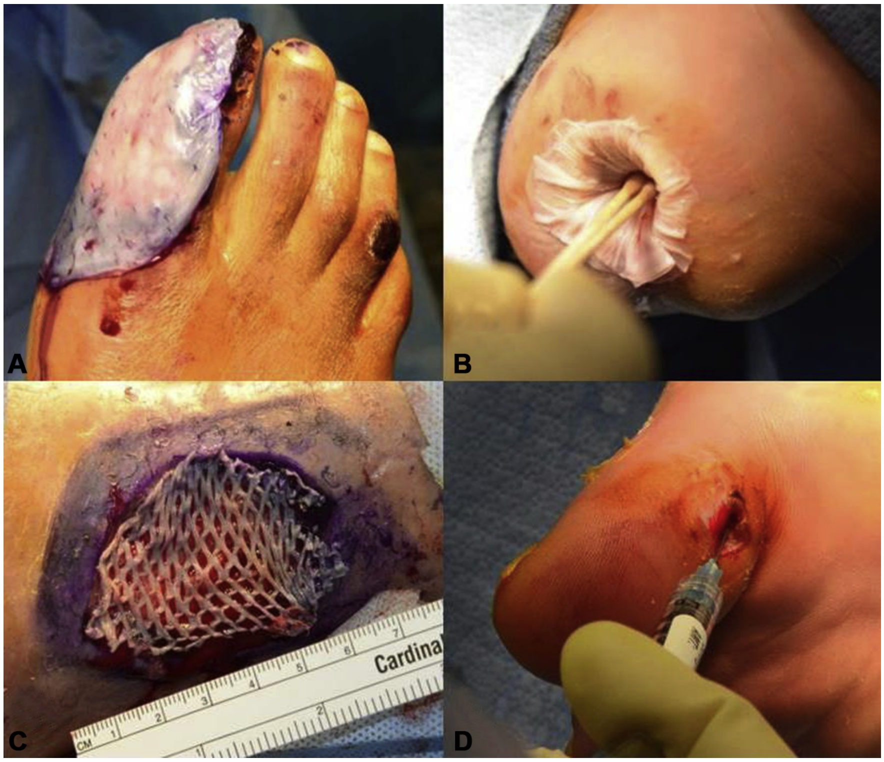

Figure 11. Intraoperative regenerative medicine. (A, B) Application of bilayered bioengineered living skin substitute to diabetic foot ulcers and (C) application after meshing to a lower-extremity venous ulcer. (D) Injection of granulocyte-macrophage colony-stimulating factor into a diabetic foot ulcer.

ensure consistent wound management, even when patients present emergently in the middle of the night. When sepsis is suspected due to a wound source, standard resuscitative procedures are performed (ie IV access, fluid and antibiotic administration, and continuous monitoring) and debridement is performed, keeping in mind that source control is crucial for patients presenting with infected wounds.[40-42]

There was a substantial commitment to patient safety by the institution through recognition of the impact of the operating physician's call schedule on patient care. This was optimized with the creation of the wound service operating suite block time, decreasing the likelihood that elective wound cases would be scheduled as "add-on" and potentially delayed numerous times.

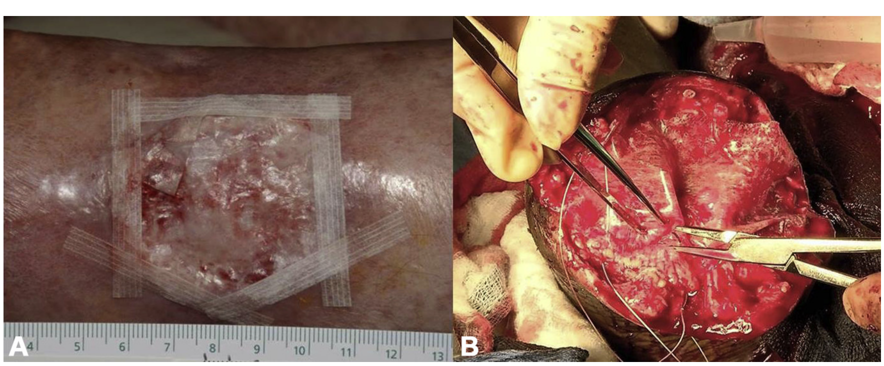

Figure 12. Securing regenerative medicine. (A) Securing onto an anterior lower-extremity wound using Steri-Strips (3M) and (B) within the margins of a lower-extremity amputation site using sutures.

In our experience, and confirmed through discussion at our center with our colleagues in infectious disease and internal medicine, the most viable treatment for infected wounds is excision. We believe that operative-based source control markedly reduces incidences of both antibiotic-induced *Clostridium difficile* infections and readmissions for repeat wound infections. Continuity of care in the outpatient setting is enhanced by having a dedicated wound surgery team, which can ultimately contribute to overall improved patient outcomes. Increased continuity and quality of care promote optimization of timing and agreed-on indications for surgical intervention. Our observation is that there are more frequent trips to the operating suite for elective procedures and a resultant decrease in emergent cases. However, additional studies are required to better delineate these benefits.

Regenerative medicine has been used commonly for more than 2 decades for patients with chronic wounds,[30,31,43] with increasing numbers of biologics now available in the marketplace. It is our experience that even the most severe wounds can heal or become prepared for grafting using these products. However, there are virtually no studies linking specific patient physiology to indications for use of a particular product. Because we are moving to pay-for-performance and capitated reimbursements, we believe it is important to reach a consensus on the target for goal-directed therapy using regenerative medicine techniques. In light of ever-escalating costs combined with an absence of clear superiority of newer therapies, we want to emphasize that we are not advocating for newer therapies to be used on every patient, just for select indications. We believe it is compelling to study any potential correlations between patient pathophysiology and specific product use that can lead to patient-tailored, pathology-based regenerative therapy. It is also vitally important in the future to look at comparative techniques, effectiveness, and cost of regenerative medicine therapies.

CONCLUSIONS

Debridement is the basis of care for nonhealing wounds, the technique of which can be applied consistently among a team of wound surgeons to wounds of varying etiologies. Once the wound bed has been adequately prepared, regenerative medicine therapies can be applied to facilitate healing.

Author Contributions

Study conception and design: Howell, Gorenstein, Castellano, Slone, Woods, Gillette, Donovan, Criscitelli, Brem, Brathwaite

Acquisition of data: Howell, Gorenstein, Castellano, Slone, Woods, Gillette, Donovan, Criscitelli, Brem, Brathwaite

Analysis and interpretation of data: Howell, Gorenstein, Castellano, Slone, Woods, Gillette, Donovan, Criscitelli, Brem, Brathwaite

Drafting of manuscript: Howell, Gorenstein, Castellano, Slone, Woods, Gillette, Donovan, Criscitelli, Brem, Brathwaite

Critical revision: Howell, Gorenstein, Castellano, Slone, Woods, Gillette, Donovan, Criscitelli, Brem, Brathwaite

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