Invited review

Comprehensive management of pressure ulcers in spinal cord injury: Current concepts and future trends

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Pressure ulcers in spinal cord injury represent a challenging problem for patients, their caregivers, and their physicians. They often lead to recurrent hospitalizations, multiple surgeries, and potentially devastating complications. They present a significant cost to the healthcare system, they require a multidisciplinary team approach to manage well, and outcomes directly depend on patients' education, prevention, and compliance with conservative and surgical protocols. With so many factors involved in the successful treatment of pressure ulcers, an update on their comprehensive management in spinal cord injury is warranted. Current concepts of local wound care, surgical options, as well as future trends from the latest wound healing research are reviewed to aid medical professionals in treating patients with this difficult problem.

Keywords: Pressure ulcer, Spinal cord injuries, Wound care, Pressure ulcer management

Introduction

Pressure ulcers and their treatment represent one of the most challenging clinical problems faced by patients who are elderly, neurologically impaired, chronically hospitalized, or have chronic spinal cord injury (SCI). Pressure ulcers often represent a costly cycle of recurrent hospitalizations, surgeries, clinic visits, and home healthcare needs. Pressure ulcers can be life-threatening in end-stage cases as a potential source of overwhelming sepsis. Complications from osteomyelitis, destruction of joints, necrosis of muscle and soft tissue, or erosion into neighboring vital structures can devastate patients' health and quality of life. Patients with SCI, its chronic comorbidities and lack of protective sensory perception, are a particularly vulnerable population for developing ulcers and are at high risk for recurrent ulcers.

There are significant ramifications of pressure ulcers in SCI; therefore, professionals caring for such high-risk patients should periodically review pressure ulcer physiology and clinical management. This review covers pressure ulcer epidemiology, cost, research history, etiology, staging, factors influencing wound healing, local wound care, surgical treatments, and future trends in wound healing research and medical technology.

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Prevalence, incidence, and cost

Pressure ulcer management has become a nationwide healthcare priority. The scope of the problem is significant on multiple levels. Estimates indicate that 1–3 million people in the United States (US) develop pressure ulcers each year.[1–3] The US Joint Commission on Patient Safety estimates that more than 2.5 million patients in acute-care facilities suffer from pressure ulcers, and that 60 000 die from pressure ulcer complications each year. The incidence and prevalence of pressure ulcers can be compared among general acute care facilities, long-term care facilities, and home care. The *prevalence* of pressure ulcers – the proportion of persons with pressure ulcers at a specific point in time – in general acute care setting is 10–18%, long-term facilities 2.3–28%, and home care from 0–29%.[1,2] The *incidence* of pressure ulcers – or new cases of pressure ulcers appearing in a pressure ulcer-free population over a period of time – ranges from 0.4–38% in acute care, 2.3–23% in long-term care, and 0–17% in

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home care.[1,2] Patients with SCI and its associated comorbidities are among the highest risk population for developing pressure ulcers. The incidence of pressure ulcers in the SCI population is 25–66%.[4,5] It has also been reported that patients with higher-level spinal cord injuries are more susceptible than those with lower-level lesions.[4] The lack of protective sensation, variable home care and access to pressure-relieving equipment, and common comorbidities (e.g. diabetes, anemia, malnutrition) contribute to the high risk for development pressure ulcers in this population.

A nationwide consensus showed that prevention of pressure sores is less costly than the management of the disease itself. The Healthcare Cost and Utilization Project (HCUP) from the Agency for Healthcare Research and Quality estimated that, in 2006, there were approximately 500 000 total hospital stays in the United States with pressure ulcers as a diagnosis, with a total annual cost of $11 billion.[3] This represented an 80% increase in hospital stays with pressure ulcers since 1993. The in-hospital mortality was reported as 4.2% when pressure ulcers were the primary diagnosis; 11.6% with pressure ulcer as a secondary diagnosis, and 2.6% of for all other conditions.[3] According to the HCUP report, paralysis and SCI were common co-existing conditions among younger adults aged 18–44 years. The HCUP analysis noted that in three out of four (75%) hospitalizations, Medicare was the most common payer of adult stays related to pressure ulcers.

In a pivotal announcement by Medicare in October of 2008, nursing homes and hospitals were notified that they would no longer be reimbursed for a host of preventable complications, including hospital-acquired pressure ulcers.[6,7] With a new focus in healthcare reform on quality of care and "pay for performance", the responsibility is even greater for individual institutions and providers to appropriately evaluate, diagnose, and manage pressure ulcers and most importantly, to prevent them.[7] In addition, a recent consensus paper by the National Pressure Ulcer Advisory Panel (NPUAP) – the independent non-profit organization founded in 1987 and dedicated to the prevention, management, treatment, and research of pressure ulcers – acknowledged that most pressure ulcers are avoidable with few exceptions.[8] These trends in the United States categorize hospital-acquired pressure ulcers as preventable, and their occurrence as a quality of care indicator for healthcare institutions. As such, knowing the physiology, etiology, and risk factors for developing pressure ulcers is an educational priority and a quality control issue for all hospital organizations.

History of pressure ulcer research

The known pathophysiology of pressure ulcers can be traced to early investigators from the nineteenth and twentieth century that focused on pressure as the primary cause of pressure ulcers. Experimental research by pioneers such as Paget, Charcot, Landis, Groth, and Kosiak has led to our current understanding of the physiology of skin microcirculation and the pathophysiology of pressure-induced tissue ischemia and ulceration. In the early nineteenth century, Paget and Charcot described the effect of external pressure on the circulation of skin and ensuing necrosis, as well as the clinical features of pressure ulcer development following paralysis.[9] In the 1930s, Landis classically described the average venous capillary pressure being 6 mmHg and the arteriolar limb pressure 32 mmHg using an experimental microinjection model of human skin.[10,11] In the 1940s, Groth noted that larger muscles withstood pressure better, that destruction of tissue from an external force was evident at the base of a wound overlying a bony prominence, and that generalized sepsis could result from local infection at the site of pressure.[12] Kosiak's classic experiments in canines demonstrated that higher pressures for short periods of time were just as injurious to tissue as lower pressures applied over longer periods of time, and both led to tissue ischemia, necrosis and ulceration.[13–15] Several other researchers independently contributed to these classic findings and were among the first to describe that muscle was more susceptible to pressure than skin, that natural weight-bearing bony prominences have mostly skin and fascia, and that friction can be synergistic with pressure in tissue destruction.[16–22] Our modern understanding of the definition, etiology, and risk factors for pressure ulcers has been an affirmation of these early research pioneers.

Pathophysiology, etiology, and risk factors

The NPUAP defines a pressure ulcer (or "sore") as a soft tissue injury resulting from unrelieved pressure over a bony prominence, resulting in ischemia, cell death, and tissue necrosis. This definition is more inclusive than the related terms bedsore or *decubitus* ulcer that implies ulcerations only over bony prominences in the recumbent position (sacrum, trochanter, heel, occiput, and back), but not ulcerations from pressure areas in the seated position (e.g. ischial tuberosities).[9] Therefore, a comprehensive list of bony prominences susceptible to pressure ulcer in SCI should include ischial tuberosities, trochanters, sacrum, heels, malleoli, back, occiput, scalp, and elbows. Several studies identify the most common sites of occurrence to be the ischium

(28%), the sacrum (17–27%), the trochanter (12–19%), and the heel (9–18%).[4,23–25] In all these susceptible areas, pressure ulcers occur when external pressure exceeds capillary pressure (12–32 mmHg), and ischemia of tissue begins to display a spectrum of injury patterns.[13] The pathological sequelae of anoxia, ischemia, and necrosis can be reversed at the ischemic stage if the factors causing injury are identified and removed.

Tissue injury is related to both extrinsic and intrinsic factors. Extrinsic factors include *pressure, shear, friction*, *immobility*, and *moisture*. Intrinsic factors relate to the condition of the patient, such as sepsis, local infection, decreased autonomic control, altered level of consciousness, increased age, vascular occlusive disease, anemia, malnutrition, sensory loss, spasticity, and contractures. There is in an inverse relationship between pressure and time to ulceration, and different tissue types have different susceptibilities to ischemia. In particular, muscle is more susceptible to ischemia than skin, and fat has less tensile strength than skin, which explains the "tip-of-the-iceberg" phenomenon, namely when unimpressive skin changes can mask a significant, deep wound down to bone.[26,27] It is known that relieving skin pressure over a bony prominence for 5 minutes every 2 hours will allow adequate perfusion and prevent tissue breakdown.[20] More recently, an analysis by Makhsous *et al.*[28] comparing wheelchair sitting protocols with pressure relieving techniques (wheelchair pushup vs. an off-loading position) using tissue perfusion measurements noted a benefit to an off-loading position every 10 minutes during prolonged sitting. These studies have led to the common recommendations for bedridden, high-risk patients to be turned every 2 hours and patients in wheelchairs to perform routine pressure reliefs during prolonged sitting (off-loading/pressure reliefs for 10 seconds every 10 minutes).

A medical team caring for patients with pressure ulcers must identify the extrinsic and intrinsic factors that can be corrected to treat the non-healing wound and prevent high-risk areas from developing new ulcers. In addition, consistency in the medical record of initial assessment, measurement, descriptors, and clarity on the natural course of any given wound is crucial. The importance of clinically staging a wound properly is at the center of education efforts of medical personnel.

Pressure ulcer staging guidelines

Besides identifying and correcting the risk factors of pressure ulcers in any particular case, medical professionals should have consistent descriptors, measurement tools, and documentation protocols at their institutions. The importance of staging the clinical wound to determine management cannot be overemphasized. Inconsistencies in the medical record in describing the initial severity of a pressure ulcer and its natural course become both financial and medico-legal liability for the caring institution. If an admitting medical professional is uncertain about the initial staging of a pressure ulcer, then a consultation from a wound care professional should be placed for proper documentation. Proper documentation of lesions present on admission and those that may be nosocomial occurrences is becoming a standard necessity for those in the wound care field. Staging the clinical wound consistently is a priority.

Although a number of staging classifications have been proposed in the past, the most commonly used staging system for pressure ulcers was proposed in 1989 (and updated in 2007) by the NPUAP Consensus Development Conference (Fig. 1).[29,30] This system provides a good basic guideline for the examining professional. It incorporates external signs of tissue injury such as erythema, blistering, and evidence of skin breakdown to determine the severity of ulceration. It is common, however, that the external signs of tissue injury underestimate the extent of injury deep to the superficial wound from the "tip-of-the-iceberg phenomenon" described above. These stages correlate with the normal layers of skin that include epidermis, dermis and the deeper layers of fat, muscle, and bone (Fig. 1).

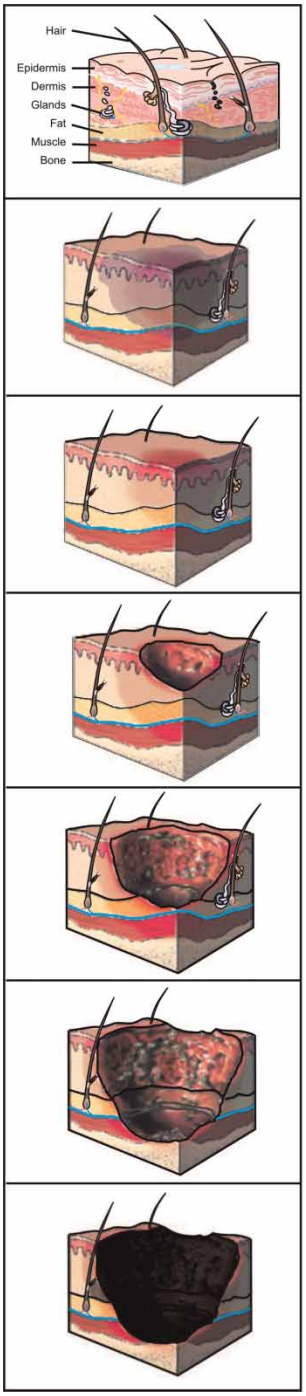
Suspected deep tissue injury is defined as "purple or maroon localized area of discolored intact skin or blood-filled blister due to damage of underlying soft tissue from pressure and/or shear. The area may be preceded by tissue that is painful, firm, mushy, boggy, and warmer or cooler compared to adjacent tissue."

Stage I is defined as "intact skin with non-blanchable redness of a localized area usually over a bony prominence. Darkly pigmented skin may not have visible blanching; its color may differ from the surrounding area."

Stage II is defined as "partial thickness loss of dermis presenting as a shallow open ulcer with a red pink wound bed, without slough. May also present as an intact or open/ruptured serum-filled blister."

Stage III is defined as "full thickness tissue loss. Subcutaneous fat may be visible but bone, tendon, or muscle is not exposed. Slough may be present but does not obscure the depth of the tissue loss. May include undermining and tunneling."

Stage IV is defined as "full thickness tissue loss with exposed bone, tendon, or muscle. Slough or eschar may be present on some parts of the wound bed. Often include undermining and tunneling."



Normal Skin

Normal skin showing intact epidermis, dermis, and the deeper layers of subcutaneous fat, muscle and bone.

Suspected Deep Tissue Injury:

Purple or maroon localized area of discolored intact skin or blood-filled blister due to damage of underlying soft tissue from pressure and/or shear. The area may be preceded by tissue that is painful, firm, mushy, boggy, warmer or cooler as compared to adjacent tissue.

Stage I:

Intact skin with non-blanchable redness of a localized area usually over a bony prominence. Darkly pigmented skin may not have visible blanching; its color may differ from the surrounding area.

Stage II:

Partial thickness loss of dermis presenting as a shallow open ulcer with a red pink wound bed, without slough. May also present as an intact or open/ruptured serum-filled blister.

Stage III:

Full thickness tissue loss. Subcutaneous fat may be visible but bone, tendon or muscle are not exposed. Slough may be present but does not obscure the depth of tissue loss. May include undermining and tunneling.

Stage IV:

Full thickness tissue loss with exposed bone, tendon or muscle. Slough or eschar may be present on some parts of the wound bed. Often include undermining and tunneling.

Unstageable:

Full thickness tissue loss in which the base of the ulcer is covered by slough (yellow, tan, gray, green or brown) and/or eschar (tan, brown or black) in the wound bed.

Figure 1 NPUAP guidelines for staging pressure ulcers.

Unstageable is defined as "full thickness tissue loss in which the base of the ulcer is covered by slough (yellow, tan, gray, green, or brown) and/or eschar (tan, brown, or black) in the wound bed."

These NPUAP staging guidelines can be taught, but staging guidelines can be difficult to apply, especially in the SCI population. Pain is often a presenting symptom of a stage I ulcer in the patient with intact sensation, but the lack of protective sensation in patients with SCI places them at higher risk for delayed presentation of pressure ulcers. The darker skin pigmentation of African Americans and other ethnicities can mask stage I ulcerations, leading to disparities in the reporting of the severity of initial presenting pressure ulcers among racial groups in some studies.[4,31,32] Darker skinned patients are therefore, at increased risk and should be closely monitored. Furthermore, in analyzing

the above guidelines, it is important to recognize that deep tissue injury and unstageable ulcers are descriptive stages and do not easily translate to definitive wound care recommendations or treatment. Deep tissue injury can progress to a stage I–IV and unstageable ulcers often require debridement (see Treatment) for the lesion's depth to declare itself as a definitive stage of tissue loss. Unstageable ulcers often represent full thickness ulceration ranging from stage III to IV.

For proper documentation of an ulcer, and for good medico-legal and reimbursement practice, a good standard to use is once a properly staged ulcer begins treatment, the original stage of the ulcer should remain constant, and during healing be referred to as a "healing stage X" ulcer. If not, a healing ulcer will have several stages assigned to it, also known as "reverse staging", an error that creates a documentation dilemma for the institution bearing full responsibility for the lesion (i.e. "hospital-acquired"). A lesion can very well deteriorate and progress in severity with inadequate or failed treatments (e.g. from a stage III to IV), but reverse staging is inappropriate. The natural course of a lesion should be clear. Consistent measuring methods are essential to proper documentation.

Measuring methods ideally should be standardized to document length, width, and depth of the pressure ulcer. In addition, a useful adjunct to staging pressure ulcers and documentation is digital photography. In many institutions, digital photographic documentation initiatives are underway. Common practices include pictures taken with "scale" stickers on admission, during a patient's hospital stay at least weekly, and on discharge. Pictures can be taken as needed if a lesion changes significantly, or a new lesion develops. Designating photographic responsibilities to specific members of the wound care team can minimize user variability. In the digital era, these initiatives, executed properly, should prove to be useful additions to the medical record.

Basics of pressure ulcer wound healing

A physiologic response to tissue injury follows the three major phases of wound healing: inflammation, proliferation, and maturation (or remodeling).[33] The inflammatory phase (days 1–6) serves to initially constrict injured vessels, and destroys injurious agents by recruiting a cellular response of neutrophils, macrophages, and lymphocytes. The proliferative phase (day 4 to week 3) begins a matrix formation cascade for angiogenesis and re-epithelialization. The maturation phase (week 3 to 2 years) involves collagen remodeling that eventually produces a scar with peak tensile strength starting at approximately 60 days of 80% preinjury strength. In the context of pressure ulcers, however, the wound healing process is arrested or impeded by multiple factors, and there are certain requirements for pressure ulcers to reassume the normal wound healing cascade. Pressure ulcer clinical management aims to stimulate physiologic wound healing with pressure relief, debridement, control of colonization or wound infection, nutrition supplementation, and measures to prevent recurrence.

Pressure relief

Relief of pressure is the standard conservative treatment for a non-healing pressure ulcer. Inpatient settings should assess pressure areas and implement pressure relief with specialty beds and mattresses, complying with turning orders, use of heel protectors, bed sheet cradles, or removal of any extrinsic pressure sources (such as strapping, pillows, restraints, IV tubing, catheters, etc.). In the outpatient setting, an analysis of the patient's home environment with a thorough interview at each clinic visit is a good practice. Knowing whether the patient is compliant with pressure relief protocols while sitting, the amount of hours sitting per day, wheelchair or cushion problems, transfer habits or protocols, turning or repositioning habits while sleeping, type of bed or mattress used, or changes in caregivers or increased independence at home will often reveal potential risk factors. Social workers, case managers, physical therapists and home equipment personnel are a vital part of the medical team when determining home care needs that are contributing to insufficient pressure relief for a new or recurrent pressure ulcer.

Debridement

The removal of devitalized tissue is essential to allow for granulation and accurate staging of the wound. Therefore, debridement is one of most basic requirements for normal wound healing. Assessing a wound for the timing and need of adequate debridement is vital. The patient can benefit from debridement when indicated with enzymatic, mechanical, biological (e.g. maggot therapy), or sharp debridement (see Treatment). Necrotic tissue will serve as a nidus for colonization and infection that will hinder and prolong the healing process. There are practical limitations of bedside debridement strategies, and is it just as important to identify when those strategies have failed, and to consider surgery when indicated.

Infection and osteomyelitis

Infection is one of the most common comorbidities leading to healing complications of pressure ulcers. The most common organisms isolated from pressure ulcers are *Proteus mirabilis, group D Streptococci,*

Escherichia coli, Staphylococcus species, *Pseudomonas* species, and *Corynebacterium* organism.[1] In patients who have extensive ulcers or who are immunocompromised, signs of systemic infection (leukocytosis, fever, hypotension, tachycardia, and altered mental status) should be treated aggressively. Control of wound colonization and infection should be a priority, but must be weighed against overuse of broad-spectrum antibiotics. The increasing incidence of methicillin-resistant *Staphylococcus aureus*, vancomycin–resistant *Enterococcus* species, and extended spectrum beta-lactamase producing Gram-negative bacilli is a national problem.[34] In addition, the side effects of broad-spectrum antibiotics are significant causes of patient morbidity. Furthermore, a common secondary sources of sepsis include intermittent catheterization, indwelling catheters, a history of urologic procedures (bladder augmentation, urostomy, suprapubic catheterization), and recurrent polymicrobial urinary tract infections.[35,36] If necessary, a medical team should consult an infectious disease specialist to treat the often complex, multifactorial, multisource, and polymicrobial infections in the SCI population.

Of special consideration is the diagnosis and treatment of osteomyelitis in pressure ulcers, area of some controversy. Plain radiographs can be confirmatory, but lack sensitivity. Nuclear bone scans have a high false-positive rate and are not useful or recommended. Magnetic resonance imaging has been found to have higher sensitivity and specificity rates.[26] The gold standard for the diagnosis of osteomyelitis is bone biopsy. It is the deep culture and histopathology of a bone biopsy that dictates the length of antibiotic treatment. Lewis *et al.*[37] performed a prospective blind trial of commonly used tests to diagnose osteomyelitis underlying pressure sores, finding the combination of a plain radiograph, white cell count, and erythrocyte sedimentation rate to be the most cost-effective workup to diagnosis osteomyelitis. Marriot and Rubayi[38] reported that chronic inflammatory changes on histology, or chronic osteomyelitis, without bacterial colonization, can be treated briefly in the perioperative period without clinical sequelae. However, the standard of care is the administration of intravenous antibiotics for 6 weeks if bone culture and sensitivity are positive for acute osteomyelitis with bacterial colonization.[37,38]

Nutrition

Nutrition is a critical component of normal wound healing, a relationship that has been known since antiquity. The NPUAP has identified that nutrition is an important aspect of comprehensive care plan for prevention and treatment of pressure ulcers.[2] Physical examination findings of malnutrition can be evident in weight loss, skin tone/quality, hair quality, muscle mass or history of wasting, pallor, signs of cachexia, and appetite among others. Biochemical markers well studied in indicating malnutrition should be monitored and include serum proteins (albumin <3.5 mg/dl; prealbumin <15 mg/dl; transferring <200 mg/dl), nitrogen balance, total cholesterol, and creatinine.[2,39] A malnourished patient is predisposed to increase risk of sepsis, pneumonia, ventilator-dependence and its complications, and failed or prolonged wound healing. In 2009, The NPUAP and the European Pressure Ulcer Advisory Panel (EPUAP) together published guidelines for nutritional assessment in patients with pressure ulcers.[2] The main NPUAP-EPUAP guidelines are summarized in Table 1. Based on the guidelines, a dietitian should be consulted or be a permanent member of the treatment team to ensure the recommended protein (1.25–1.5 g protein/kg) and non-protein (30–35 Kcal/kg) supplementation is being administered. Clinicians and patients should be reminded that for surgical patients, the surgery itself will often times depress the initial trend of nutritional parameters during the acute phase reaction following the procedure (~7 days), but recovery is expected with adequate nutritional support.[40] Interestingly, excision and reconstruction of the ulcer has been shown to result in correction of anemia, serum protein, and markers of inflammation, suggesting these clinical indicators are a consequence of pressure ulceration and the catabolic state.[41,42]

Support surfaces and specialty beds

Support surfaces and specialty beds are a widespread modality in the treatment and prevention of pressure ulcers. There are many products available in the market and their availability is institution dependent. In 1992, Bryant[43] introduced a classification system distinguishing 3 types of devices: mattress overlays,

Table 1 NPUAP-EPUAP Guidelines for Nutrition*

Screen and assess nutritional status on admission and with change in condition/lack of progress toward ulcer closure
Refer all individuals with a pressure ulcer to dietitian
Provide sufficient calories (30–35 Kcal/kg)
Provide adequate protein for positive nitrogen balance (1.25–1.5 grams protein/kg)
Provide and encourage adequate daily fluid intake for hydration
Provide adequate vitamins and minerals
Offer vitamin and mineral supplements when dietary intake is poor or deficiencies are confirmed or suspected

*NPUAP, National Pressure Ulcer Advisory Panel; EPUAP, European Pressure Ulcer Advisory Panel.
Source: Dorner *et al.* 2009.

mattress replacements, and specialty beds. Mattress overlays are designed to be applied directly over a mattress. Mattress replacement systems are for the use on a hospital bed frame without an underlying mattress, and specialty beds are freestanding entire units in place of hospital beds. Mattress overlays and replacements use water, gel, foam, air, and combinations as mediums. They can be static (redistributing pressure over a wider tissue area) or dynamic systems (using a power source to alternate air currents and pressure against the body). Specialty beds include low-air loss beds (utilizing separate air-filled cushions individually monitored) and air-fluidized beds (utilizing warm air forced through silicone beads to simulate a fluid environment).[43]

An important threshold for comparison of these devices is whether a surface reduces pressure over bony prominences to below capillary pressure (i.e. 32 mmHg). Since this pressure cannot be directly measured, tissue interface pressure is used as an estimate – defined as the force per unit area that acts perpendicularly between a body and the support surface – and is calculated by using a pressure sensor placed between the patient and the support surface. From these measurements, there have been historical categorizations of "pressure-reducing" devices that keep pressures lower than with the standard hospital bed but not consistently below capillary closing pressure and "pressure-relieving" devices that consistently reduce pressure below capillary closing pressure. However, this nomenclature is transitioning out of favor with national definition guidelines set by the NPUAP. The more generic term of describing mattress and specialty bed technology as *pressure redistribution* devices with varying applications depending on the clinical need is currently the standard terminology (see www.npuap.org under "Terms and Definitions Related to Support Surfaces"). Most overlays and replacement mattresses are considered less sophisticated, non-powered pressure redistribution surfaces, while low air-loss and air-fluidized beds are considered as the advanced, powered pressure redistribution surfaces.

The relative lack of research comparing support surfaces in comparison to the amount of available products underscores the need for continued studies to define use and treatment guidelines. However, there are published studies on the topic. For example, for pressure redistribution surfaces aimed at prevention of pressure ulcers, a recent Cochrane Database review of available studies noted foam mattresses are generally more effective than standard mattresses[44] Available clinical trials support the cost-effectiveness of low-air loss beds to prevent pressure ulcers and accelerate healing vs. standard mattresses and a significant advantage in time to healing of pressure ulcers of air-fluidized beds vs. alternating air mattress with foam pads.[45–48]

Appropriate selection of support surface should be tailored to a patient's individual needs and guided by clinical judgment. Any patient thought to be at risk for developing pressure ulcers should be placed on an advanced, powered pressure redistribution surface. Patients using wheelchairs should also be evaluated for customized cushions. Recommendations by the wound team in managing an existing pressure ulcer must be a dynamic process of continual risk assessment. However, a patient with large stage III or IV pressure ulcers on multiple turning surfaces should be on a powered pressure redistribution product until definitive treatment is planned. When patients being evaluated for reconstructive surgery have preoperative pressure mapping performed and repeated postoperatively, wheelchair cushions or support surfaces can be tailored prior to discharge to home. Recurrent ulcers require a re-evaluation of all support surfaces for optimal management.

In summary, pressure relief, debridement, control of infection, nutrition, patient education, and device technology should all be considered in tandem when planning a patient's comprehensive healing and prevention protocol. Despite these strategies, however, patients with SCI commonly develop new ulcers or recurrences of varying severity and require treatment.

Treatment guidelines

Once a patient has developed a pressure ulcer, immediate treatment is recommended. Treatment can be non-operative local wound care (solutions, ointments, creams, dressings, topical or mechanical debridement, and electrical stimulation) and surgery (surgical debridement, direct wound closure, skin grafts, and skin, fasciocutaneous, or myocutaneous flaps). In general, a great majority of ulcers will eventually heal by secondary intention, but healing can be enhanced and beneficial to patients with non-operative wound care or surgery. Stage I and II pressure ulcers usually require only non-operative wound care. Stage III and IV ulcers will commonly require surgical treatments. Both strategies should incorporate pressure redistribution therapy, nutrition optimization, ulceration precautions, and patient education to manage the ulcer and prevent new ulcers or recurrence.

The accurate staging of a pressure ulcer, with its description of histological damage to skin structures, already suggests the general principles of treatment.

Stage I ulcers require pressure relief, careful clinical monitoring, and hydrating dressings. Stage II ulcers usually require pressure relief, antibacterials to control infection, and a moist dressing for re-epithelialization. Stage III and IV ulcers require pressure relief, broad-spectrum antibacterials to control superinfection, debridement, control of exudate, and usually reconstruction of involved tissues with surgery.

Local wound care

Local wound care utilizes cleansing solutions, antimicrobial ointments and creams, debriding agents (e.g. proteolytic enzymes), and dressings (with passive or active wound effects). Wound care products vary by institution, but general principles remain the same. The purpose of cleansing solutions is to facilitate healing of a wound by providing irrigations, hydration, and decreasing a wound's bioburden. Normal saline solution, with no germicidal activity, is recommended as a hydrating agent and a rinse when using other solutions that can be irritants to skin or healing tissue. Wet-to-dry dressing changes with normal saline will keep the wound moist and mechanically debride superficial tissue, but should not be used on temperature-controlled air-fluidized beds, which will dehydrate the dressing dramatically after application. Besides normal saline, the most commonly used cleansing solutions (historically povidone-iodine, acetic acid, and sodium hypochlorite) have both beneficial antimicrobial activity and some toxic effects on wound healing. Povidone-iodine has antimicrobial effects against bacteria, spores, fungi, and viruses, though it has also been shown to be toxic to fibroblasts *in vitro*. Acetic acid (0.5%) can be effective against *Pseudomonas aeruginosa*, but may change the wound bed color and odor and make interpretation of progress difficult. Finally, sodium hypochlorite (2.5%) is available for cleansing, with some germicidal activity and debridement activity. It is known to irritate local tissue and some studies suggest that pretreatment with zinc oxide can minimize these deleterious side effects. The diluted formulation of sodium hypochlorite with boric acid, described by English chemist Henry Drysdale Dakin in the early twentieth century, is still in use today. Since the early 1980s, a stable commercial version of Dakin's solution (0.25% strength) has been available, which has been shown to be bactericidal but preserving fibroblasts in the wound.[26,49] It should be noted that the use, indications, and length of treatment of these topical agents with potential harmful events in the microenvironment is a subject of debate. Institutions and practitioners vary in their use of these solutions for local wound care. However, these agents aside, many antibacterial ointments and creams are now available that achieve good therapeutic results without the deleterious toxic side effects to local healthy tissue.

Antibiotic ointments and creams are a mainstay of local wound care, the most common of which are bacitracin, mupirocin, silver sulfadiazine, and mafenide acetate. Silver sulfadiazine has broad antimicrobial properties inhibiting the DNA replication of multiple bacterial species with minimal pain on application. There are accounts of transient leucopenia with its use in patients with large burn wounds.[1] Mafenide acetate, also used in treating burn injuries, has better eschar penetration, but has the known side effect of metabolic acidosis.[50] The choice of antibiotic ointments and creams depends on the bacteriology of wound sensitivities.

Chemical debriding agents achieve removal of necrotic tissue, eschar and slough by topical treatment of proteolytic enzymes on chronic wounds. Their mechanism of action relate to their enzymatic degradation of collagen and liquefaction of necrotic debris without damaging granulation tissue.[1] These agents may have a role in sensate patients who are poor surgical candidates, or in the preparation of a contaminated wound for definitive closure. Sharp debridement, or surgical removal of eschar and devitalized tissue, remains an efficient way to alter the natural history of a wound, with the practitioner determining the extent of debridement.[1]

Pressure ulcer dressings fall into two major categories: passive action and active action on the wound. The passive dressings come in a variety of forms. Transparent adhesive dressings are semipermeable, non-absorptive, and occlusive that allows gaseous exchange and transfer of water vapor from the skin to prevent maceration. They do not work well on wounds with excessive exudates. Hydrocolloid wafer dressings contain hydroactive particles that interact with wound exudates to form a gel. They provide absorption of minimal to moderate amounts of exudate and keep the wound surface moist. Gel dressings keep the surface of the wound moist as long as the gel does not dehydrate and provide atraumatic removal. Calcium alginate dressings are derived from brown seaweed and are semiocclusive, highly absorbent, natural, and sterile. Finally, the active dressings having similar indications on moderate-to-heavy exudate wounds and have antimicrobial properties (e.g. dressings impregnated with silver) or collagen scaffold properties. The main classes of pressure ulcer wound dressings and their characteristics are summarized in Table 2.

Table 2 Pressure ulcer wound dressings

	Characteristics
Passive	
Gauzes	Obliterate dead space, absorb exudates, retain moisture, mechanical debridement
Foams	Obliterate dead space, absorb exudates, retain moisture, mechanical debridement
Transparent films	Occlusion, retain moisture, and autolytic debridement
Hydrocolloids	Occlusion, moisture, obliterate dead space, and autolytic debridement
Hydrogels	Retain moisture and autolytic debridement
Alginates	Exudate absorption, obliterate dead space, autolytic debridement
Active	
Antimicrobial dressing	Exudate absorption, silver-releasing foam
Collagen dressing	Exudate absorption, scaffold for tissue ingrowth, hemostasis, chemotaxis, sequesters growth factors

Source: Salcido *et al*. 2012 and Fan *et al*. 2011.

Negative pressure wound therapy

In 1997, plastic surgeons Drs Louis Argenta and Michael Morykwas from the Wake Forest University School of Medicine presented their 9-year experimental and clinical experience using the vacuum-assisted wound closure device in a variety of chronic, subacute, and acute wounds, demonstrating enhanced granulation tissue and successful wound closure using this new technology.[51–53] They theorized the device improved local blood flow, removed chronic edema, and reduced bacterial counts in the wound bed. Since then, negative pressure wound therapy (NPWT) has become an important tool in the management of a wide spectrum of wounds. The vacuum-regulation device provides continuous or intermittent controlled negative pressure to the wound through air-tight dressings, which are changed every second or third day. The use of NPWT has been described for chronic wounds including pressure sores, where the therapy is particularly beneficial in patients who are poor surgical candidates, require significant care, have failed previous operations, or develop areas of wound dehiscence following surgery.[54–56]

There are special considerations in using NPWT on patients with SCI. First, it is contraindicated to use NPWT on wounds with exposed vital structures, thick exudates, necrotic material, or significant purulence that will render therapy ineffective or lead to bleeding complications.[52] The very rare complication of NPWT masking the clinical presentation of necrotizing fasciitis in a patient with paraplegia has been reported.[57] Second, NPWT foam can irritate normal skin and proper application in patients with SCI can be challenging. In some areas it may be difficult to achieve an adequate seal due to fragile skin integrity.[58] Finally, the application of the NPWT device in patients with SCI must be carefully monitored such that the device foam/tubing do not generate any new pressure points over healthy skin that can lead to new ulcers. Despite these considerations, NPWT has been a revolutionary contribution to the wound care field and will continue to be an important option in pressure ulcer management, particularly as it simplifies chronic wound management in the aging population and as an outpatient treatment option.[59]

Electrical stimulation

Electrical stimulation has been used to enhance wound healing for more than 50 years.[60] It has been postulated that electrical current attracts fibroblasts and macrophages, improved wound microcirculation by directly stimulating local cutaneous nerves, and orient and affect mesenchymal stem cell migration.[61–63] Baker *et al.*[61] reported their experience in identifying a biphasic waveform of electrical current as the optimal wound healing protocol among 185 pressure ulcers in 80 patients with SCI who were treated for 45 minutes/day for 4 weeks. Based on these studies, the use of electrical stimulation as an adjunct to local wound care can be used in both the inpatient and outpatient setting, and is particularly helpful in accelerating healing of small wound dehiscences that can develop in high-risk post-surgical patients.

Surgical treatment

When conservative treatments fail, such as in the context of chronic, deep stage III or IV ulcers, surgical excision and reconstruction are recommended. However, since pressure ulcer surgery is largely considered elective, several factors need to be addressed by the multidisciplinary team before a patient is considered a good candidate for surgery. The patient with chronic medical comorbidities should be stabilized in the preoperative period (e.g. diabetes mellitus, hypertension, malnutrition, anemia) and if need be, appropriately risk-stratified by subspecialty consultants for a several hour operative procedure under general anesthesia. Muscle

Table 3 Medical and surgical treatment of spasticity in SCI

	Cumulative Dose Range
Medical	
Diazepam (Valium)	10–40 mg
Clonazepam (Klonopin)	0.5–20 mg
Baclofen	15–100 mg
Dantrolene sodium	50–400 mg
Tizanidine (Zanaflex)	18–24 mg
Clonidine	0.2–2.4 mg
Dronabinol (Marinol)	5–20 mg
Procedural/Surgical	
Neurolysis (botulin toxin, phenol, alcohol, lidocaine)	
Botulin toxin muscle injection	
Intrathecal phenol/baclofen	
Neurosurgical treatments (selective dorsal rhizotomy)	
Contracture release (tendon lengthening/release)	
Girdlestone procedure (proximal femorectomy)	

spasms should be controlled, as they jeopardize flap healing, risking wound dehiscence, seroma, or bursa formation, either medically or with variety of procedures or surgical interventions (e.g. phenol neurolysis or botulinum toxin, contracture release, Girdlestone; see Table 3). If the ulcer or ulcers are in close proximity to the anus, clinical judgment should address the need for bowel diversion by colostomy. When an ulcer involves the perineal urethra in men, temporary or permanent urinary diversion should also be considered. Finally, the patient with SCI should undergo a complete psychological evaluation and treatment of any pre-existing conditions preoperatively. This evaluation serves as a screening and risk assessment of patient compliance that is crucial for success. All surgical patients face a physically and psychologically demanding inpatient stay, rehabilitation, and outpatient recovery.

Surgical management of pressure ulcers involves a spectrum of options, from simple debridement with direct closure, skin grafting, fasciocutaneous flaps, myocutaneous flaps, combination proximal femoral osteotomy and flap reconstruction (Girdlestone procedure), or end-stage lower extremity disarticulation and total thigh flap.[64–66] There are several advantages for surgical closure of a pressure ulcer with muscle flaps in SCI, including definitive wound debridement with skin and soft tissue coverage, elimination of dead space, improved vascularity, improved healing from underlying osteomyelitis, improved penetration of antibiotics, and restoration of resilient tissue to resist shearing, friction, and pressure. A comprehensive reconstruction will allow the patient to regain the activities of daily living more efficiently. The choice of flap reconstruction depends on the anatomical location of the pressure ulcer, and several options exist for the most common sacral, coccygeal, ischial, and trochanteric ulcers (Table 4).[65] When hip pathology exists and is a contributing factor to pressure ulceration (e.g. arthritic erosion, subluxation, rotation, dislocation, or fracture), a unilateral or bilateral proximal femoral osteotomy with flap reconstruction, or Girdlestone procedure, is indicated in some patients, particularly those that recur. An informed consent of the risks and benefits and a candid discussion of the patients' expectations are important in this setting given the permanent effects on lower extremity laxity, spatial control and transferring after this procedure.[67] When multiple pressure ulcers require reconstruction, a single-stage procedure has proven advantages in SCI, with overall lower hospital stays and anesthetic procedures, which ultimately may contain costs.[68] Finally, end-stage disease represents the patient with multiple previous failed flap reconstructions and Girdlestone procedures with extensive recurrent ulceration. In this scenario, unilateral or bilateral disarticulation and total thigh flap reconstruction is well described.[65]

Postoperative pressure ulcer complications, recurrence rates, and mortality rates in the published literature are largely retrospective or case series data.[41] The reported data from these studies or weighted systematic review show recurrence of pressure ulcers following reconstruction varying widely from 2.9–33.3%, and overall

Table 4 Pressure ulcer common flap options by location

Pressure Ulcer	Common Flap	Blood Supply
Sacral Coccygeal	Gluteus maximus (rotation, sliding, muscle splitting flap) Superior gluteal artery perforator	Superior and inferior gluteal artery
Ischial	Gluteus maximus (rotation)	Superior and inferior gluteal artery
	Gracillis (tunneled or not)	Medial femoral circumflex artery
	V-Y Hamstring advancement	Profunda femoris perforators
	Inferior gluteal perforator	Inferior gluteal artery
	Medial thigh fasciocutaneous	Medial femoral circumflex artery
	Posterior thigh fasciocutaneous	Profunda femoris perforators
Trochanteric	Tensor fascia latae (rotation, V-Y)	Lateral femoral circumflex artery
	Anterior lateral thigh	Superior gluteal artery

Source: Rubayi & Chandrasekhar, 2011.

Table 5 Regional flap pressure ulcer complication and recurrence rates

Complications	Range of Complication Rates (%)	Reference
Overall complication	6.6–53%	Tchanque-Fousso & Kuzon, 2011[41]; Sameen *et al.* 2012[77]
Overall recurrence	2.9–33%	Tchanque-Fousso & Kuzon, 2011[41]; Sameen *et al.* 2012[77]

Table 6 Common postoperative pressure ulcer flap protocol

Week 1	Surgery, bedrest on air-fluidized bed, delayed bowel program
Week 2	Nutrition optimization, bedrest on air-fluidized bed
Week 3–6	Progressive sitting program, prone gurney rehabilitation, pressure mapping, wheelchair/cushion evaluation
Week 7–8	Complete acute rehabilitation, complete sitting protocol, transition to home with optimized wheelchair, outpatient home health/physical therapy, and follow-up plan

complication rates ranging 6.6–53% (Table 5). The most commonly reported complications are sepsis, wound dehiscence, hematoma, seroma, partial flap loss, and total flap necrosis.[41] Interestingly, in a recent systematic review of musculocutaneous, fasciocutaneous, and perforator-based flaps for the treatment of pressure sores showed no statistically significant difference in complication or recurrence rate from these three techniques.[69] Multiple episodes of recurrence and end-stage disease represent a moral and ethical dilemma for the reconstructive surgeon when counseling patients and their families on continued surgical procedures.

Postoperative protocols following flap reconstruction date back decades. The timing of when to begin a progressive sitting program varies in the literature. Complete rest from 3 to 6 weeks to allow flap healing has been proposed for the surgical site to reach sufficient tensile strength to withstand mobilization. When sitting is initiated, it should be implemented slowly during the first two weeks, eventually allowing the patient to sit up to 4–6 hours/day. Taken together, a complete postoperative flap protocol can range from 5 to 8 1/2 weeks for patients with SCI deemed to be good surgical candidates (Table 6). With the current trends in healthcare reimbursement in the United States, these types of postoperative protocols for pressure ulcer reconstruction will need to balance flap monitoring with medical need and cost of inpatient hospitalization. The trend to transition these protocols to skilled nursing facilities, subacute care institutions and outpatient settings is increasingly becoming a reality. Multi-institutional relationships will be necessary to provide optimal care for patients in the postoperative period.

Prevention

Preventing pressure ulcers from occurring in the first place and recurring after successful treatment is the optimal management of this difficult problem in the SCI population. Prevention begins with the patient, but must be re-emphasized, encouraged, and promoted by the multidisciplinary team, especially in young patients with new injuries. Clark *et al.*[70] have led a qualitative research initiative to understand the lifestyle principles that are relevant in pressure ulcer development, in particular suggesting that patients with SCI have at least eight lifestyle principles that govern their risk (Table 7).[71] Minimizing risk for skin breakdown in high-risk adults with SCI requires monitoring activities that increase their risk of pressure ulcers. Furthermore, since lifestyle factors can be vastly different from patient to patient, the risk profile of patients becomes an individualized assessment, with likely individualized prevention strategies in need of definition and implementation.

Understanding the interplay between lifestyle choices and changes over time and how these decisions relate to pressure ulcer risk is an ongoing area of research. At present, patient outreach strategies for pressure ulcer prevention are institution dependent. More research is needed on how best to design outreach programs that effectively promote prevention in high-risk patients with SCI.

Future trends

The revolution of wound regenerative medicine and medical technology in the past two decades has highlighted several exciting new treatment possibilities for

Table 7 Lifestyle principles and pressure ulcer development*

I.	Perpetual danger (SCI patients are constantly at risk for pressure ulcers).
II.	Change/disruption in routine
III.	Decay in prevention behaviors
IV.	Lifestyle risk ratio
V.	Individualization
VI.	Simultaneous presence of awareness/motivation
VII.	Lifestyle trade-off
VIII.	Access to needed care, services and support

**Source*: Jackson *et al.* 2010.

Table 8 Emerging advance wound care therapies

Medical
Growth factor-based therapy
Medicinal honey
Collagenase therapy
Autologous stem cell therapy
Platelet-rich plasma therapy
Procedural/Technology
Subepidermal moisture (SEM) measurement
Low Frequency Ultrasound
Tissue Engineered Skin Substitutes
Fluid immersion pressure redistribution surfaces

chronic wounds, and potentially, pressure ulcers. Cytokine growth factor therapy (e.g. recombinant human platelet-derived growth factor (rhPDGF), basic fibroblast growth factor), cell-based therapies (platelet-rich plasma, autologous stem cell delivery), and improvements in pressure-relieving surface technology (e.g. fluid immersion technology) are all contributing to a rapidly evolving field of modern wound healing therapies for pressure ulcer treatment.[72–77] For instance, Rees and colleagues treated pressure ulcers with daily rhPDGF at 100 μg/g and 300 μg/g compared with controls and noted the incidence of >90% healing in the beclapermin groups to be 58 and 59%, respectively.[78] In addition, new detection modalities using subepidermal moisture may one day be used to detect high-risk skin before pressure ulcerations occur.[79]

A recent review by Levine *et al.* [80] has reported multiple preoperative and surgical modalities of managing pressure sores and compared them on their level of evidence-based data. The advanced wound care team will need to assess new technologies for their relevance to evidence-based clinical practice. Ultimately, more research is needed to identify therapies that will prove to be cost-effective and evidence-based improvements over the current standard of care. A brief list of the emerging advanced wound care therapies is presented in Table 8.

Summary

Practitioners treating patients with SCI continue to work diligently to assemble the necessary treatment teams, resources, and patient education programs to treat pressure ulcers comprehensively. Prevention of pressure ulcers is ideal, and there are medical, financial, and quality of care indicator incentives for healthcare institutions to adopt policies to educate patients and medical professionals on prevention, pathophysiology, staging, and treatment options for this difficult problem. As the population ages and the average life expectancy continue to increase in the US, pressure ulcers will continue to require multidisciplinary teams to treat them successfully. No other patient population is more vulnerable than that with SCI. Understanding the comprehensive management of pressure ulcers in this population will remain a timely topic for years to come.

References

1 Salcido R, Popescu A, Potter A, Talavera F, Kolaski K, Allen K, *et al.* Pressure ulcers and wound care. [Accessed 2012 February 14] Medscape Available from: www.emedicine.medscape.com/article/31984-overview.
2 Dorner B, Posthauer ME, Thomas D. The role of nutrition in pressure ulcer prevention and treatment: National Pressure Ulcer Advisory Panel white paper. Adv Skin Wound Care 2009;22(5):212–21.
3 Russo CA, Steiner C, Spector W. Hospitalizations related to pressure ulcers among adults 18 years and older, 2006: statistical brief #64. Healthcare Cost Utilization Project December 2008. 2006.
4 Fuhrer MJ, Garber SL, Rintala DH, Clearman R, Hart KA. Pressure ulcers in community-resident persons with spinal cord injury: prevalence and risk factors. Arch Phys Med Rehabil 1993;74(11):1172–7.
5 Regan MA, Teasell RW, Wolfe DL, Keast D, Mortenson WB, Aubut JA. A systematic review of therapeutic interventions for pressure ulcers after spinal cord injury. Arch Phys Med Rehabil 2009;90(2):213–31.
6 Levine JM. Preparing for the new Medicare reimbursement guidelines: Part I–when are pressure ulcers in the hospital avoidable? Clin Geriatr 2008;16(6):19–24.
7 Rosenthal MB. Nonpayment for performance? Medicare's new reimbursement rule. N Engl J Med 2007;357(16):1573–5.
8 Black JM, Edsberg LE, Baharestani MM, Langemo D, Goldberg M, McNichol L, *et al.* Pressure ulcers: avoidable or unavoidable? Results of the National Pressure Ulcer Advisory Panel Consensus Conference. Ostomy Wound Manage 2011;57(2):24–37.
9 Janis JE, Kenkel JM. Pressure sores. Sel Read Plast Surg 2003;9(39):1–42.
10 Landis E. Microinjection studies of the capillary blood pressure in human skin. Heart 1930;15:209.
11 Landis EM, Gibbon JH. The effects of temperature and of tissue pressure on the movement of fluid through the human capillary wall. J Clin Invest 1933;12(1):105–38.
12 Groth K. Clinical observations and experimental studies of the pathogenesis of decubitus ulcers. Acta Clin Scand 1942;87(suppl 76):207.
13 Kosiak M. Etiology of decubitus ulcers. Arch Phys Med Rehabil 1961;42:19–29.
14 Kosiak M. Prevention and rehabilitation of pressure ulcers. Decubitus 1991;4(2):60–2 4, 6 passim.
15 Kosiak M, Kubicek WG, Olson M, Danz JN, Kottke FJ. Evaluation of pressure as a factor in the production of ischial ulcers. Arch Phys Med Rehabil 1958;39(10):623–9.
16 Husain T. An experimental study of some pressure effects on tissues, with reference to the bed-sore problem. J Pathol Bacteriol 1953;66(2):347–58.
17 Keane FX. The function of the rump in relation to sitting and the Keane Reciprocating Wheelchair Seat. Paraplegia 1979;16(4):390–402.
18 Keane FX. The minimum physiological mobility requirement for man supported on a soft surface. Paraplegia 1979;16(4):383–9.
19 Dinsdale SM. Decubitus ulcers in swine: light and electron microscopy study of pathogenesis. Arch Phys Med Rehabil 1973;54(2):51–6. Passim.
20 Dinsdale SM. Decubitus ulcers: role of pressure and friction in causation. Arch Phys Med Rehabil 1974;55(4):147–52.

21 Daniel RK, Faibisoff B. Muscle coverage of pressure points – the role of myocutaneous flaps. Ann Plast Surg 1982;8(6):446–52.
22 Daniel RK, Hall EJ, MacLeod MK. Pressure sores-a reappraisal. Ann Plast Surg 1979;3(1):53–63.
23 Allman RM. Pressure ulcers among the elderly. N Engl J Med 1989;320(13):850–3.
24 Garber SL, Rintala DH, Hart KA, Fuhrer MJ. Pressure ulcer risk in spinal cord injury: predictors of ulcer status over 3 years. Arch Phys Med Rehabil 2000;81(4):465–71.
25 Garber SL, Rintala DH, Rossi CD, Hart KA, Fuhrer MJ. Reported pressure ulcer prevention and management techniques by persons with spinal cord injury. Arch Phys Med Rehabil 1996;77(8):744–9.
26 Bauer J, Phillips LG. MOC-PSSM CME article: pressure sores. Plast Reconstr Surg 2008;121(1 Suppl):1–10.
27 Reuler JB, Cooney TG. The pressure sore: pathophysiology and principles of management. Ann Intern Med 1981;94(5):661–6.
28 Makhsous M, Priebe M, Bankard J, Rowles D, Zeigler M, Chen D, *et al.* Measuring tissue perfusion during pressure relief maneuvers: insights into preventing pressure ulcers. J Spinal Cord Med 2007;30(5):497–507.
29 Pressure ulcer prevalence, cost and risk assessment: consensus development conference statement–The National Pressure Ulcer Advisory Panel. Decubitus 1989;2(2):24–8
30 Black J, Baharestani MM, Cuddigan J, Dorner B, Edsberg L, Langemo D, *et al.* National Pressure Ulcer Advisory Panel's updated pressure ulcer staging system. Adv Skin Wound Care 2007;20(5):269–74.
31 Li Y, Yin J, Cai X, Temkin-Greener J, Mukamel DB. Association of race and sites of care with pressure ulcers in high-risk nursing home residents. Jama 2011;306(2):179–86.
32 Saunders LL, Krause JS, Peters BA, Reed KS. The relationship of pressure ulcers, race, and socioeconomic conditions after spinal cord injury. J Spinal Cord Med 2010;33(4):387–95.
33 Gurtner GC, Werner S, Barrandon Y, Longaker MT. Wound repair and regeneration. Nature 2008;453(7193):314–21.
34 Leclercq R. Epidemiological and resistance issues in multidrug-resistant staphylococci and enterococci. Clin Microbiol Infect 2009;15(3):224–31.
35 Montgomerie JZ. Infections in patients with spinal cord injuries. Clin Infect Dis 1997;25(6):1285–90. quiz 91–2.
36 Morton SC, Shekelle PG, Adams JL, Bennett C, Dobkin BH, Montgomerie J, *et al.* Antimicrobial prophylaxis for urinary tract infection in persons with spinal cord dysfunction. Arch Phys Med Rehabil 2002;83(1):129–38.
37 Lewis VL, Bailey MH, Pulawski G, Kind G, Bashioum RW, Hendrix RW. The diagnosis of osteomyelitis in patients with pressure sores. Plast Reconstr Surg 1998;81:229–32.
38 Marriott R, Rubayi S. Successful truncated osteomyelitis treatment for chronic osteomyelitis secondary to pressure ulcers in spinal cord injury patients. Ann Plast Surg 2008;61(4):425–9.
39 Kavalukas SL, Barbul A. Nutrition and wound healing: an update. Plast Reconstr Surg 2011;127(Suppl 1):38S–43S.
40 Nakamura K, Moriyama Y, Kariyazono H, Hamada N, Toyohira H, Taira A, *et al.* Influence of preoperative nutritional state on inflammatory response after surgery. Nutrition 1999;15(11–12): 834–41.
41 Tchanque-Fossuo CN, Kuzon WM, Jr. An evidence-based approach to pressure sores. Plast Reconstr Surg 2011; 127(2):932–9.
42 Scivoletto G, Fuoco U, Morganti B, Cosentino E, Molinari M. Pressure sores and blood and serum dysmetabolism in spinal cord injury patients. Spinal Cord 2004;42(8):473–6.
43 Bryant R. Acute and chronic wounds: nursing management. St Louis: Mosby-Year Book; 1992.
44 McInnes E, Jammali-Blasi A, Bell-Syer SE, Dumville JC, Cullum N. Support surfaces for pressure ulcer prevention. Cochrane Database Syst Rev 2011;(4):pCD001735.
45 Allman RM, Walker JM, Hart MK, Laprade CA, Noel LB, Smith CR. Air-fluidized beds or conventional therapy for pressure sores: a randomized trial. Ann Intern Med 1987;107(5):641–8.
46 Ferrell BA, Keeler E, Siu AL, Ahn SH, Osterweil D. Cost-effectiveness of low-air-loss beds for treatment of pressure ulcers. J Gerontol A Biol Sci Med Sci 1995;50(3):M141–6.
47 Ferrell BA, Osterweil D, Christenson P. A randomized trial of low-air-loss beds for treatment of pressure ulcers. JAMA 1993;269(4): 494–7.
48 Inman KJ, Sibbald WJ, Rutledge FS, Clark BJ. Clinical utility and cost-effectiveness of an air suspension bed in the prevention of pressure ulcers. JAMA 1993;269(9):1139–43.
49 Heggers JP, Sazy JA, Stenberg BD, Strock LL, McCauley RL, Herndon DN, *et al.* Bactericidal and wound-healing properties of sodium hypochlorite solutions: the 1991 Lindberg Award. J Burn Care Rehabil 1991;12(5):420–4.
50 Lee JJ, Marvin JA, Heimbach DM, Grube BJ. Use of 5% sulfamylon (mafenide) solution after excision and grafting of burns. J Burn Care Rehabil 1988;9(6):602–5.
51 Argenta LC, Morykwas MJ. Vacuum-assisted closure: a new method for wound control and treatment: clinical experience. Ann Plast Surg 1997;38(6):563–76. discussion 77.
52 Argenta LC, Morykwas MJ, Marks MW, DeFranzo AJ, Molnar JA, David LR. Vacuum-assisted closure: state of clinic art. Plast Reconstr Surg 2006;117(7 Suppl):127S–42S.
53 Morykwas MJ, Argenta LC, Shelton-Brown EI, McGuirt W. Vacuum-assisted closure: a new method for wound control and treatment: animal studies and basic foundation. Ann Plast Surg 1997;38(6):553–62.
54 Ford CN, Reinhard ER, Yeh D, Syrek D, De Las Morenas A, Bergman SB, *et al.* Interim analysis of a prospective, randomized trial of vacuum-assisted closure versus the healthpoint system in the management of pressure ulcers. Ann Plast Surg 2002;49(1): 55–61. discussion 61.
55 Gupta S, Baharestani M, Baranoski S, de Leon J, Engel SJ, Mendez-Eastman S, *et al.* Guidelines for managing pressure ulcers with negative pressure wound therapy. Adv Skin Wound Care 2004;17(Suppl 2):1–16.
56 Evans D, Land L. Topical negative pressure for treating chronic wounds: a systematic review. Br J Plast Surg 2001;54(3):238–42.
57 Citak M, Backhaus M, Meindl R, Muhr G, Fehmer T. Rare complication after VAC-therapy in the treatment of deep sore ulcers in a paraplegic patient. Arch Orthop Trauma Surg 2010;130(12): 1511–4.
58 Aydin U, Ozgenel Y. A simple solution for preventing air leakage in VAC therapy for sacral pressure sores. J Plast Reconstr Aesthet Surg 2008;61(10):1267–9.
59 Orgill DP, Bayer LR. Update on negative-pressure wound therapy. Plast Reconstr Surg 2011;127(Suppl 1):105S–15S.
60 Carey LC, Lepley D, Jr. Effect of continuous direct electric current on healing wounds. Surg Forum 1962;13:33–5.
61 Baker LL, Rubayi S, Villar F, Demuth SK. Effect of electrical stimulation waveform on healing of ulcers in human beings with spinal cord injury. Wound Repair Regen 1996;4(1):21–8.
62 Griffin M, Iqbal SA, Sebastian A, Colthurst J, Bayat A. Degenerate wave and capacitive coupling increase human MSC invasion and proliferation while reducing cytotoxicity in an in vitro wound healing model. PLoS One 2011;6(8):e23404.
63 Zhao Z, Watt C, Karystinou A, Roelofs AJ, McCaig CD, Gibson IR, *et al.* Directed migration of human bone marrow mesenchymal stem cells in a physiological direct current electric field. Eur Cell Mater 2011;22:344–58.
64 Bruck JC, Buttemeyer R, Grabosch A, Gruhl L. More arguments in favor of myocutaneous flaps for the treatment of pelvic pressure sores. Ann Plast Surg 1991;26(1):85–8.
65 Rubayi S, Chandrasekhar BS. Trunk, abdomen, and pressure sore reconstruction. Plast Reconstr Surg 2011;128(3):201e–15e.
66 Rubayi S, Cousins S, Valentine WA. Myocutaneous flaps: surgical treatment of severe pressure ulcers. Aorn J 1990;52(1):40–7. 50, 2–5.
67 Rubayi S, Pompan D, Garland D. Proximal femoral resection and myocutaneous flap for treatment of pressure ulcers in spinal injury patients. Ann Plast Surg 1991;27(2):132–8.
68 Rubayi S, Burnett CC. The efficacy of single-stage surgical management of multiple pressure sores in spinal cord-injured patients. Ann Plast Surg 1999;42(5):533–9.
69 Sameen M, Au M, Wood T, Farrokhyar F, Mahoney J. A systematic review of complication and recurrence rates of musculocutaneous, faciocutaneous, and perforator-based flaps for treatment of pressure sores. Plast Reconstr Surg 2012;130:67e–77e.

70 Clark FA, Jackson JM, Scott MD, Carlson ME, Atkins MS, Uhles-Tanaka D, *et al.* Data-based models of how pressure ulcers develop in daily-living contexts of adults with spinal cord injury. Arch Phys Med Rehabil 2006;87(11):1516–25.
71 Jackson J, Carlson M, Rubayi S, Scott MD, Atkins MS, Blanche EI, *et al.* Qualitative study of principles pertaining to lifestyle and pressure ulcer risk in adults with spinal cord injury. Disabil Rehabil 2010;32(7):567–78.
72 Brower J, Blumberg S, Carroll E, Pastar I, Brem H, Chen W. Mesenchymal stem cell therapy and delivery systems in nonhealing wounds. Adv Skin Wound Care 2011;24(11):524–32. quiz 33–4.
73 Fan K, Tang J, Escandon J, Kirsner RS. State of the art in topical wound-healing products. Plast Reconstr Surg 2011;127(Suppl 1): 44S–59S.
74 Ko SH, Nauta A, Wong V, Glotzbach J, Gurtner GC, Longaker MT. The role of stem cells in cutaneous wound healing: what do we really know? Plast Reconstr Surg 2011;127(Suppl 1):10S–20S.
75 Scott-Williams S. Materials that help reduce pressure injuries. Outpatient Surgery Magazine 2009;10(11). Reprint available at http://www.biologics900t.com/materials_that_help_reduce_pressure_injuries_outpatient_surgery_magazine_article_biologics.pdf.
76 Sarasua JG, Lopez SP, Viejo MA, Basterrechea MP, Rodriguez AF, Gutierrez AF, *et al.* Treatment of pressure ulcers with autologous bone marrow nuclear cells in patients with spinal cord injury. J Spinal Cord Med 2011;34(3):301–7.
77 Evers L, Bhavsar D, Broder K, Breithaupt A, Bodor R. Preserving skin microcirculation with "dolphin" bed technology. J Plast Reconstr Aesthet Surg 2009;62(6):831S–2S.
78 Rees RS, Robson MC, Smiell JM, Perry BH. Becaplermin gel in the treatment of pressure ulcers: a phase II randomized, double-blind, placebo-controlled study. Wound Repair Regen 1999;7: 141–7.
79 Bates-Jensen BM, McCreath HE, Pongquan V, Apeles NC. Subepidermal moisture differentiates erythema and stage I pressure ulcers in nursing home residents. Wound Repair Regen 2008;16(2): 189–97.
80 Levine SM, Sinno S, Levine JP, Saadeh PB. An evidenced-based approach to the surgical management of pressure ulcers. Ann Plast Surg 2012;69:482–4.