5 Understanding Wound Bed Preparation

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Key Points

- Proper wound bed preparation is fundamental in achieving wound healing.
- The primary goal of wound bed preparation is to support a positive healing trajectory or to support a graft or flap.
- There are a variety of techniques, devices, and biologics available that can accelerate wound bed preparation.
- Excisional debridement is fundamental to wound bed preparation.

5.1 Introduction

Wound bed preparation is essential for the next stage of wound healing. This next stage may include an application of a bioengineered alternative tissue, primary closure, autologous skin graft, local flap, or free tissue transfer. In some instances, the wound may be left to heal through secondary intention. A wound bed must be maximally perfused with low bioburden to increase the odds of success. This may include vascular intervention, the use of negative pressure wound therapy (NPWT) with or without instillation, antibiosis, or the use of topical antiseptics. The use of classification systems is helpful to assess and describe the wound, and there are a variety of ulcer classification systems utilized (Table 5.1) [1–3]. These systems include descriptions of aspects of the wound including depth, infection, and ischemia. None of the currently utilized classification systems are all encompassing and do not describe the impact of biomechanical influences or make treatment recommendations. In addition to local factors, the patient's comorbidities must be addressed. For example, a diabetic patient must have blood glucose control to decrease complication rates including surgical site infections [4, 5]. Nutrition must also be addressed to support a healing environment [6]. The goal is to achieve a wound bed that is ready to support ultimate healing.

Appropriate wound bed preparation can be achieved through a variety of methods including serial clinic-based sharp debridement, surgical excisional debridement in the operating room, use of negative pressure wound therapy with or without instillation, or application of a bioengineered alternative tissue to create a neodermis.

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Table 5.1 Diabetic foot ulcer classifications

Wagner and Meggitt	
Grade 0	Intact skin; hyperkeratotic lesion around or under bony deformity
Grade 1	Superficial ulcer; base may be necrotic or viable with early granulation tissue
Grade 2	Deep lesion extending to bone, ligament, tendon, joint capsule, or deep fascia; no abscess or osteomyelitis
Grade 3	Deep abscess, osteitis, or osteomyelitis
Grade 4	Portion of the toes or forefoot is gangrenous (moist or dry)
Grade 5	Complete involvement of foot; no foot healing or local procedure possible

The University of Texas at San Antonio Ulcer Classification				
	Grade 0	Grade 1	Grade 2	Grade 3
Stage A	Pre- or post-ulcerative lesions completely epithelialized	Superficial wound not involving tendon, capsule, or bone	Wound penetrating to tendon or capsule	Wound penetrating to bone or joint
Stage B	Infected	Infected	Infected	Infected
Stage C	Ischemic	Ischemic	Ischemic	Ischemic
Stage D	Infected and ischemic	Infected and ischemic	Infected and ischemic	Infected and ischemic

The Society for Vascular Surgery Lower Extremity Threatened Limb Classification System: Risk Stratification Based on Wound, Ischemia, and foot Infection (WIfI)			
Wound	Ulcer	Gangrene	Clinical description
Grade 0	No ulcer	No gangrene	Ischemic rest pain (requires typical symptoms + ischemia grade 3); no wound
Grade 1	Small, shallow ulcer(s) on distal leg or foot; no exposed bone, unless limited to distal phalanx	No gangrene	Minor tissue loss. Salvageable with simple digital amputation (1 or 2 digits) or skin coverage
Grade 2	Deeper ulcer with exposed bone, joint, or tendon; generally not involving the heel; shallow heel ulcer without calcaneal involvement	Gangrenous changes limited to digits	Major tissue loss salvageable with multiple (≥3) digital amputation or standard TMA ± skin coverage
Grade 3	Extensive, deep ulcer involving forefoot and/or midfoot; deep, full thickness heel ulcer ± calcaneal involvement	Extensive gangrene involving forefoot and/or midfoot; full thickness heel necrosis ± calcaneal involvement	Extensive tissue loss salvageable only with a complex foot reconstruction or nontraditional TMA (Chopart or LisFranc); flap coverage or complex wound management needed for large soft tissue defect
Ischemia	ABI	Ankle systolic pressure	TP, $TcPO_2$
Grade 0	≥0.80	>100 mmHg	≥60 mmHg
Grade 1	0.6–0.79	70–100 mmHg	40–59 mmHg
Grade 2	0.4–0.59	50–70 mmHg	30–39 mmHg
Grade 3	≤0.39	<50 mmHg	<30 mmHg
Foot infection	Clinical manifestation of infection	SVS	IDSA/PEDIS infection severity
No symptoms or signs of infection		0	Uninfected

Table 5.1 (continued)

The Society for Vascular Surgery Lower Extremity Threatened Limb Classification System: Risk Stratification Based on Wound, Ischemia, and foot Infection (WIfI)			
Wound	Ulcer	Gangrene	Clinical description
Infection present, as defined by the presence of at least 2 of the following items: • Local swelling or induration • Erythema >0.5 to ≤2 cm around the ulcer • Local tenderness or pain • Local warmth • Purulent discharge (thick, opaque to white, or serosanguinous) Local infection involving only the skin and the subcutaneous tissue (without involvement of deeper tissues or without systemic signs described below) Exclude other causes of an inflammatory response of the skin (e.g., trauma, gout, acute Charcot neuro-arthropathy, fracture, thrombosis, venous stasis)		1	Mild
Local infection(as described above) with erythema >2 cm, or involving structures deeper than skin and subcutaneous tissues (e.g., abscess, osteomyelitis, septic arthritis, fasciitis) No systemic inflammatory response signs (as described below)		2	Moderate
Local infection (as described above with the signs of SIRS, manifested by two or more of the following: • Temperature > 38° or < 36 °C. • Heart rate > 90 beats/min • Respiratory rate > 20 breaths/min or $PaCO_2$ < 32 mmHg • White blood cell count >12,000 or < 4000 cu/mm or 10% immature (band) forms		3	Severe

TMA transmetatarsal amputation, *ABI* ankle-brachial index, *PVR* pulse volume recording, *SPP* skin perfusion pressure, *TP* toe pressure, *$tcPO_2$* transcutaneous oximetry, *SVS* Society for Vascular Surgery, *IDSA* Infectious Disease Society of America, *IWGDF* International Working Group on the Diabetic Foot, *PEDIS* perfusion, extent/size, depth/tissue loss, infection, sensation, *$PACO_2$* partial pressure of arterial carbon dioxide, *SIRS* systemic inflammatory response syndrome

There are more conservative methods for wound bed preparation including the use of collagenases, maggot therapy, or wet-to-dry dressing changes [7]. A novel perforated foam design for negative pressure wound therapy with instillation has also been introduced to accelerate removal of nonviable tissue [8]. All these approaches attempt to remove nonviable tissue, decrease bacterial bioburden, increase local perfusion, and release prohealing cells and proteins. The focus of this chapter will be on the surgical approach to wound bed preparation.

There are key indicators that allow the surgeon to identify whether or not the wound has been sufficiently prepared for the next stage. Infection is a key indicator that the wound is not sufficiently prepared. The surrounding tissue must not have signs of infection which include increased drainage, purulence, malodor, erythema, edema, calor, or dolor. In an immunocompromised host, these classic signs or symptoms (including malaise, flu-like symptoms, fever, nausea, vomiting) may not be present. It is especially concerning when, for example, a diabetic patient with peripheral neuropathy and an infected foot ulcer presents with pain or their blood glucose elevates significantly. In this population it is often malodor that may signal the presence of an infection. All wounds have some degree of serous drainage (except in cases of dry

gangrene); however, frank purulence, liquified tissue, or a sudden increase in the amount of drainage may indicate an infection. The wound is deemed appropriately prepared when there is visible evidence of granulation tissue and the absence of necrotic or nonviable tissue as well as the absence of the above. A bed of granulation tissue should not be thought of as a goal but rather as an indicator that the wound bed has low bioburden and is adequately perfused.

Laboratory markers may not be a good indicator of infection in the immunocompromised host. The white blood cell count may not be elevated until later stages of infection. Further, markers of inflammation including C-reactive protein and erythrocyte sedimentation rate may not be helpful in infection diagnosis, but down-trending of these markers can indicate waning infection. Radiographic markers of gas and bone destruction on plain films are clear and unambiguous indicators. Advanced imaging utilizing computer tomography, magnetic resonance imaging, and indium-labeled scan can be helpful but often is unnecessary. A gestalt approach that includes assessing the clinical signs and symptoms, laboratory makers, radiographic findings, and the patient's wound and medical history should be utilized to ensure that wound bed is sufficiently prepared.

5.2 Pre-operative Evaluation and Special Considerations

Maximizing perfusion to the wound bed is critical. Both global and regional/local perfusion should be assessed. This may include the assessment and optimization of cardiac function. Regional/local perfusion assessment should be performed that escalates from a hand-held doppler to contrast angiography. Chronic lower extremity wounds often have compromised perfusion to the wound and surrounding tissue. Diagnostic angiography can assist in determining the areas of ischemia. If intervention via open bypass or angioplasty is not possible, then the diagnostic angiogram will still provide vital information necessary in planning soft tissue reconstruction. Optimally, if revascularization is possible, the target should be to the affected angiosome [9]. There is no consensus as to the timing of wound bed closure or coverage after vascular intervention [10, 11]. In the author's opinion, generally, if an angioplasty is performed it is recommended to delay closure or coverage for a period of 3–7 days. Further, it is recommended to perform wound coverage or closure as soon as possible after this initial period in order to maximize the window of arterial intervention patency. Venous disease can also contribute to nonhealing ulcers in the lower extremity. An obstruction in the venous system or incompetent valves can contribute to retarding the conversion of a wound to a healthier state. Thus, a complete venous system work-up that includes ultrasonography with appropriate intervention including venous ablation as well as compression therapy may be needed.

Vascular intervention is a reliable method of improving arterial flow for larger vessels. However, in some instances (e.g., diabetes) small vessels are also compromised. This is important because of the arterioles and capillaries that directly feed the wound bed. It is true that opening larger vessels can assist in opening the smaller vessels by increasing the velocity of flow to the smaller vessels and opening up of choke vessels. However, this may not be sufficient. Other methods have been proposed that can enhance local perfusion such as hyperbaric oxygen therapy (HBO). There is some evidence to support the use of HBO to increase flap survival post free tissue transfer [12, 13]. It can also be used in preparation of wound closure or coverage including in areas of irradiated tissue [14]. The efficacy of HBO in healing diabetic foot ulcers remains controversial [15]. There are limitations to HBO therapy including narrow indications, contraindications, the need for multiple serial treatments, and potential adverse effects.

Bacterial contamination/infection in the form of biofilm and planktonic bacteria can delay wound bed conversion to a healthy state as well as cause complications post closure or coverage. The use of antibiotics is effective against planktonic bacteria but has limited efficacy on biofilm

due to the biofilm's decreased metabolic state [16]. Further, if there is arterial compromise the antibiotic may not be able to reach the target tissue. There are also other limitations in identifying and speciating the offending bacteria. Classic swab culturing methods may not accurately represent the offending bacteria [17]. Sampling should include tissue obtained from the deepest margins of the wound which may provide more accurate representation of the offending bacteria. Further, biofilm cannot be captured utilizing the standard agar culturing technique. More advanced culturing methods utilizing quantitative polymerase chain reaction (qPCR) can capture and identify bacteria in biofilm form. This technique also has limitations including its limited availability and the results may provide excessive information with identifying hundreds of species of bacteria that may not be relevant to the clinical scenario.

Topical antimicrobials can be used to decrease the amount of bacteria counts on the surface of the wound. This includes the use of neomycin/polymyxin, gentamycin, mupirocin, and compounds including polyhexanide. The effectiveness/efficacy of these products in chronic wounds is unclear [18]. The topical antibiotic formulations still have the same limitations as oral or parenteral antibiotics in its inability to impact biofilm due to their mechanism of action. Further, the majority of topical antibiotics are petrolatum base which acts as a barrier to exudate release into the dressing which can cause periwound maceration and subsequent loss of skin integrity. The use of antiseptic solutions can impact both planktonic bacteria and surface biofilm (Table 5.2). Antiseptics are often used as wound washes via irrigating the solution over the wound for a short period. However, to maximize the effects of antiseptics a longer contact time is needed through a soaked gauze medium placed or packed onto/into the wound for greater than 10 min [19–21]. Antiseptics typically lyse cells and require contact with differing levels of efficacy depending on the type of bacteria. For example, dilute acetic acid is more effective against gram-negative bacteria than gram-positive bacteria [22], whereas Dakins solution has a long history and has demonstrated efficacy against a broad spectrum of microbes [23]. Biofilm can be deeply embedded into the tissue. Thus, antiseptics cannot reach the biofilm without debridement. Further, long-term antiseptic use can have deleterious effects on healthy tissue and can delay healing [24].

Table 5.2 Examples of commonly used antiseptic solutions

Solution	Formulation and typical concentrations
Chlorhexidine	Chlorhexidine gluconate (0.005–0.05%)
Dakin's solution	Dilute sodium hypochlorite (0.025–0.05%)
Dilute vinegar	Dilute acetic acid (0.25–1%)
Dilute betadine	Povidone-iodine (0.5–1%)
Hypochlorous acid	Water 99.57%, sodium chloride 0.4%, Hypochlorous acid 0.025%, sodium chlorate 0.001%
Polyhexanide with betaine	Polyaminopropyl biguanide 0.1% and undecylenamidopropyl betaine 0.1%

Medical optimization is critical for wound bed preparation. Beyond better blood glucose management in diabetic patients, often patients with chronic diseases are nutritionally compromised. Specifically, protein deficiency can have significant deleterious effect on wound healing. Classic markers of malnutrition such as prealbumin, albumin, and total protein may not accurately reflect a patient's nutritional state [25, 26]. These laboratory markers are often diluted if the patient is in an inflammatory state. Thus, these laboratory markers can be used to track trends which assists in timing for surgical planning.

5.3 Approach to Wound Bed Preparation

Excisional debridement is fundamental to wound healing [27]. Excisional debridement removes surface contaminants and nonviable tissue and activates the coagulation cascade which mobilizes proteins and growth factors that converts the wound from a chronic state into an acute state (Table 5.3). A surgical approach to wound care

differs from that of nonsurgical approach. A nonsurgical approach includes serial clinic-based sharp wound debridement and the reliance on topical therapies and dressings [28]. Generally, the nonsurgical goal is healing through secondary intension, although a referral to a surgeon for final closure or coverage is sometimes conducted. Alternatively, a surgeon may perform the above activities but also includes an operating room-based approach of one-stage or multi-staged excisional debridement that terminates in closure or coverage of the wound. There are advantages and limitations to both approaches (Table 5.4) (Fig. 5.1). The surgical approach is preferred for larger, deeper, or more complex wounds. However, a patient may not be a surgical candidate due to a variety of reasons including the risk of anesthesia or the patient declines surgical intervention. Other factors include practical matters including limited availability to the operating room or limited access to qualified surgeons.

Table 5.3 Goals of debridement

Removal of inhibitory healing factors (matrix metalloproteinases)
Growth factor activation
Removal of fibrotic/indurated tissue
Removal of tissue *likely* to become infected
Removal of infected tissue
Disruption of biofilm
Pressure relief- edge effect

The algorithm for a surgically based approach varies from surgeon to surgeon and institution to institution. There is no widely adopted singular approach. Multiple factors may dictate the algorithm utilized and should

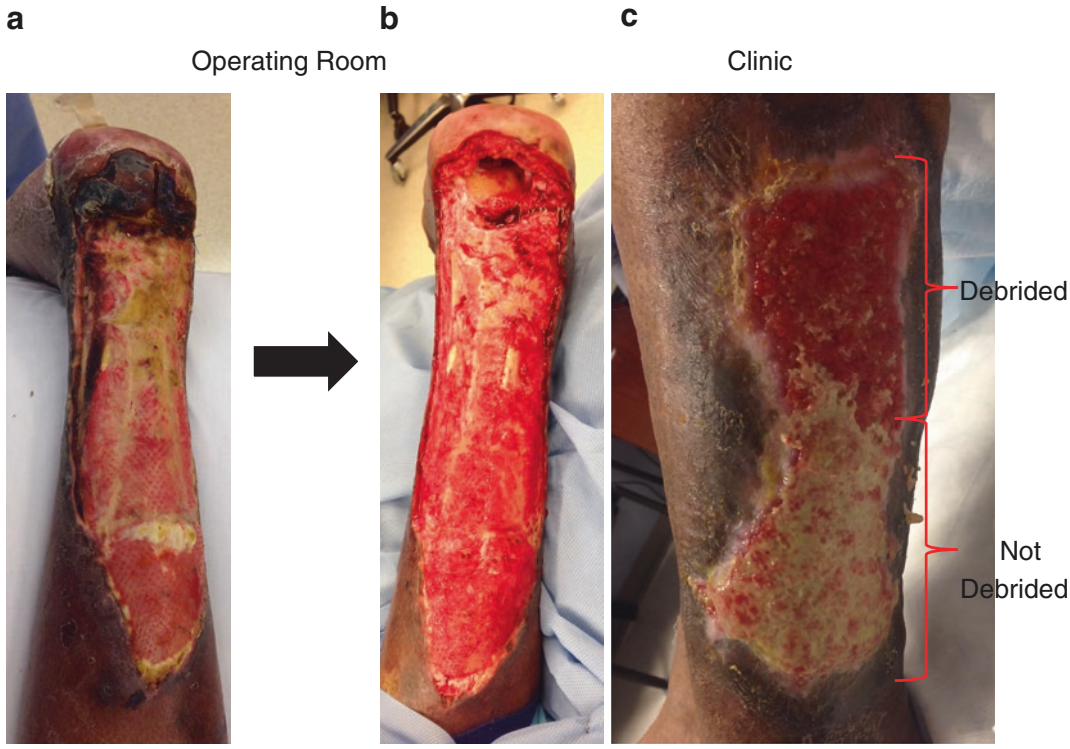

Fig. 5.1 (**a**) depicts a posterior leg wound prior to excisional debridement in the operating room. Note the necrotic tissue around the posterior heel as well as the necrotic tendon on the lateral border. (**b**) shows the wound after excisional debridement is performed. Note the absence of nonviable tissue and the appearance of healthy tissue. (**c**) depicts a chronic lateral leg wound managed in the clinic setting. The inferior portion depicts the nondebrided portion of the wound with significant bioburden. The superior portion has been sharply debrided. However, note the remaining islands of nonviable tissue that still remain

be individualized for the needs of the patient. In general, wounds have bacterial contamination and are perhaps acutely infected. Thus, a staged approach is a prudent to reduce or eliminate bacteria prior to closure or coverage (Fig. 5.2). The initial stage involves eliminating or reducing the amount of bacteria through decompression and excision of all nonviable tissue. The appearance of the wound, culture results, radiographic findings, as well as laboratory values should guide the surgeon as to the necessity of additional excisional debridement in the operating room. Once the wound bed is sufficiently prepared and the patient is medically optimized, the final operation is used to close or cover the wound.

Table 5.4 Advantages and limitations of clinic-based vs. surgery-based wound bed debridement

	Advantages	Limitations
Clinic-based	No regional or general anesthesia risk Nonsterile environment Convenience for the patient	Cannot be as aggressive in debridement due to limited pain management capabilities as well as risk of blood loss Nonsterile environment
Surgery-based	Can be aggressive in excisional debridement technique due to anesthesia and the ability to control bleeding Sterile environment Availability of equipment	Patient not a surgical candidate due to underlying medical condition(s) Risk of anesthesia complications Patients may elect not to undergo surgery

Generally, the technique for excisional debridement is uncomplicated. Again, the goal is to remove all infected, contaminated, as well as nonviable tissue. Nonviable tissue is defined as tissue that is necrotic, liquefied, fibrinous, and/or nonvascularized. It is important that the wound bed and the wound perimeter be excised. The approach should be conducted as if the wound is a soft tissue tumor. This mandates an aggressive

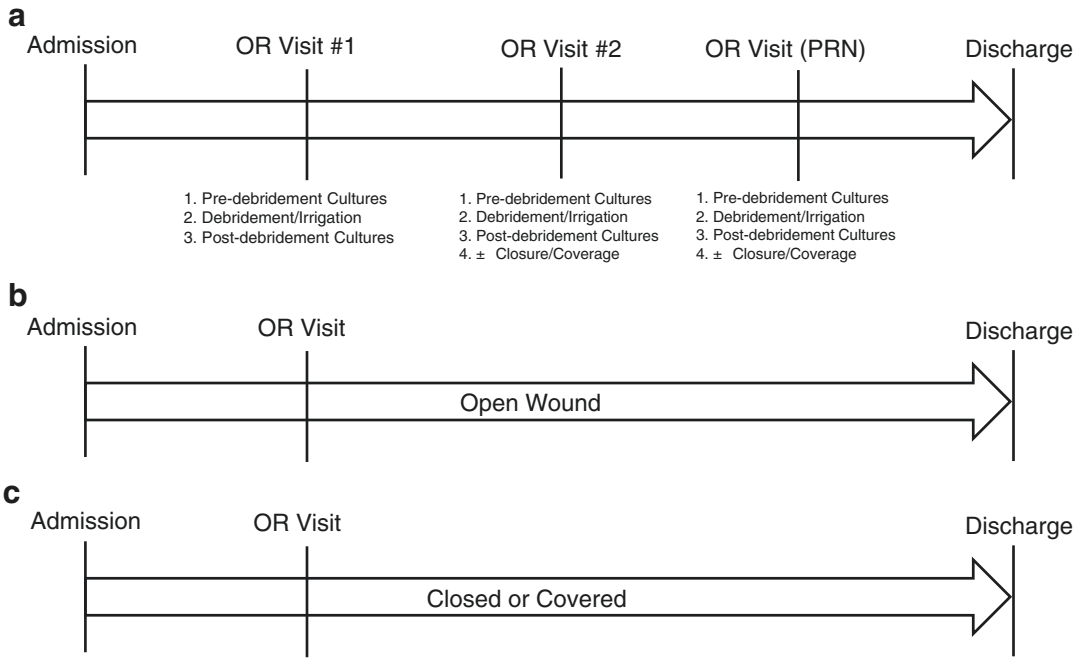

Fig. 5.2 (**a**) depicts a suggested algorithm for and infected wound. (**b**) depicts an algorithm when an initial excisional debridement is performed and the wound is not closed or covered before discharge. The patient can then have the definitive wound at a later date. (**c**) depicts an algorithm where a one stage of excisional debridement and wound closure or coverage is performed

approach with complete excision of the wound and its margins. This excision should penetrate several millimeters in depth as well as encompass several millimeters of the wound perimeter. The typical sharp instruments of a scalpel, scissors, curettes, and rongeur are utilized, but additional devices may be helpful. Contact ultrasound or a hydrosurgical scalpel can be helpful to expedite excisional debridement. These devices may have the added advantage of more precise and efficient removal of tissue. However, with both of the above devices the visual field may become obscured as well as the potential for aerosolizing bacteria during the procedure. Further, these devices may lull the surgeon into a false sense of comprehensive excision. Punctate bleeding, healthy appearing tissue, and lack of odor are cues that excisional debridement has been adequately performed. Absence or presence of certain colors can denote healthy appearing tissue. A general rule is to remove all the tissue that is not red, yellow, or white. Blue tissue can also indicate nonviable tissue unless it is identified as a vein. Another technique that may assist in confirming complete excisional debridement is to paint the surface of the wound with a dye (e.g., methylene blue) prior to excisional debridement. The absence of this applied color after the excisional debridement has been performed ensures that all surfaces have been comprehensively addressed.

The use of NPWT has been utilized for decades to accelerate wound healing to terminal epithelialization [29]. NPWT can also be used to expedite wound bed preparation for surgical coverage or closure by decreasing the dimensions of the wound as well as to build tissue over deeper exposed structures. NPWT is also used for a staged surgical approach during hospitalization in between operating room visits, after the initial excisional debridement, or at the time of discharge. Innovations to traditional NPWT include the use of intermittent installation of a topical solution which can decrease bacterial counts as well as promote greater granulation tissue growth [30–32]. Essentially, this device provides the benefits of standard NPWT combined with irrigation in a programmed fashion. Normal saline or an antiseptic can be used as the choice on solution [33]. The cycling of negative pressure and dwelling of a solution on the wound bed allows for cleansing of the wound bed between surgical debridement procedures as well as for preparation of the wound for closure or coverage. A novel foam dressing used in conjunction with NPWT with instillation encompasses large perforations in the foam dressing that can expedite removal of nonviable tissue for more efficient wound bed preparation [34].

Bioengineered alternative tissue (BAT) are products that can assist in wound bed preparation [35]. There are many categories of BATs with the class of dermoconductive agents (scaffolds) playing the most prominent role from the surgical perspective. Dermoconductive agents are acellular tissues including allografts and bioengineered animal-derived tissues (Table 5.5). These scaffolds typically produce a neodermis to cover deeper structures with planned staging to cover the area with a local flap, free tissue transfer, or autologous skin graft. These are unlike the classic xenografts used in burn surgery which is typically used as a biological dressing. There are no robust comparative studies of the effectiveness/efficacy of these products; hence, product selection is driven by surgeon preference. The cost may be prohibitive factor. However, the use of these products can preclude the need for a local flap or free tissue transfer [36]. After the neodermis is formed an autologous skin graft can be applied or the wound can be left to heal through secondary intention. The neodermis should be pink in color without any necrosis. The disadvan-

Table 5.5 Examples of commonly utilized bioengineered alternative tissues: dermoconductive agents

Tissue type	Composition
Human dermis	Acellular cadaver dermis
Bovine derived	Adult type 1 collagen ± shark chondroitin-6-sulfate Fetal type 1 and type 3 collagen
Porcine derived	Small intestine submucosa Basement membrane and subjacent lamina propria of urinary bladder
Marine derived	Acellular dermal matrix

tage of this approach is the delay between the time of application of the dermoconductive agent and the application of the flap or autologous skin graft. It takes several weeks for neodermis to form which places the wound at risk of an infection or further tissue loss may ensue during this period. A single-stage approach with application of these products in addition to an autologous skin graft has been reported but is largely relegated to clinical observations and case reports. The surgeon must ensure that bacterial count is low to ensure neodermis formation. This approach places significant demand on the wound bed for vascularization to occur; thus, adequate wound bed preparation is vitally important.

5.4 Discussion

The formation of granulation tissue is often an indicator for achieving the goal of appropriate wound bed preparation. Thus, there is hesitation of removing granulation tissue at the time of closure or coverage. It is important to understand that granulation tissue is marker of wound health and not necessarily a primary goal. There is a high likelihood that if granulation tissue developed once, it will develop again. There may be bacteria deeply imbedded in the underlying granulation tissue that must be uncovered and removed. Thus, excision of granulation tissue is recommended every time excisional debridement procedures are performed and at the time of closure or coverage.

5.5 Conclusion

Wound bed preparation is necessary for the next stage of wound healing whether it is to advance secondary healing or for closure or coverage. Wound bed preparation encompasses impacting both local and host factors. Optimization of medical comorbidities, maximizing perfusion, and minimizing bacterial burden is critical for appropriate wound bed preparation.

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