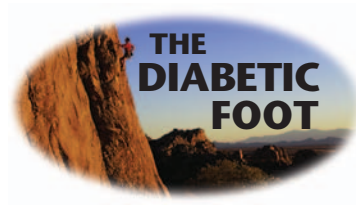
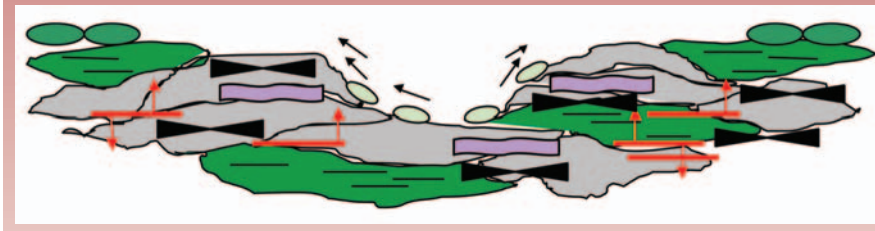



Continuing Medical Education

# Optimizing Wound Prevention and Healing

*Here is a ten-step model with a clinical algorithm.*



## Objectives

1) Review the stage of wound healing, including the major molecular and cellular events.

2) Review the classification and common causes of lower extremity wounds as well as factors affecting wound healing.

3) Introduce a ten-step clinical model and clinical algorithm (template) for wound prevention, diagnosis and treatment.

4) Explain the value of an integrated multidisciplinary approach to wound prevention and care.

5) Demonstrate the potential impact on wound prevention and healing outcomes using this approach both in the developed and developing world.

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**By Cornelius M. Donohue, DPM, Larry R. Goss, DPM, Frederick B. LaVan, MD, Michael S. Weingarten, MD, and Mazen A. Abboud, DPM**

**Abstract**

Wound healing proceeds in a predictable series of seamless molecular and cellular events, most often initiated by injury or infection. While some wounds cannot be prevented or healed, dramatic reductions in wound occurrence and increases in healed wounds can be obtained with the implementation of systematic wound prevention and care protocols. The value of encouraging the coordination of multi-disciplinary involvement in clinical wound-

*Continued on page 138*

**Optimizing...**

healing settings has consistently demonstrated improved prevention and healing outcomes. The authors introduce a ten-step model with a clinical algorithm and discuss the importance of developing a consistent and methodical approach to wound prevention, diagnosis and treatment that is based on fundamental principles and evidence-based medicine.

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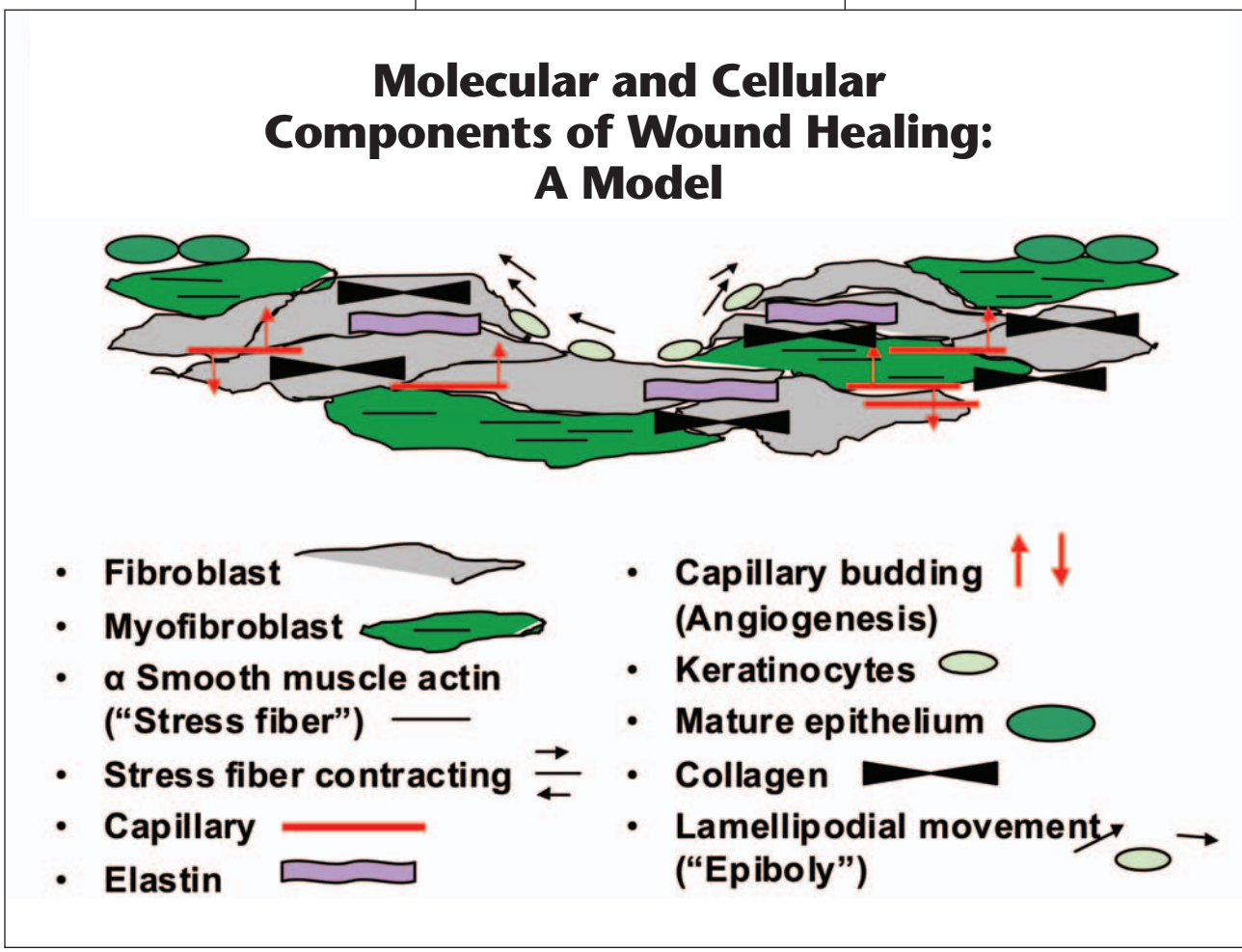


**Figure 1**

## TABLE 1

### Stages of Wound Healing with Prominent Findings and Molecular and Cellular Events

| Stage | Time | Prominent Findings | Cellular events | Molecular events |
|---|---|---|---|---|
| Inflammatory / Substrate | 0-4 Days | Injury / Infection<br>Coagulation<br>Inflammation | Platelets<br>Neutrophils<br>Macrophages | Cytokines<br>Growth factors<br>Chemokines<br>Nitric oxide |
| Fibroblastic / Lag | 5-20 Days | Angiogenesis<br>Migration<br>Proliferation | Fibroblasts<br>Myofibroblasts<br>Vascular endothelial cells | Receptors<br>Proteases<br>Protease inhibitors |
| Remodeling / Maturation | 21 Days-Years | Epithelialization<br>Scar maturation | Keratinocytes<br>Mature epithelial cells | |

## Optimizing...

### Introduction

Before invoking a discussion on wound healing, several fundamental wound-healing concepts need to be reviewed. A "wound" is historically described as a clinical defect in soft-tissue and/or bone caused by trauma, ischemia, infection or non-infectious inflammatory disorders. The common denominator in any wound is the presence of tissue necrosis. Similarly, "wound-healing" is portrayed as a condition in previously 'injured' tissue represented by removal of necrotic tissue, resolution of infection and inflammation, with organized collagen and mature, stable epithelium overlying viable tissue. This process can be divided into three distinct phases: the inflammatory phase, the proliferative phase and the remodeling phase.[1-3] The three essential stages of wound healing, as well as the prominent findings and molecular and cellular events, are listed in Table I. The inflammatory (substrate) phase occurs immediately following the injury and lasts approximately six days.[4] The fibroblastic (lag) phase occurs at the termination of the inflammatory phase and can last up to four weeks. The remodeling phase begins at the fourth week and can last for years.[5-8] A schematic representation of the molecular and cellular components of a healing wound can be seen in Figure 1.

The stages of wound healing do not occur as isolated events, but rather as a continuous flow of molecular and cellular events with considerable overlap (Figure 2).

*The common denominator in any wound is the presence of tissue necrosis.*

Initial wound healing hinges on the concept of angiogenesis, which is the central process orchestrating the migratory and proliferative stages of wound healing (Figure 3). Angiogenesis is defined as "the growth of new capillary blood vessels in the body, a naturally occurring process required for wound granulation and tissue repair. In the healthy adult, angiogenesis is regulated by molecules that stimulate angiogenesis or inhibit the process. Angiogenesis is a balance between angiogenic growth factors (AGF) and angiogenic inhibitors (AI) in both normal and abnormal wound healing."[8-10] The role of nitric oxide and its relationship to the other molecular and cellular events in wound repair is currently under investigation[11] (Table 1). The stages of wound healing proceed seamlessly to a healed condition unless this process is impeded by factors that will negatively affect a successful wound-healing outcome (Table 2).

When it comes to healing wounds of the lower extremity, particularly the foot and ankle, the standard must be set high for acceptable healing outcomes. Furthermore, there are essentially two levels of repair, tissue healing and functional healing. In the distal lower extremity, just achieving "tissue healing" is only half the battle. Keeping the wound healed or "functional healing" requires an additional level of healed tissue mobility and strength in order to endure the forces of weight-bearing, including ground-reactive pressure, torque and shear forces.

There are many ways to approach a patient with a wound. A meticulous and methodological sys-

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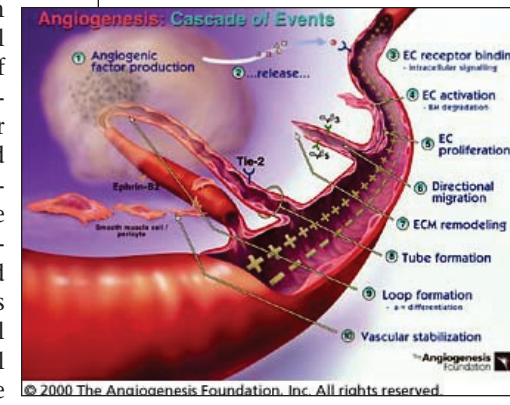



**Figure 3**

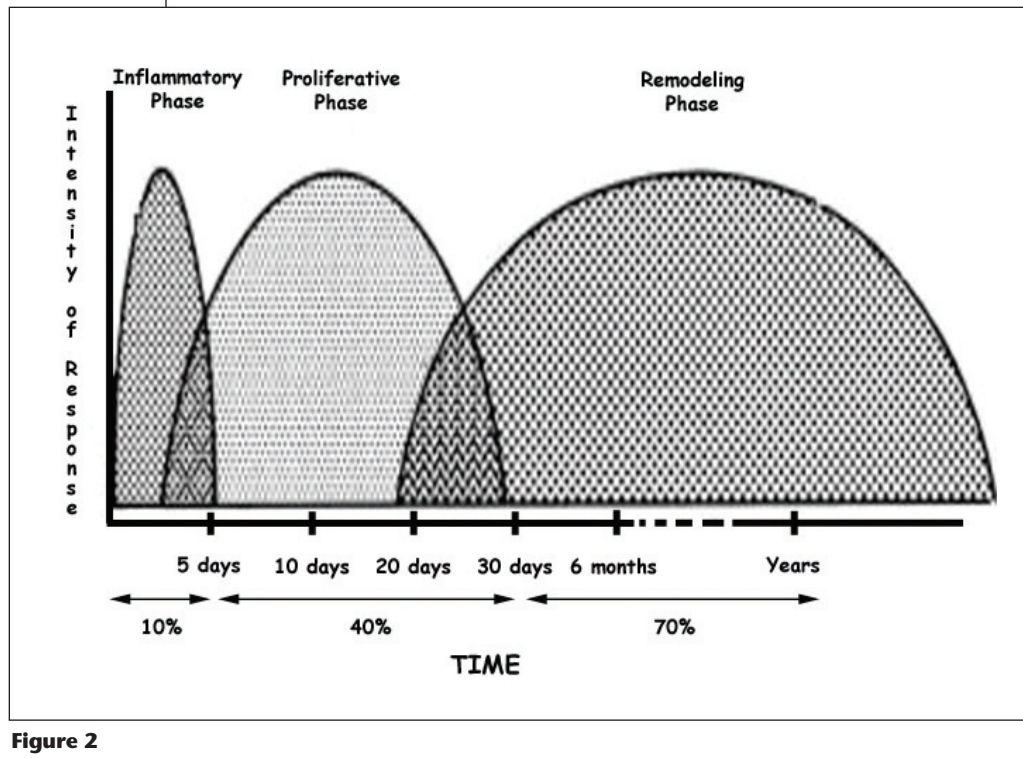



**Figure 2**

## Optimizing...

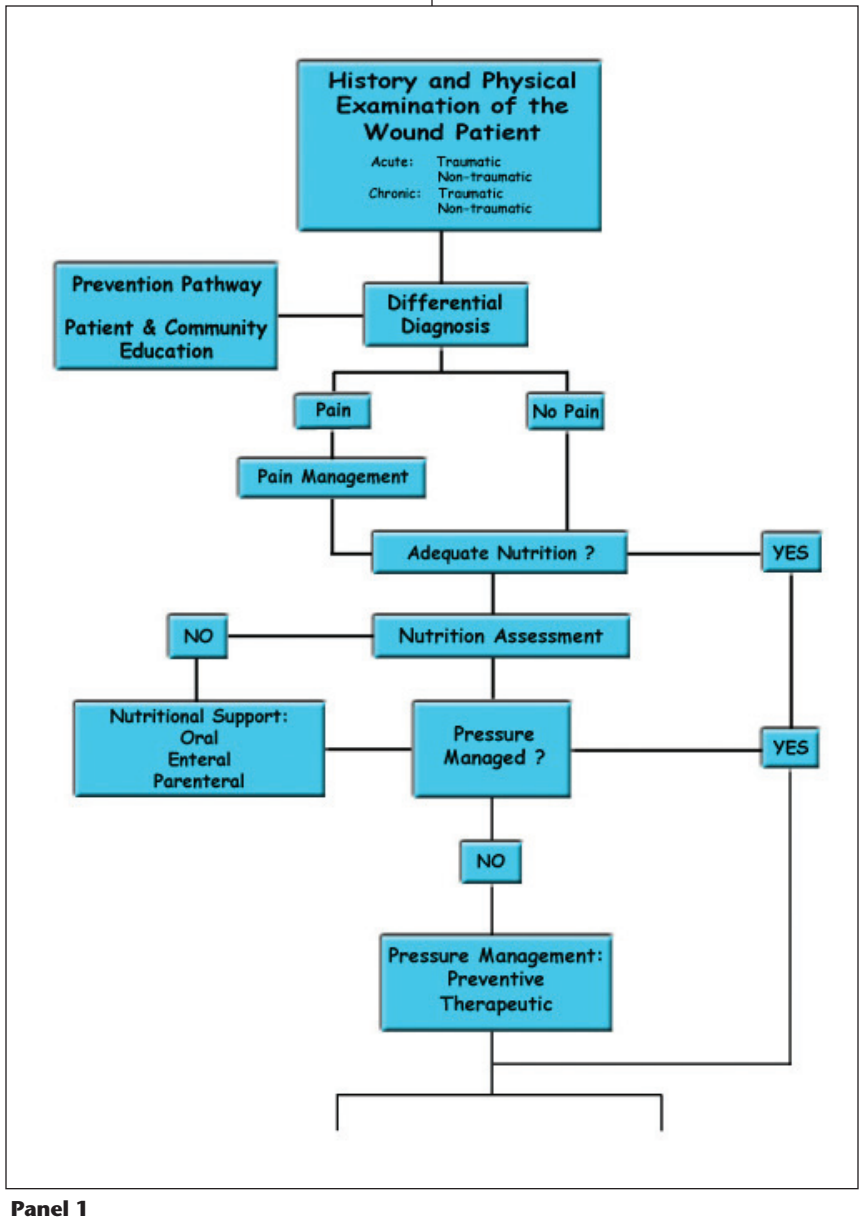
tem, including integrated prevention, diagnosis and therapeutic protocols, should create an environment for optimizing healing outcomes. The ten-step model and algorithm described in this article represent one system designed to deliver those prevention and healing outcomes.

A discussion of wound prevention is placed as the first step in the model to reinforce the importance of establishing patient and community wound education programs in any population, whether in the developed or developing world. Worldwide diabetes, especially type II, is growing considerably with a potentially equivalent increase in diabetic complications, including lower-extremity wounds.[12, 13, 14] Focusing on wound treatment alone, at the expense of preventive measures, will surely minimize the potential for successful programs on a widespread scale, either in the developed or developing world.

Similarly, the second step includes a discussion of the importance of a thorough history and physical examination in order for a proper diagnosis to be made. In addition, the consequences of multiple diagnoses contributing to the persistence or chronicity of a wound will be reinforced. Without an adequate diagnosis and treatment plan, healing outcomes will be unacceptable because the treatment plan is built on a "castle of sand" of deficient differential and final diagnoses.

**TABLE 2**
**Factors Affecting Wound Healing**

| | |
|---|---|
| Incorrect or delayed diagnosis | Wound tension |
| Infection | Pressure |
| Presence of necrotic tissue | Edema |
| Foreign body | Ischemia / Hypertension/Vasculitis |
| Neuropathy | Malignancy |
| Malnutrition | Abnormal metabolic processes |
| Medication | Advanced age |




**Panel 1**

***Without an adequate diagnosis and treatment plan, healing outcomes will be unacceptable.***

### Wound-Healing Algorithm

Subsequent steps of the model described here are clustered around the "spine" of an algorithm, consisting of seven s. Following the initial principles of prevention, history and physical examination and wound diagnosis, the model continues with principles of systemic

*Continued on page 141*

## Optimizing...

disease management, surgical management of necrotic and infected tissue, anesthesia considerations, levels of bony reconstruction and principles of primary and secondary soft-tissue healing. The model is completed with guidelines for wound-maintenance through proper follow-up with the wound specialist, physical medicine, physical therapy, patient educators and other specialists necessary for the patient to continue to see after discharge from the hospital.

*Wounds can be categorized into those of traumatic, infectious and primary ulcerative disease etiologies.*

### Step I. Wound Prevention (Panel 1)

Wound prevention protocols should be developed among all populations, regardless of the sophistication of the community resources available. Ryan discussed the need for global wound prevention initiatives.[15] Many organizations, such as the American Diabetes Association (ADA), International Diabetes Foundation (IDF), Pan American Health Organization (PAHO), World Health Organization (WHO) and the University Diabetes Outreach Project (UDOP) of the University of the West Indies have developed prevention protocols for diabetics and other high risk populations for wound formation such as patients with renal disease, peripheral vascular disease, Hansen's disease, AIDS, malnutrition and those at risk for traumatic wounds.[16-20]

Paradoxically, living in a developed country like the United States does not guarantee that a diabetic will have a foot risk assessment and appropriate measures taken, including patient education, regular foot care, as well as orthotic and shoe therapy. Vast populations in the United States still need education about diabetic and other wound prevention modalities. Similarly, caregivers in all medical communities need to be educated in wound prevention and care protocols.[13, 21-24]

Healthcare providers must reinforce prevention protocols and develop a trust within the communities they serve. This can be accomplished through activities such as practical patient and community educational materials and programs. For example, a simple chart in the public health center with wound prevention reminders, signs and symptoms of wounds and measures to take when a wound is found, supplemented with a take-home form, can create a community "prevention consciousness" whether in a city, town or village. In addition to reinforcing and reviewing these materials with each patient, the staff should create a program for encouraging weight control, smoking cessation, proper exercise and nutrition. Screening programs for diabetes, lipids and HgA1C can be integrated into these community programs whenever possible.[25-28]

When diabetics are diagnosed, a foot wound-risk assessment should be performed, orthotic intervention instituted, routine care performed, skin care begun and appointments made for foot care based on the risk assessment protocol. A program such as this has been shown to contribute to reduction of diabetic wounds, infections and amputations secondary to untreated hyperkeratotic lesions and nail disease.[12,13,29] Creating an impactful system of patient and community education and wound risk assessment and treatment programs remains a universal challenge. Ideas regarding effective models need to be shared among the leadership in both developed and developing regions.

### Step II. History and Physical Examination with Differential Diagnosis (Panel 1)

Wounds can be categorized into those of traumatic, infectious and primary ulcerative disease etiologies (Table 3). Anesthetic wounds can be further subdivided in various etiologies as depicted in Table 4. A thorough history and physical examination is essential to healing a patient with a wound for two reasons. First, the correct diagnosis must be made if the treatment is to be successful. Second, multiple factors influencing the wound may co-exist, contributing to a wound being refractory to treatment (Table 2). If one major etiology or influencing factor of a

*Continued on page 142*

## TABLE 3
## Categories of Wounds

| Traumatic Wounds | Infected Wounds | Wounds from Primary Ulcerative Disease |
|---|---|---|
| Lacerations | Abscess | Vascular I (Chronic PVD) |
| Crush | Necrotizing | Vascular II (Vasculitis) |
| Puncture | TEN | Anesthetic |
| Bite | Wet gangrene | Dermatologic |
| Sting | Ecthyma | Purulent |
| Pressure / Tension | Impetigo | Tropical |
| Iatrogenic | Erythrasma | |

## Optimizing...

wound is not diagnosed, wound healing may not progress in a timely fashion. Smith describes a "One Glitch Sampler," a pneumonic assessment tool to identify potential causes of problem wounds.[30] After the history and physical examination is completed, a differential diagnosis is constructed. The more common causes of wounds can be seen in Table 5.

### *Physical Examination*

The central role of proper wound assessment in the physical examination of the wound patient cannot be underestimated, particularly, probing of the wound to establish whether or not there is osseous involvement. It has been demonstrated that osteomyelitis is present in a high percentage of wounds that clinically probe to bone.[31]

### *Vital Signs*

Vital signs should be obtained on every wound patient. Initial stabilization of the traumatic, unconscious or septic wound patient must always include an assessment of airway patency, breathing, cardiac function by auscultation and palpation of peripheral pulses, identification of external or internal bleeding and renal function.

### *Pain*

Pain must be assessed and treated when appropriate, if doing so does not either interfere with the patient's diagnosis or complicate the patient's condition. Pain management may contribute directly to wound tissue preservation due to vasoconstriction of blood vessels at the arteriolar level in response to pain.[32-35]

### *Nutritional Assessment*

Nutritional assessment should begin with information obtained from the history and physical examination. Determination of the degree of catabolism and whether it is acute or chronic, should guide a plan for oral, enteral or parenteral nutritional supplementation including fluids, protein, lipids, carbohydrates, vitamins and co-enzymes. Ideally, the five tests for nutritional status include albumin, pre-albumin, total lymphocyte count, total protein and total iron-binding capacity.[36-38] In chronic wound cases, nitrogen balance studies may need to be performed.

Antibiotics should be given for both therapeutic and preventive (empiric) reasons based on the condition of the patient and the nature of the wound, including the type of infection or suspected degree of "critical colonization."[39, 40] Wound pressure management should begin without delay, including offloading and splinting techniques.[41] Acute treatment of edema with non-weight-bearing, compression and elevation can begin immediately unless contraindicated by ischemia and/or infection.

### Step III. Vascular Evaluation and Treatment (Panel 2)

The discussion of vascular diagnosis and management is placed as the third step due to the lynch-pin position of this variable in the wound-healing timeline. In a clinical setting, vascular studies may be ordered early in the work-up, certainly even before a thorough evaluation and management of systemic disease can be completed.

If there is a deficit in palpated peripheral pulses or other signs or symptoms of ischemia, including rubor, cyanosis and rest pain or intermittent claudication, respectively, non-invasive studies are generally ordered. Included in this order to the vascular laboratory should be "non-invasive vascular studies with segmental pressures, including toe pressures."[42-44] A vascular specialist should evaluate the non-invasive data after seeing the patient, to determine

*Continued on page 143*

## TABLE 4
## Anesthetic Wounds

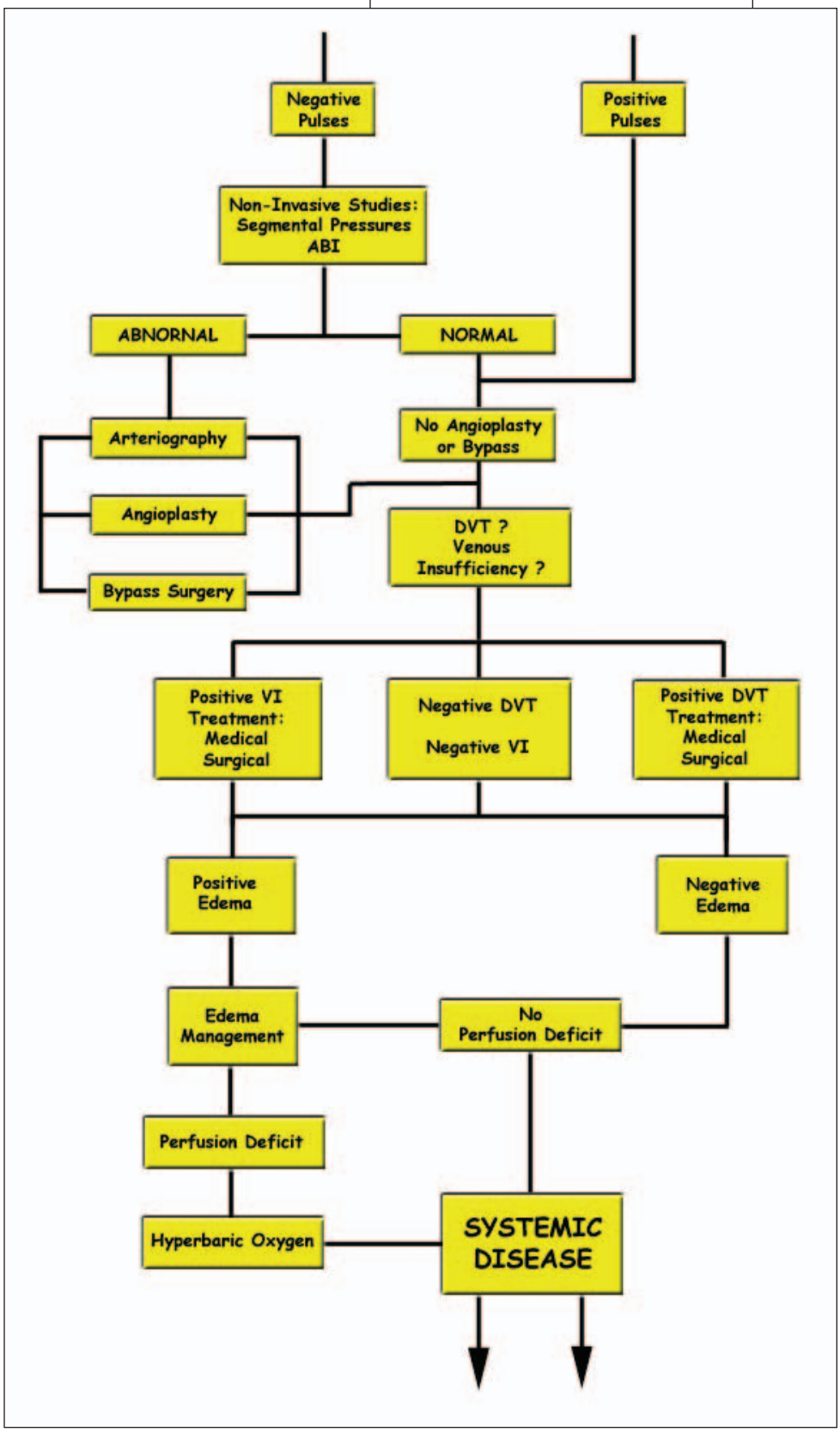
- Diabetes
- Hansen's disease
- Syphilis
- Nutritional deficiencies (B-12)
- Heavy metals (Lead, Arsenic, Mercury, Thallium)
- Alcohol abuse
- Amyloidosis
- Sarcoidosis
- Pharmacologic (Chemotherapeutic agents)
- Guillaine-Barre Syndrome
- Endocrine diseases
- Toxic materials (Amiodarone)

## TABLE 5
## Common Causes of Lower Extremity Wounds

- Ischemia
- Venous disease
- Trauma
- Pressure
- Neuropathy
- Infection
- Dermatitis
- Surgery
- Thermal injury
- Hypertension
- Diabetes
- Renal disease

whether arteriograms are warranted when a consideration of the need for vascular reconstruction is made.

After arteriography, a determination is made as to the candidacy of the patient for bypass surgery. The use of vein or artificial graft and the need for a proximal versus a distal bypass are determined. It is important to note that all vascular surgeons do not do distal bypass procedures, so it is important that a dialogue be maintained among all involved physicians which may include the need to refer the patient to another vascular surgeon at another institution, e.g., if the patient would benefit from a popliteal-medial plantar artery bypass in order to adequately perfuse the foot prior to reconstruction.




**Panel 2**

During the history and physical examination, a determination of the possible presence of deep vein thrombosis (DVT) needs to be made. If suspected, a venous duplex Doppler should be ordered. In most cases a positive duplex Doppler for DVT will provoke hospital admission with appropriate medical treatment. Wound treatments can be started upon admission and surgical debridement can be delayed until after the DVT has stabilized unless the infection is considered to be a surgical emergency, e.g., a deep space abscess with gas in the tissues.

At the same time as the vascular examination, signs and symptoms of venous disease should be evaluated.[45-50] Lymphedema can be primary or secondary. Associated with venous insufficiency and chronic lymphedema are hyperpigmentation, lipodermatosclerosis and intermittent secondary cellulitis. Intermittent cellulitis can contribute to a more severe degree of chronic, intractable lymphedema and ulceration. In the case of unilateral edema, proximal obstruction such as an intrapelvic mass must be ruled out. Other causes of edema should be considered, including Milroy's

*Continued on page 144*

## Optimizing...

disease (congenital lymphedema), congenital familial lymphedema, lymphedema tarde, lymphedema praecox (congenital hypoplasia of the lymphatics), postphlebitic syndrome, and neuropathy, especially neuropathy associated with Charcot disease.[51] There is some speculation that the edema from neuropathy may be due to vasodilation with subsequent arteriovenous shunting.[52, 53]

### Lymphedema Management

Lymphedema management includes elevation, compression, with both single and multiple-layer dressings being used in various combinations. Single-layer wraps are available which create a pressure gradient in the foot and leg, from distal to proximal (Setopress™). In extreme cases of intractable massive lymphedema, consideration should be given to referral to a lymphedema clinic where the specialty staff incorporates various foam materials into multilayer compression dressings as well as other treatments, including massage. Historically, edema management, particularly subtle forms of lympedema, have been therapeutically underserved but it has been substantially established in modern wound-healing literature that even mild cases of lymphedema can significantly delay wound healing.[51]

Compression dressings are used regularly for venous ulcers, with ionized silver products, xenografts and allografts applied directly on the debrided wound prior to the application of the compression dressing. Pentoxyfylline has been used for treatment of venous ulcers with and without compression (54). Surgical procedures for venous ulcers include autografts, traditional open venous ligation (Linton procedure) and subfascial endoscopic perforator surgery (SEPS).[46]

If a patient is optimally perfused after bypass surgery or was non-bypassable and still shows a perfusion deficit, consideration should be given to out-patient hyperbaric oxygen therapy (HBO). Many patients benefit from HBO therapy, including those with wounds where primary closure has been delayed to optimize tissue oxygenation with HBO before primary closure.[55-59]

In the presence of significant amounts of infected tissue in an extremity being prepared for bypass surgery, consideration should be given to a pre-bypass debridement to avoid contamination and infection of extremity tissue, including intravascular infection, significantly increasing the risk of bypass failure, as well as sepsis.

### Step IV. Management of Systemic Disease (Panel 3)

The importance of communication with a primary care physician

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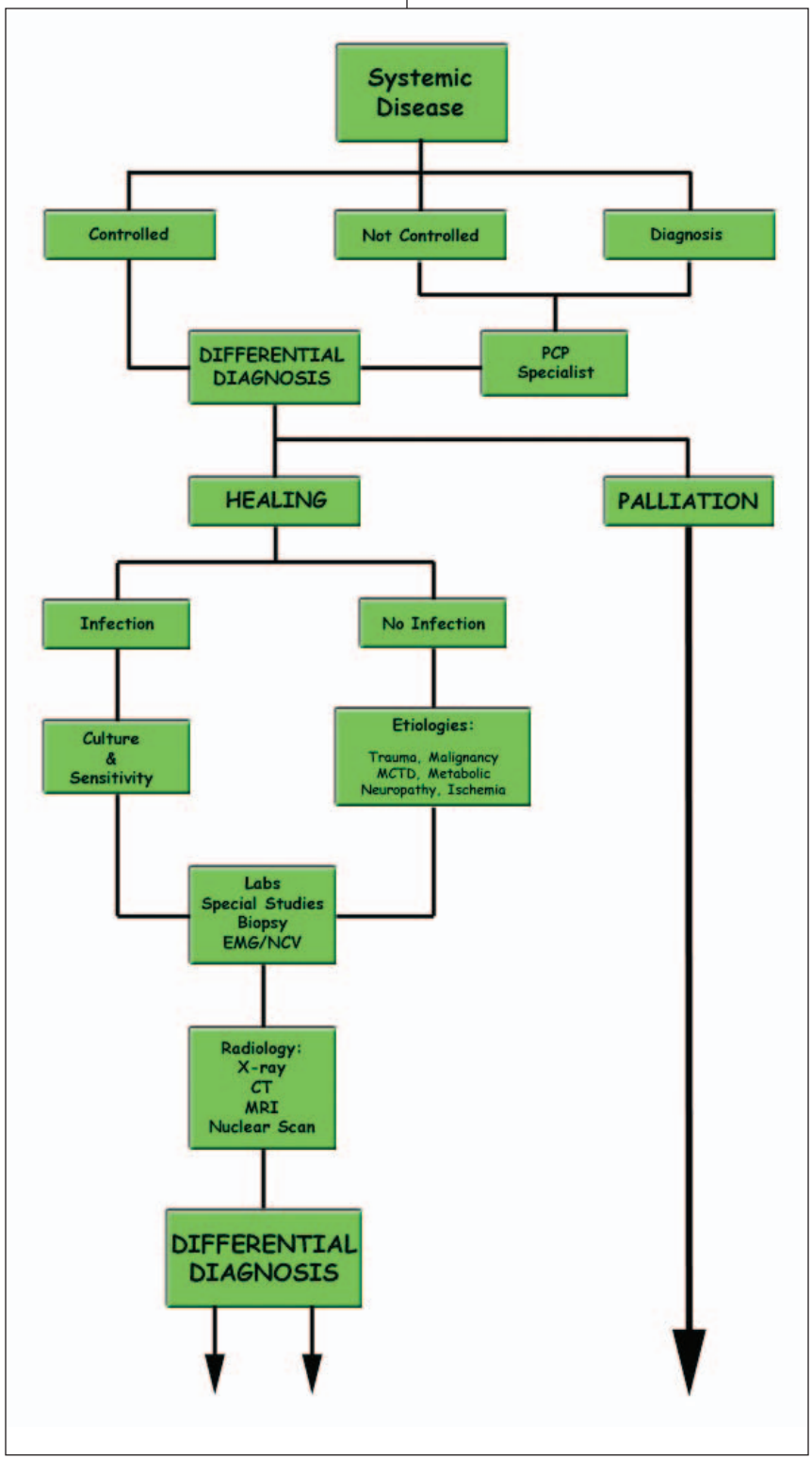


**Panel 3**

## Optimizing...

(PCP), internist or other medical specialist cannot be underestimated. The role of systemic disease in the natural history of a wound cannot be adequately determined without a thorough history and physical examination. Acute versus chronic disease, in addition to the various complications of systemic disease, affect the course of wound healing in different ways.[61]

The final common pathways in the development of a healed wound are directly affected by most organ systems, including: cardiac (tissue perfusion), pulmonary (tissue pO2), gastrointestinal (nutrition, antibiotics), hepatic (protein synthesis, osmotic edema), pancreatic (insulin), renal (advanced glycosylated end products, hypertension, fluid and electrolyte balance) and immune (infection resis-

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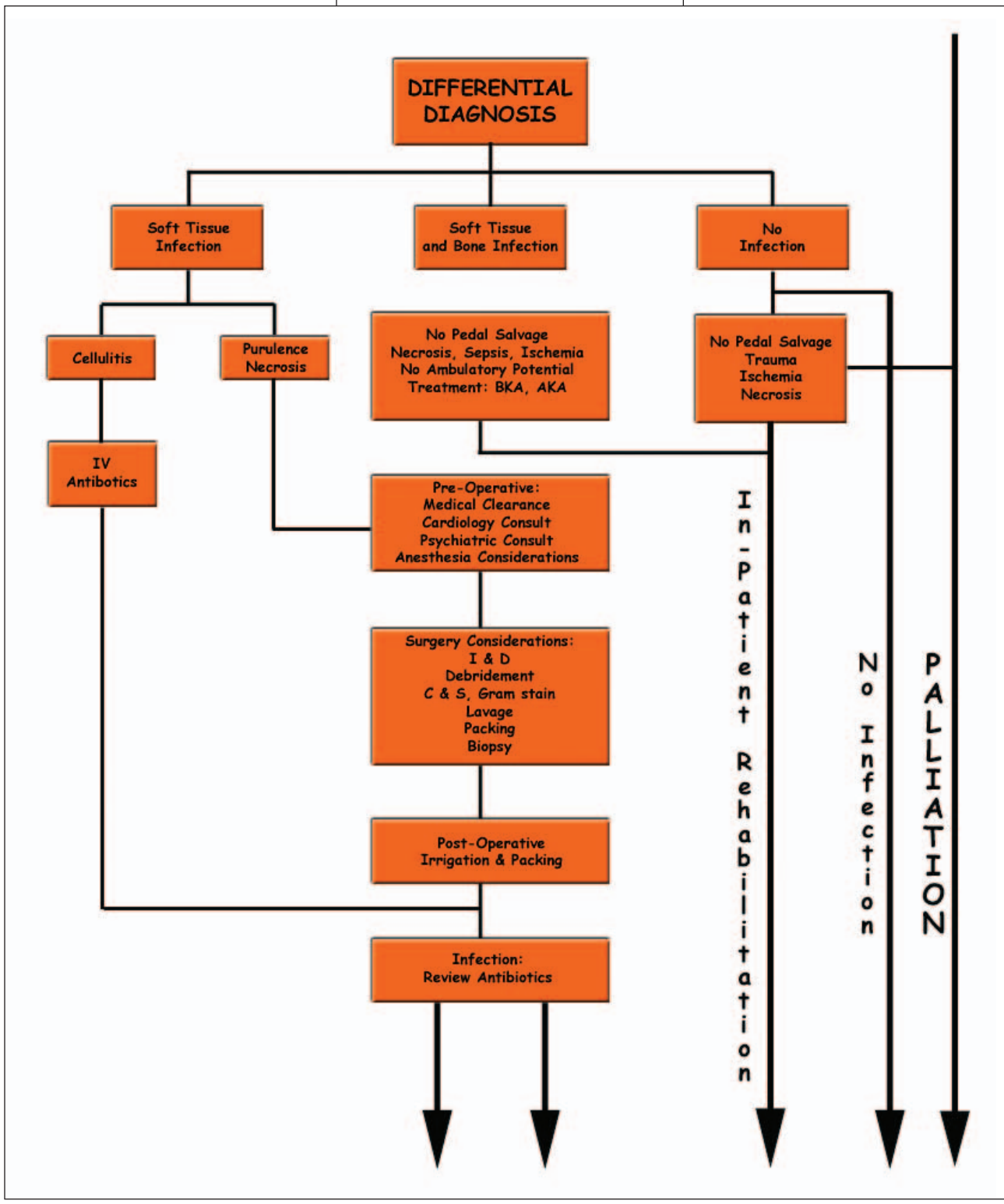


**Panel 4**

## Optimizing...

tance and response).[61, 62] Obviously, any acute or chronic disease, whether diagnosed or not, will influence the normal stages of wound healing, anywhere in the body. Even in the best circumstances, wound healing may become difficult due to pharmacological factors, such as corticosteroid use in rheumatoid arthritis or to pathophysiologic factors such as lymphedema secondary to arteriovenous shunting in diabetic neuropathy.[52, 53, 63]

The differential diagnosis is a "work in progress," a dynamic versus static list of etiologic contributors, to be subtracted from and added to as new information from the laboratory, radiology and special studies are obtained or as the patient and wound condition changes. The possibility of co-existing, multiple etiologies must constantly be considered and acted upon to achieve optimal healing outcomes.

### Step V. Healing Versus Palliation (Panel 3)

The subject of healing versus palliation should not be one relegated to a "gray" area when it comes to wound management. Early on after the encounter with a wound patient, a determination needs to be made as to the "healability" of the particular patient. Attending physicians and family members should be enjoined in a dialogue about whether healing or palliation is the outcome of choice. These discussions, in many cases, coincide with a discussion of a consideration of hospice measures for a patient. If indeed, pre-hospice wound management is considered the best course, the focus can be made on proper wound treatment interventions, including pain management, odor control, prevention of further decubitus changes and wound product choices that encourage a dry versus wet condition. The palliative pathway is unique because sometimes moist wound-healing principles are pre-empted by the goal of wound-bed drying both to retard further bacterial colonization and to control wound odor. In a long-term care facility, appropriate communication among the wound specialist, attending physician, nursing staff and families, will facilitate a humane transition to hospice or palliative wound care.

### Step VI. Peri-Operative Assessment: Identification and Treatment of Infection, Necrotic Tissue and Malignancy (Panel 4 and 5)

As the differential diagnosis is refined during the work-up of the wounded patient, focus is directed on the role of infection in the wound or systemically, in the case of a septic patient. Proper cultures are obtained, preferably with tissue and bone, versus swab cultures of soft tissue. In many cases, tissue for culture and sensitivity (C&S) is obtained in the emergency room, office setting, wound center or at

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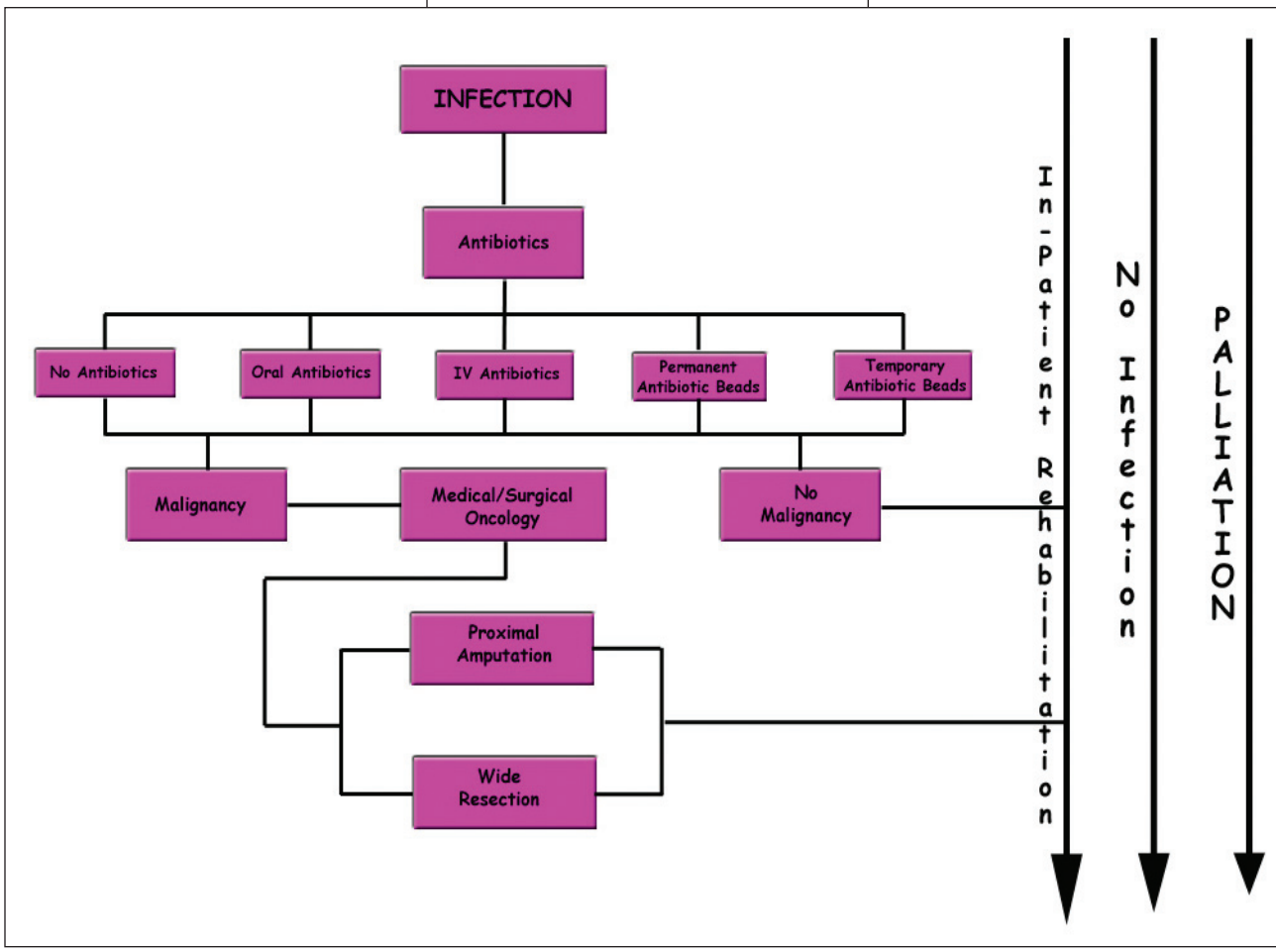


**Panel 5**

bedside after hospital admission. These cultures should, in most cases, be repeated in the operating room after appropriate anesthesia has been administered. It is well established that superficial swab cultures from sinus tracts are poor representations of the etiologic bacteria in underlying osteomyelitis.[64] Bone for biopsy should be harvested for both C&S, as well as pathology, so that a correlation can be made between the microbiological determination and the histological interpretation after decalcification and sectioning. The pathological information generates important questions asking whether the osseous cellular infiltrate is more suggestive of chronic versus acute osteomyelitis, the periosteum is violated by the contiguous soft-tissue infection, there are histological signs of necrotic and/or infected bone or whether the bone looks normal, e.g., uninfected.[65]

*Clinical distinction must be made among cellulitis, purulence, necrotic tissue and no observable necrotic tissue or surgical infection.*

An infectious disease specialist can help determine the appropriateness of oral versus parenteral antibiotics as well as the value of combination antibiotics and also can assist in the management of antibiotic complications. Communication between the wound specialist and infectious disease specialist is essential regarding harvesting of appropriate tissue for C & S, including soft-tissue and bone, and to the level of resection of infected soft tissue and bone by the surgeon. This communication should include a discussion of intra-operative use of implantable antibiotic-impregnated beads, either non-absorbable (PMMA beads) or absorbable [OsteoSet® (Wright Medical), Vitoss® (Orthovita)].

In many cases, the infectious disease specialist will limit the course of IV antibiotics post-operatively if he has been informed by the wound surgeon that the infected and necrotic bone has been aggressively resected prior to primary closure of the wound. The management of methicillin-resistant staphylococcus aureus (MRSA) and vancomycin-resistant enterococcus (VRE) should always be done in conjunction with an infectious disease specialist when one is available for consultation. The potential toxicity of antibiotics such as linezolid (Zyvox™), e.g., seizures in dialysis patients, needs to be constantly monitored for by the infectious disease specialist.

Clinical distinction must be made among cellulitis, purulence, necrotic tissue and no observable necrotic tissue or surgical infection. Traditionally, cellulitis is treated with oral or parenteral antibiotics only, depending on the severity of infection. No surgical intervention is required. On the other hand, surgical debridement and/or incision and drainage is required in the presence of necrotic tissue or purulence. The old adage, "never let the sun set on an abscess" is as true today as it was before the discovery of antibiotics. If no infection is observable, other sources of wound etiology must be investigated, including trauma, ischemia, vasculitis, or primary ulcerative disease (Table 2, 3, 4).

*Sometimes, it is easy to forget that wound caregivers are not just treating "wounds" but rather people with wounds.*

Maintaining perspective is sometimes difficult when limb preservation becomes personal. Strict criteria should be maintained for deciding on a higher amputation. Consideration of the whole patient must be kept in constant focus to avoid the risk of sepsis. The best wound healers are those that do not lose perspective and allow a patient to proceed to amputation and prosthetic rehabilitation when other distal preservation alternatives become unrealistic or life-threatening. Awareness that patient conditions change, including the need for consideration for hospice care, should be provided with constant vigilance. Sometimes, it is easy to forget that wound caregivers are not just treating "wounds" but rather people with wounds.

Pre-operatively, the timing of appropriate consultations, including medicine, cardiology, anesthesia, physiatry, and sometimes psychiatry, cannot be underestimated. Many patients suppress expression of anxiety and depression over the thought of even partial foot amputation let alone an above or below-knee amputation. Time should be taken to elicit these emotions and suggest to the patient and their family that a psychiatric consultation might be beneficial. Many times, decisions on amputation are made and the patient is scheduled for surgery in a short window of time. Clinicians forget sometimes that the psychological impact on the patient can be devastating and that this negative mindset may contribute to a poor healing outcome.

When ordering laboratory tests, radiological studies and special studies, it is important that coordination and communication among specialists be maintained. The details of the patient's nutritional status should be completed earlier rather than later. Dietary and surgical nutrition consultations should be obtained under circumstances of suspected malnutrition. It is paramount to remember that every surgical procedure contributes to endocrine-system mediated catabolism. Constant consideration should be given to creating an anabolic condition in every wound patient.[37, 38]

The choices of anesthesia should be based on giving the most

*Continued on page 148*

## Optimizing...

benign type of anesthesia that will achieve the desired result, both for debridement, incision and drainage, delayed and primary closure and amputation procedures. Historically, general and spinal anesthesia have been used for lower-extremity wound management, when in many of these cases, local or regional anesthesia would suffice. The negative effects of catecholine release from the stimulus of afferent pain impulses on the hypothalamic-pituitary pathways, particularly in patients with cardiac disease and metabolic instability such as diabetes, are well established.[66] Local and regional blocks such as digital, partial ray, ankle or popliteal-saphenous, have significantly fewer complications when compared to general and spinal anesthesia and should be considered as the primary anesthetic technique.[67]

At this time, attention can focus on the actual surgical needs of any particular wounded patient. Objectivity is many times lost when debriding a wound. Anticipation of what tissue layers will be left after debridement for future reconstruction often precludes a thorough debridement. As a general rule of thumb, if tissue looks marginally viable today, it will probably be necrotic in the near future. Trying to preserve this irreversibly-damaged tissue serves no purpose for the patient and, if anything, will necessitate an additional visit to the operating room with the additional risks of surgical stress, anesthetic complications and blood loss. There are many valuable techniques to obtain healing through secondary healing pathways that should be considered when evaluating wound healing options which will make more aggressive debridements more acceptable. These include xenografts, allografts, vacuum-assisted closure and growth factors.

*Determination for final wound closure or delayed closure should only be done when all infected bone and soft-tissue is removed with no signs of residual or recurrent infection.*

Debridement must be thorough, with only bleeding tissue remaining when completed. Similarly, incision and drainage of purulence must be complete, with all potential spaces being observed for occult residual infection. From the removed necrotic tissue, biopsy specimens may be obtained, not only for C & S, but also to evaluate for vasculitis and malignant transformation of a chronic wound, e.g., a "Marjolin's" ulcer with squamous cell carcinoma (Figure 4) at the site of a chronic wound. When biopsy demonstrates squamous cell carcinoma, wide resection is most often indicated, with a sentinel node biopsy to assess for regional metastasis. This diagnostic test is best managed by interventional radiology.[68]

**Figure 4**

Completion of the application of debridement principles at this juncture in treatment requires adequate lavage, with or without antibiotics, and tissue packing to ensure unrestricted drainage of post-surgical fluid. The continuum of surgical wound care requires that irrigation and re-packing be continued post-operatively, with appropriate consideration given to premedication for pain control prior to each dressing change. It is during this time that intra-operative C & S results should be reviewed and appropriate changes or additions made to the antibiotic regimen.

At this point in the treatment pathway, the infection management should begin to be under control, with regular communication occurring between the wound specialist and the infectious disease specialist through progress notes and verbally. Discussion topics such as antibiotic bead removal, further debridement, primary or delayed closure and management of complications from antibiotics should be discussed on a regular basis.

If malignancy is discovered, a continued dialogue should occur among wound specialist, pathologist, hematologist-oncologist, interventional radiologist, plastic surgeon and vascular, general or orthopedic surgeon, in deciding the proper treatment, including wide resection of the wound or potentially, a proximal level of amputation such as BKA or AKA.

### Step VII. Levels of Osseous Reconstruction (Panel 6)

The importance of ambulatory potential in decision-making in the level of amputation relates to the fact that there are more biomechanical restrictions on choices of procedures when planning the reconstruction of the foot and ankle in the wounded patient.[69, 70] For example, a transmetatarsal amputation (TMA) would be a much better choice for an ambulatory patient than a Lisfranc's amputation due to the potential loss of tendinous planar balance provided by the tibialis anterior, tibialis posterior, peroneus longus and peroneus brevis tendons. Traditional-

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## Optimizing...

ly, in the ambulatory patient, a Chopart's amputation is usually considered if there is not enough tissue to close adequately at the transmetatarsal level. In the non-ambulator, healing may be more important than the functional result. Post-operative planar deformity in the non-ambulatory patient, however, can cause boney prominences that can increase the risk of decubitus ulcers even from mattresses and when in sitting in a chair or wheelchair.

Another issue that has received inadequate discussion is reasons to avoid BKA in patients who may have limited ambulatory potential. Many patients can use their lower extremity to help move themselves around in bed, with and without assistance. An intact extremity with a reconstructed partial foot can be used to help a patient participate in his or her transfer. Awareness by caregivers of the loss of self-esteem and sometimes even depression after a BKA or AKA should be part of the decision-making process involved with each patient, each one deserving individual consideration. Certainly, patients and families must be educated as to the implications of an emergency higher amputation if the patient is septic or at risk of impending sepsis. Sometimes, a physiatrist can advise the multi-specialty team, including the surgeon, about the pros and cons of pedal salvage versus amputation after a thorough functional assessment, which should be requested on every patient at risk for limb loss with a significant foot infection or necrotic wound.

*Ideally, primary-flap closure of the wound is the first choice when completing the healing process of a wound.*

Determination for final wound closure or delayed closure should only be done when all infected bone and soft-tissue is removed with no signs of residual or recurrent infection. Correspondence with an infectious disease specialist regarding the presence or absence of infected bone or soft tissue in the foot is important. An infectious disease specialist will decide, based on the immune status of the patient, the virulence of the infection and the amount of tissue involved, how long the course of the antibiotic treatment should ensue.

There are and will probably be for a long time, differences of opinion regarding a protocol for levels of amputation within the foot, particularly those related to ambulatory patients. Conservative approaches and respect for this type of prudent protocol, based on years of experience by podiatric, orthopedic, vascular and general surgeons, suggests that "pushing the envelope" to gain some extra tissue in the foot may not, in most cases, be the best choice for the patient. Biomechani-

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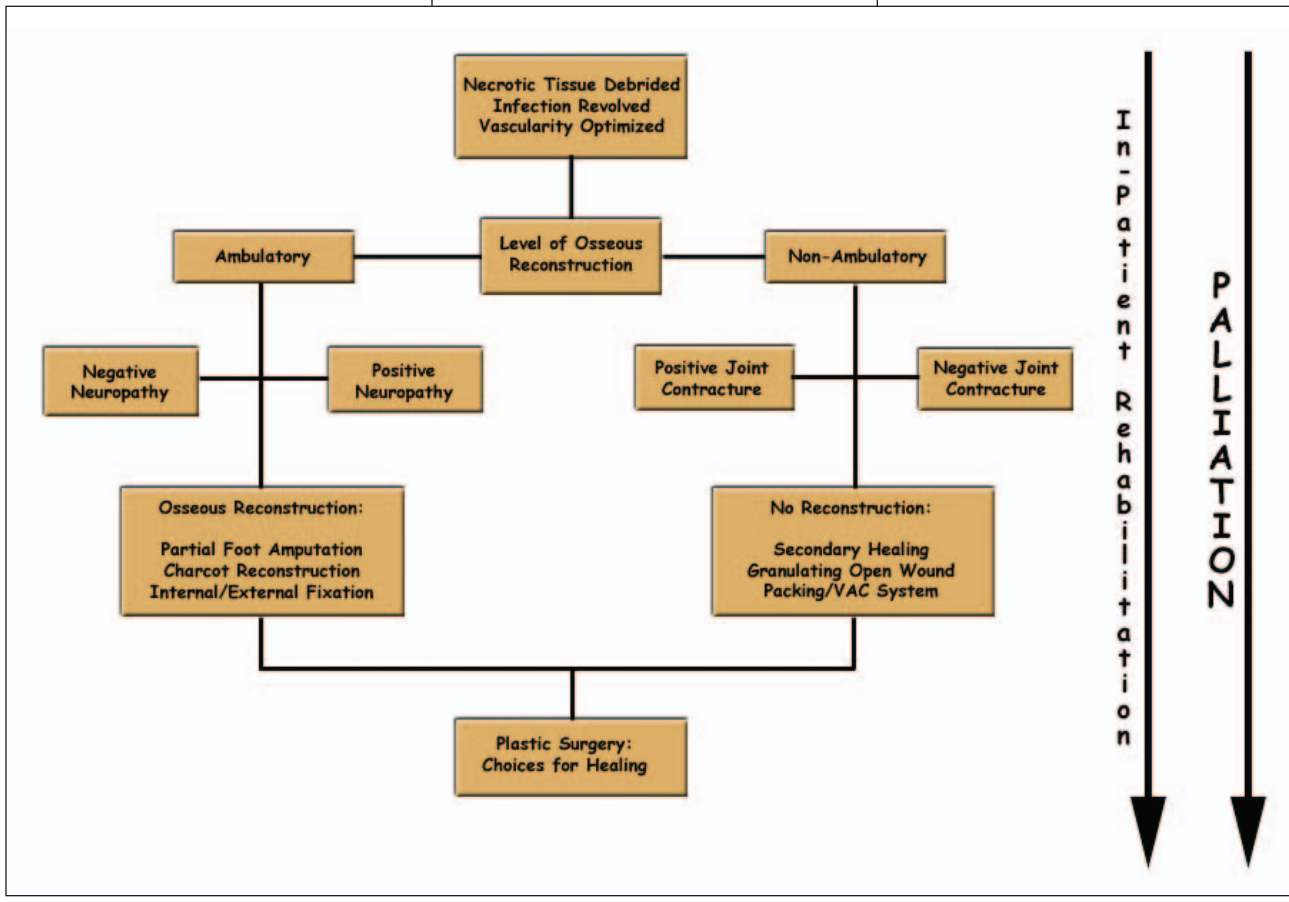


**Panel 6**

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cally sound choices of levels of amputation within the foot can minimize the incidence of transfer hyperkeratotic lesions with subsequent ulceration and risk of further infection, tissue necrosis and another series of operative procedures.[71, 72, 73]

Notable decisions at this time involve those regarding the Charcot foot, the use of internal and external fixation, Achilles tendon lengthening, possible need for bone grafting, and final decisions on either complete primary closure or planning for some degree of secondary healing.

Internal fixation can be used in bone that has been thoroughly debrided and treated with appropriate antibiotics. For example, Steinman pins and an external fixation device may be needed in a diabetic with a pathologic fracture of the calcaneus secondary to osteomyelitis. Use of external fixaton has gained considerable support in the literature in recent years, suggesting the early surgical intervention in the Charcot foot may be the prudent choice and not an unconventional one as previously thought in the past.[74, 75]

Calcium diphosphate beads, with and without antibiotics, can be left in the foot or mixed with other types of auto and allograft. The effect of residual equinus on a reconstructed foot, particularly in the presence of neuropathy, is well established.[76, 77] Strong consideration should be given to lengthening the Achilles tendon in these cases to avoid excessive ground-reactive forces when weight-bearing rehabilitation begins.

Closure options after debridement and/or amputation should be thought of as a continuum of choices, not an "all or nothing" process. For example, obtaining layer closure over the bone with viable soft tissue, can at least simplify the wound by making it a soft-tis-

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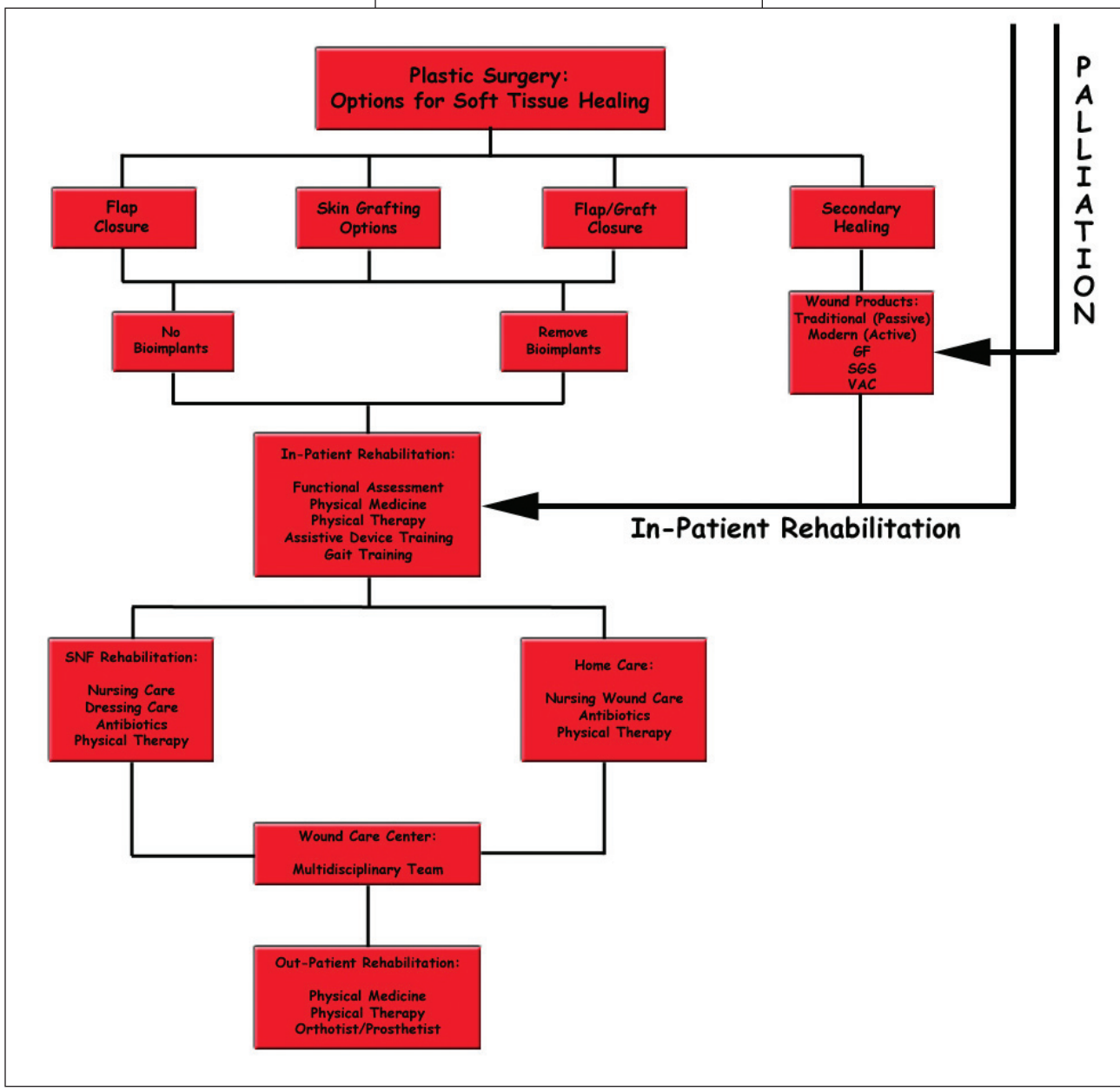


**Panel 7**

sue-based wound and not one based in bone. Another important outcome of this first layer of closure is to protect viable, uninfected bone from recontamination. This first part of wound closure should be referred to as "the most important suture," because this layer of closure can protect the bone if the more superficial layers dehisce. At worst, in this situation, the clinician has a dehisced soft-tissue wound and not one complicated by osteomyelitis. Closing only the deep layer of soft tissue over bone is best described as "partial primary closure."

**Step VIII. Soft Tissue Healing (Figure 7)**

First, the general condition of the patient must be established prior to attempts at wound closure. Medicine, endocrinology and cardiology must be continually consulted as the final stages of reconstruction approach. Choices of anesthesia should be considered in the same manner as they were before the first series of debridements.

Graft surveillance may be requested by the vascular surgeon if bypass has been performed earlier. Close communication with the vascular surgeon should be done prior to closure, particularly regarding specifics of distal grafts, in an attempt to avoid graft compromise. Care by the surgeon doing the pedal reconstruction must not only involve the soft-tissue and osseous surgery but should include careful technique if administering ankle or combined popliteal-saphenous nerve blocks at the knee.[67]

Sometimes the vascular surgeon will request that the reconstructive foot surgery be done immediately after the bypass procedure.[78] Usually the vascular team can prep and drape the foot and ankle and seal off the foot segment until after the bypass is completed. This sequential surgery has a number of valuable components. First, the foot is usually optimally perfused immediate after the bypass. Second, the patient will only have a relatively small increase in anesthesia time with the added foot procedure, avoiding the need for a subsequent visit to the operating room.

Furthermore, a supplemental ankle block or combined popliteal-saphenous nerve block at the knee can be performed to allow anesthesia to bring the patient out of general anesthesia. Contraindications to the sequential bypass-foot reconstruction procedures would include cardiopulmonary complications from anesthesia, excessive blood loss during the bypass, excessive general anesthesia time or the use of a synthetic vascular graft.

Normal white-blood-cell count and temperature should be achieved prior to scheduling soft-tissue closure. Many times, compromise in this area will result in wound dehiscence, infection, and further tissue necrosis. This could necessitate additional surgery and anesthesia time.

*The value of drains cannot be overemphasized, since all wounds drain.*

***Edema***

Prior to closure, edema is another variable that is often not given enough consideration. Even subtle forms of edema can increase the risk of post-operative wound dehiscence, particularly in patients compromised by marginal perfusion, malnutrition and chronic disease.

***Primary Closure***

Ideally, primary-flap closure of the wound is the first choice when completing the healing process of a wound. This method of closure provides the most direct course to final healing of all the possible choices, including delayed primary closure, partial primary closure and secondary healing.

Prior to primary closure, tendons should be reattached, either with bone anchors, anchoring by suturing through oblique drill holes in the bone or in the case of osteopenic and/or osteoporotic bone, sutured directly to capsular tissue. Judgment whether to use an absorbable or non-absorbable suture is left to the surgeon at the time of closure.

***Delayed Primary Closure***

Delayed primary closure would be used at the time of debridement and/or incision and drainage, in order to preserve as much viable tissue for future flap closure when the infection and necrosis have been managed. With flexible, delayed flaps such as those at a transmetatarsal or Chopart's level, a loose retention suture or sutures can be used to keep optimal tissue-to-tissue contact, allowing enough cubic volume in the wound for flushing and packing. Open flaps tend to remain moister and subsequently more viable with closer apposition to other viable tissue. Avoidance of retention sutures may be a prudent choice in the presence of a fetid, mixed aerobic and anaerobic infection despite an apparently successful aggressive debridement.

Partial primary closure may be a practical choice in the situation when there is enough deep fascial tissue for layered closure over bone but inadequate flap for a tension-free skin closure. Again, even if the superficial tissues are left open for secondary healing pathways, at least the bone segment has been covered and can begin to heal primarily to avoid further infection. In addition, tendons that have been reattached will begin to heal with this primarily closed layer.

***Drains***

The value of drains cannot be overemphasized, since all wounds drain. If the wound bed does not demonstrate sanguinous drainage, it probably will not heal and reconsideration should not be given to closing the wound at this level. Once the fascial layer can be closed, a drain can be inserted and can be attached to wall suction. We utilize a technique called "peri-closure lavage" where a 20 cc. syringe and 18 gauge needle is inserted into the

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deep tissue through the peri-wound during wound closure. In this manner, the wound is continuously lavaged during closure. This technique removes much of the blood from the internal wound bed, long before the collection device is attached at the end of the procedure.

If one observes the behavior of small to medium-sized drains used in the foot, it seems that much of the sanguinous drainage progresses to clotting before it can be evacuated and essentially becomes "unavailable" to the drainage device. This contributes to a greater volume of hematoma formation with all of its potential complications and negative effects on the ultimate healing outcome of the wound.[79] Another technique, for larger volume wounds, is the use of a compression cuff placed on a NSS bag to provide hands-free, continuous peri-closure lavage of the wound.

When doing sequential bypass-reconstructive foot procedures, the patient is routinely heparinized peri-operatively and excessive bleeding can be expected. Measures should be taken to minimize the intra-operative blood loss and hematoma in these situations. First, meticulous surgical technique must be maintained during the foot reconstruction with the avoidance of unnecessary vascular tissue laceration. Second, electrocautery should be employed to cauterize all visible bleeders, with attention being given to recessed areas (e.g. between the plantar intrinsic muscles) where occult bleeding can continue post-operatively). Third, liquid thrombin can be combined with cellulose (Gelfoam™) and packed in the wound for 5-10 minutes prior to flap closure to reduce the general sanguinous ooze. The cellulose packing can be removed prior to flap closure but the effects of residual thrombin are still active in contributing to hemostasis. Finally, fluff dressings with mild compression can be safely applied to the foot, while avoiding excessive pressure to any components of a vascular graft, if present.

### *Secondary Healing*

Secondary healing offers many options of wound bed dressing products. When the decision is made to allow the wound to granulate, some thought must be given to the best way of managing that wound. Once the wound has been debrided and the bioburden of bacteria and necrotic tissue has been removed, other variables for wound healing should be evaluated, similar to the methodology with primary or partial primary healing.

Passive products, whose goal is to provide a moist wound bed and/or assist in removal of drainage, include NSS, topical antibiotics, hydrogels, hydrocolloids, foams, films, alginates and ionized silver.[80] New concepts of "critical colonization" of wounds have provoked the use of ionized silver products to reduce this level of colonization in open wounds which may be undergoing active chronic inflammatory tissue damage even without clinical signs of infection.[39, 40, 81]

*Equinus deformities can exacerbate neuropathic plantar lesions when weight-bearing begins.*

More active products and techniques, such as growth factors, metalloprotease inhibitors, electrical stimulation, vacuum-assisted closure (VAC®, KCI), xenografts, allografts and monochromatic infrared energy (MIRE), can influence directly or indirectly the molecular and cellular components of the body's own wound healing phases.[82-91] Education about these new products and technologies is essential to optimizing healing outcomes with their use. For example, capricious use of a particular allograft without either concern for other variables of wound healing such as infection management and edema control will ultimately lead to graft failure and poor healing outcomes in general. In an attempt to synergize the various newer wound technologies, combination therapies have been attempted, mostly with positive anecdotal reports, suggesting the value of their continued investigation. For example, vacuum-assisted closure is used with xenografts, for the same reason it was originally used for use with autografts, i.e., elimination of shearing forces, optimal graft-to-bed contact and drainage of seroma and hematoma.

### *Split-Thickness Skin Grafting*

Split-thickness skin grafting (STSG) still plays a major role in wound healing and can be used sequentially over various types of allografts after the allograft has created a substantial wound base for final skin grafting. As with allografts or xenografts, some wounds should not be skin grafted with autograft as the first choice, e.g., patients with sickle cell disease. The graft failure rate is high in this patient population due to the micro-ischemic nature of the disease. Other alternatives are probably better options in the sickle cell patient, such as an allograft after an adequate course of hyperbaric oxygen therapy (HBO).[92]

Whether in the ambulatory or non-ambulatory patient, splinting of the foot in neutral position to the leg is important for a number of reasons. First, immobilization can augment the reduction of post-operative pain. Second, a posterior splint often discourages a patient from weight-bearing on the foot in the immediate post-operative period more than a simple dressing with elastic bandage. Third, the prevention of planar deformities is extremely important both for the ambulatory and non-ambulatory patient but particularly for those who will be rehabilitated to weight-bearing status.

Equinus deformities can exacerbate neuropathic plantar lesions when weight-bearing begins. Varus or valgus deformities can cause weight-bearing hyperkeratotic lesions which progress to ulceration. Transverse plane deformities, both abduction and adduction, can also

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cause decubitus lesions. In addition, all three planar-types of deformities, individually or in combination, can make it very difficult for the orthotist and prosthetist to fit the healed wound patient with orthotics, ankle-foot orthoses, shoes and braces.

Sometimes, peripherally-inserted central catheters (PICC) will be placed while the patient is still in the hospital and will need to be managed by home care infusion nurses after discharge or in a skilled nursing facility. Simultaneous with the home antibiotic, treatment will include home wound nursing care or nursing home wound care. The placement of the patient at home or in a skilled facility, along with the particular antibiotic and wound care needs, is the responsibility of the case management department in the hospital.

### Step IX. Maintaining a Healed Wound

Non-weight-bearing during the healing process is always a safe default order but there are many wounds which can withstand partial weight-bearing forces. Communication with the physical therapist, including a plan for transition from non-weight-bearing to partial weight-bearing to full weight-bearing with or without as-

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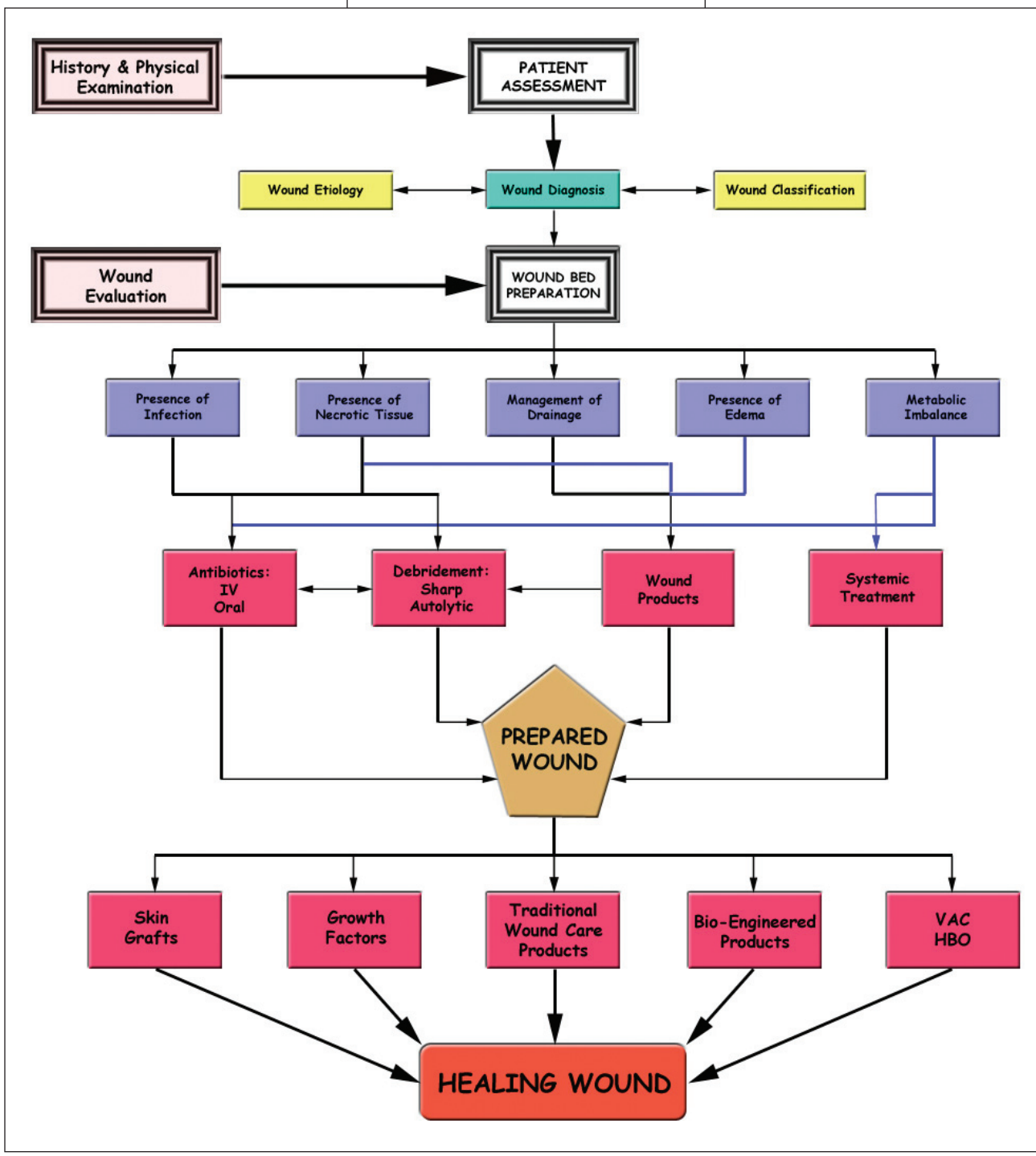


**Figure 5**

sistive devices is the responsibility of the wound specialist.[41] Unfortunately, all too often, there is a certain loss of control over the patient's wound management after the patient is discharged from the hospital. Whether the patient is discharged to home or a nursing facility, there must be an attempt made at not only maintaining appropriate wound care, antibiotic therapy and physical therapy, but also maintenance of communication between the wound specialist and patient for follow-up appointments.

Complicating the picture even further are the somewhat fastidious needs of some of the new wound products and technologies such as allografts and vacuum-assisted closure devices required for the patient to obtain the optimum healing benefits from them. The wound specialist needs to use his staff very efficiently to continue this communication to ensure that appropriate post-operative care is being maintained, signs and symptoms of complications monitored for and the patient and family members kept informed regarding the patient's progress. One weak link at the time of discharge is the incomplete discharge instruction form. The wound specialist should take the responsibility to fill out the specific details of wound care, antibiotic therapy, weight-bearing status and follow-up appointment.[93, 94]

### X. Multidisciplinary Approach to Wound Prevention and Treatment

The important role of multiple specialists in complicated wound care is well established.[24, 95-99] Timing of initiation of this specialty involvement in a wound case is the responsibility of the primary wound specialist. Specialty care may begin in an out-patient setting and continue in the hospital, but must continue to be coordinated after discharge. Vascular surgeons need to have close control over their bypass patients after discharge. The podiatric surgeon needs to see his patient regularly and when appropriate, refer the patient for fitting for orthoses, shoes, ankle-foot orthoses and braces. Convenient access to these specialists can facilitate the process of rehabilitation. Plastic surgeons will want to monitor the success of autografts or allografts which are preparing the wound for possible future autograft.

The role of the diabetic/wound educator needs to be central in the wound practice, including continuing education for the nursing home staff who are caring for the recovering and rehabilitating wound patient. In addition to the direct wound caregivers, other specialists need to continue their involvement in the wound patient's care. Patients with malignant wounds need to be followed by the oncologist, particularly those with malignancies like squamous cell carcinoma with significantly high rates of metastasis.

*The important role of multiple specialists in complicated wound care is well established.*

Many wound patients need regular management by an endocrinologist, nephrologist, cardiologist, considering that many wound patients have severe and chronic diseases, directly contributing to the occurrence of new wounds and difficulty in healing existing ones. A composite view of the ten-step model with algorithm can be seen in Figure 5.

### Discussion

The coordination of multi-specialty care is difficult enough until the philosophy of the team approach becomes integrated into any hospital community. The primary wound specialist must take the responsibility of coordinating both in-patient and out-patient care, including preventive education. Increasing healing outcomes contributes to more interest in maintaining the team concept, yet the financial realities of modern medicine constantly risk eroding the integrity of a team because of all the extra time and effort needed to keep the team functioning.

The potential value of the wound prevention and care algorithm as described in the article should not be overlooked both in the developed and the developing world. The model can be used and expanded for use at all levels to coordinate collaboration among medical personnel and organizations, both public and private, who are working toward the same goal of wound prevention and care in a given community. The concept of early recognition of wounds, cleansing, dressing, debridement, offloading and transport to appropriate surgical caregivers needs to be propagated. Measurable outcomes, such as creating a favorable "Wagner Shift" from more severe diabetic wounds to fewer severe diabetic wounds, after implementation of wound prevention and care programs, would be a worthy goal in any population.[100, 101]

### Summary

Sometimes, a busy practice distracts the caregiver from a thorough and consistent approach to every wound patient. The authors have introduced a model and companion algorithm as a working clinical template that may assist the physician, nurse and other caregivers in maintaining their focus on the organization and timing of prevention, diagnosis and treatment of wounds. This focus is most important in those cases when diligent coordination of multi-specialty care is essential to achieving optimal healing outcomes. ■

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Continuing Medical Education

## EXAMINATION

***See instructions and answer sheet on pages 206-208.***

1) A _____ is historically described as a clinical defect in soft-tissue and/or bone caused by trauma, ischemia, infection or non-infectious inflammatory disorders.
- A) protease
- B) wound
- C) fibroblast
- D) growth factor

2) _____ is portrayed as a condition in previously 'injured' tissue represented by removal of necrotic tissue, resolution of infection and inflammation, with organized collagen and mature, stable epithelium overlying viable tissue.
- A) Wound healing
- B) Angiogenesis
- C) Malnutrition
- D) Epiboly

3) _____ is defined as *"the growth of new capillary blood vessels in the body, a naturally occurring process required for wound granulation and tissue repair."*
- A) Epithelialization
- B) Proliferation
- C) Angiogenesis
- D) Collagen synthesis

4) Angiogenesis is a balance between_____ and Angiogenic Inhibitors (AI) in both normal and abnormal wound healing.
- A) Metalloproteases
- B) Keratinocytes
- C) Vasculitis
- D) Angiogenic growth factors (AGF)

5) Which of the following does not have a negative effect on wound healing?
- A) Foreign body
- B) Angiogenic growth factor
- C) Infection
- D) Malnutrition

6) There are essentially two levels of repair, _____
- A) tissue healing and functional healing
- B) primary and tertiary healing.
- C) flap and skin graft healing.
- D) molecular and cellular healing.

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Continuing Medical Education

# EXAMINATION

(cont'd)

7) Without an adequate _____, healing outcomes will be unacceptable because the therapy is built on a "castle of sand" of deficient differential and final diagnoses.
A) diagnosis and treatment plan
B) growth factor and nutrition
C) HgA1C and nitric oxide
D) amount of wound dressing choices

8) When diabetics are diagnosed, a _____ assessment should be performed, orthotic intervention instituted, routine care performed, skin care begun and appointments made for foot care based on the risk assessment protocol.
A) renal
B) glucose
C) foot wound-risk
D) obesity

9) Wounds can be categorized into those of _____, infectious and primary ulcerative disease etiologies.
A) painful
B) traumatic
C) disabling
D) nutritional

10) Which of the following is not a common cause of lower-extremity wounds?
A) Ischemia
B) Neuropathy
C) Malignancy
D) Venous disease

11) The central role of proper _____in the physical examination of the wound patient cannot be underestimated, particularly, probing of the wound to establish whether or not there is osseous involvement.
A) cranial nerve evaluation
B) wound assessment
C) gait analysis
D) wound measurement

12) One of the following is not a measurement of patient nutritional status:
A) albumin
B) total lymphocyte count
C) total iron-binding capacity
D) creatinine

13) Antibiotics should be given for both therapeutic and preventive (empiric) reasons based on the condition of the patient and the nature of the wound, including the type of infection or suspected degree of _____.
A) "angiogenesis"
B) "inflammation"
C) "neuropathy"
D) "critical colonization"

14) If there is a deficit in palpated peripheral pulses or other signs or symptoms of ischemia, including rubor, cyanosis and rest pain or intermittent claudication, respectively, _____ are generally ordered.
A) non-invasive vascular studies
B) $CO_2$ arteriograms
C) hyperbaric oxygen (HBO) treatments
D) lymphedema stockings

15) The role of _____in the natural history of a wound cannot be adequately determined without a thorough history and physical examination.
A) nitric oxide
B) growth factors
C) systemic disease
D) genetics

16) Early on after the encounter with a terminal wound patient, a determination needs to be made as to the _____of the particular patient.
A) healability
B) age
C) occupation
D) socio-economic status

17) Generally, _____is required in the presence of necrotic tissue or purulence in a wound.
A) an oral antibiotic
B) surgical debridement and/or incision and drainage
C) amputation
D) an intravenous antibiotic only

18) Historically, general and spinal anesthesia have been used for lower-extremity wound management, when in many of these cases, _____would suffice.
A) sedation only
B) local or regional anesthesia
C) topical anesthesia
D) muscle relaxants

19) A _____ would be a much better choice for an ambulatory patient than a Lis Franc's amputation due to the potential loss of tendinous planar balance provided by the tibialis anterior, tibialis posterior, peroneus longus and peroneus brevis tendons.
A) below-knee amputation (BKA)
B) Piragoff amputation
C) transmetatarsal amputation (TMA)
D) Chopart's amputation

20) Ideally, _____ of the wound is the first choice when completing the healing process of a wound.
A) primary flap closure
B) secondary healing
C) split-thickness skin grafting
D) a free flap

**SEE INSTRUCTIONS AND ANSWER SHEET ON PAGES 206-208**