REVIEW ARTICLE

Off-Loading Practices for the Wounded Foot: Concepts and Choices

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Abstract A wound practitioner's best-laid plan of care and strategy for healing an ulcerated foot is doomed to fail without a properly conceived approach based on sound off-loading principles. Wound healing that has stalled despite best-practice techniques may require reevaluation of off-loading choices. This is particularly true in the patient with abnormal foot pathologies. Special considerations are certainly required with neuropathic ulcers; however, any wound on a weight-bearing surface of the foot requires proper off-loading. This discussion explores the basic biomechanical and pathomechanical concepts that modify and influence ambulation and gait patterns. Integration of these concepts into the choices for off-loading to deter pathologic influences will alert the reader of precautionary measures and other factors for consideration. The aim of this column is to provide both an adequate working knowledge of the available off-loading devices and the necessary tools and concepts needed to stimulate wise decision protocols for wound management and healing.

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Regardless of the etiology of the ulceration, the practitioner must off-load the wounded extremity. Diabetic foot ulcers result in considerable morbidity and mortality. Armstrong et al examined the 5-year mortality rates for neuropathic and ischemic diabetic foot ulcers and diabetes-related amputations.¹ This number reached nearly 50%. Moreover, 60% of those patients who have had diabetes longer than 5 to 10 years have neuropathy at the time of diagnosis.² Additionally, one-third of patients with diabetes mellitus also have peripheral vascular disease, and of these, one-half have neuropathy.³ Therein lies the challenge for wound healing. In addition to a moist wound environment, saucerization of wound edges, and above-standard wound

care techniques, other requirements exist. Occupational surfaces and environmental factors, both external to and within the shoe gear, such as the shoe or sock type that is being worn by the patient, and any systemic complications that may influence the wound must be well thought out. The primary goal in off-loading is to preserve foot function and rectify abnormal gait patterns. Besides application or modification with an external device, accomplishing this goal may require surgical intervention. Tendo Achillis lengthening or digital surgery procedures reduce forefoot pressure. The removal of bony prominences is often required as a means of off-loading the stress on skin structures and decreasing potential pathologic biomechanical influences.

The biomechanics of gait and the deformities or faults in the anatomic structure of the feet are a direct cause of ulceration, which increases markedly in the neuropathic patient. In normal ambulation, weight bearing occurs with a

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constant transfer of weight from one limb to the other. Simultaneously, vertical ground reactive forces (GRFs) are produced and responded to. As the weight-bearing limb progresses in a linear fashion, it is subject to both torque forces and linear shear forces. The distribution of vertical forces at the metatarsal heads varies in intensity among individuals. Abnormal foot function or deformity intensifies the degree of variability and intensity of these forces on the forefoot. Vertical forces acting at the sole of the foot may exceed the body weight by 20%.⁴ In the neuropathic patient, secondary protruding metatarsals, claw toes, and tendon rupture from unrelenting tension due to loss of protective sensation are common. The formation of ulceration in the insensate or pathologic foot can occur from a single acute episode or repeated low-intensity contact. The breakdown will occur at the lowest weight-bearing area of the arch or forefoot. Resultant claw toes, or hammer toes, further influence the risk of breakdown to the dorsal and distal surfaces of the digits, as well as those surfaces under any bony prominences of the forefoot.

The majority of pathology occurs during the propulsive phase of gait. A pathologic foot is more susceptible to vertical GRFs during this phase of gait. Because the patient's entire weight distributes to the forefoot, this trauma can exceed the tolerance of the soft tissue's ability to endure the load. This condition in turn leads to physiological changes and symptomatology. A plantar hyperkeratosis may develop initially; then as the changes advance, subluxation of the joints of the foot may ensue, provoking further risk factors. With repeated force exceeding its limits, the foot reaches the threshold for risk of developing structural and skin breakdown. Repeated assaults at or in excess of this threshold result in wound formation. The duration of this stress load also has an impact on the foot structures during gait. Increasing the strain rate or the amount of force the foot is subject to over time increases the likelihood of meeting or exceeding the foot's threshold for risk.⁵ These sequelae of structural foot changes, complicated by diabetes or the insensate foot of neuropathy, often lead to the inability to sense or appreciate the increased load on the foot, further heightening risk.

There are added concerns beyond the biomechanical status of the patient that the astute practitioner must consider. A multitude of variables exist that surround the choice of an off-loading device. It is important to judge age, gender, weight, and presence of an open wound or infection. In addition, the integrity of the skin and the influence of the vasculature and neurologic status must be integrated into one's decision process. Other factors that can influence the strategy of off-loading include socioeconomic and compliance status, a history of amputation, and the presence of osseous malformations. Off-loading must above all provide prevention and protection of the wounded foot. Applying basic off-loading principles based on pathomechanics and an appraisal of the reaction of skin to GRFs and decelerating the foot onto the ground while reducing the

amount of time the foot is on the ground will lead to outcomes that are more successful. Management of any hyperkeratosis in the ulcerated and nonulcerated foot is mandatory as a basic principle of off-loading. Thinking must go beyond the wound, however, when one develops off-loading strategies. Numerous materials and devices can be kept on hand in the clinic or office. Conversely, a prescription, custom-fabricated device may require access to a certified pedorthist, orthotist, or knowledgeable clinician. In any case, one must focus on using and maintaining devices that will relieve total contact pressure on foot surfaces. In general, concepts that encompass the even distribution of the forces along the entire plantar foot and incorporate the specific biomechanical needs of the individual will point to increased success with off-loading. In addition, it is extremely important to take into account the dermatologic, musculoskeletal, circulatory, and neurosensory systemic pathology that may coexist. Primarily, the goals of off-loading wound patients are to reduce tissue motion, accommodate osseous deformities or protrusions, provide maximum shock absorption, and reduce the amount of time the foot is on the ground.

Several off-loading devices are readily available. The benefits of total or partial non-weight-bearing devices such as crutches, walkers, wheelchairs, or knee walkers is total removal of pressure from the plantar surface of the foot and from the ankle. However, these devices are often not practical because of patient obesity, debilitation, or other influencing systemic factors. Often other off-loading devices are more pragmatic and provide excellent outcomes for reduction in pressure and strain load to the wounded foot or extremity.^{6,7} The gold standard for off-loading plantar diabetic ulcers is the total contact cast.⁸ It is a composite, anatomically conforming, below-knee cast applied over minimal padding, often enclosing the toes. Variations in design and materials occur, dependent on the practitioner, clinical environment, and plantar foot wound. Total contact casting, an ambulatory treatment of superficial or full-thickness midfoot and plantar foot ulcers, usually requires reapplication every 5 to 7 days with regular monitoring and weekly to biweekly visits. Treatment with a total contact cast is complete when the wound heals and appropriate footwear is available. There are several contraindications or drawbacks to the use of a total contact cast. An experienced clinician is required for application. It does not off-load the plantar heel ulcer and is not for use with deep ulcers with exposed tendon. One must avoid the use of total contact casts in patients with a history of poor compliance or poor skin quality associated with venous insufficiency or severe arterial insufficiency. An arterial system evaluation resulting in an ankle-brachial index less than 0.45, Doppler toe pressures less than 30 mm Hg, and/or transcutaneous oxygen pressure less than 30 mm Hg makes the use of a total contact cast very risky for the patient.⁸ Absolute contraindications to the use of a total contact cast include deep infections or abscess, active osteomyelitis, and gangrene.

Figure 1 The Charcot restraint orthotic walker. A, Total contact ankle-foot option. B, With bivalve anterior and posterior shell, customized to accommodate bony deformity.

Other scenarios that require proceeding with caution and using one's clinical judgment include the presence of fluctuating edema, blindness, obesity, and an ataxic or unsteady gait.

The Charcot Restraint orthotics walker is another option available. **Figure 1** A and B shows a total contact ankle-foot option with a bivalve anterior and posterior shell, customized to accommodate bony deformity. An additional feature is the rocker bottom sole to assist in ambulation. The Charcot restraint orthotic walker can reduce plantar forefoot and midfoot pressure by 50%⁹ and provides success with patients who have fluctuating edema. The device also provides a means for progression from a total contact cast after treatment of diabetic neuro-osteoarthropathy (Charcot foot).

Frequently, the above-mentioned devices, although considered primary choices, are not always practical. Several commercial walking braces, or removable cast walkers, are available in ample supply and in many forms to aid in the management of a plantar wound or diabetic neuro-osteoarthropathy. Their primary function is to decrease forefoot plantar pressure by maintaining a 90° ankle position. These devices are notable for their effectiveness in limiting the propulsion phase of gait.¹⁰ Furthermore, removable cast walkers are useful for wounds, which require protection and regular monitoring. These devices may contain accommodative, easily customized off-loading padding at the insole, with additional padding if necessary. The accommodative padding serves to disperse the force away from the wound edge. The main advantage of the removable walking cast is its effortless removal, which permits

close monitoring of both infected and noninfected wounds. Its easy removal is a disadvantage, however, with patients who are noncompliant and do not wear the device. Measures may be necessary to secure it and prevent its removal by the patient. A comparison study assessed the ability of 4 commercially available brands of removable cast walkers to decrease dynamic foot pressure. They included the Active Off-Loading Walker™ (Royce Medical), Pneumatic Walker™ (Aircast), Dura Stepper™ (DeRoyal Industries), and CAM Walker™. Of these, the Active Off-Loading Walker demonstrated lower mean peak pressure, followed by the Pneumatic Walker™ (Aircast), Dura Stepper™ (DeRoyal Industries), and CAM Walker™, respectively. Furthermore, this comparison study found no resultant significant difference in peak pressure between the Active Off-Loading Walker and the total contact cast.¹⁰

Clinical studies have shown that fewer wounds heal with off-loading shoes, pads, and custom inserts than with the total contact cast or removable cast walker. However, the total contact cast and removable cast walker are often burdensome or not available.^{6,7} Three prescription shoe types are available: the postoperative ("post op") shoe, the depth inlay shoe, and custom-made molded shoes. Initially, and often most convenient and available at low cost, is the post op shoe. Designed initially for use after surgery to accommodate extreme swelling and bulky bandages, these shoes maintain a wide forefoot and an open or closed toe. The uppers are constructed of canvas or nylon mesh with Velcro straps or laces, and the shoe has a rigid rocker sole. One has the ability to add accommodative padding to the sole or uppers to relieve bony dorsal or plantar pressure.

Figure 2 Healing Shoe: A much more expensive but sturdier modification of the “Post op” shoe.

Although the sizes of these shoes are limited, they can be the primary footwear for the minimally ambulating or non-ambulating patient or can serve as an interim shoe while the patient waits for a prescription shoe. A much more expensive but sturdy modification of the post op shoe is the healing shoe (Figure 2). It contains a closed toe, with extrawide nylon-covered moldable polyethylene foam. This shoe is moldable directly to the patient’s foot. Wide ranges of sizes are available and can serve long-term use for the ambulating patient.

Commonly the practitioner desires to choose a forefoot-off-loading shoe (Figure 3). The Orthowedge™ and Barouk® second-generation post op forefoot relief shoe are examples. These shoes possess a wedged sole ending proximal to the metatarsal heads, with a raised heel to provide 10° of dorsiflexion at the ankle and treatment for forefoot wounds. Fleischli et al¹¹ conducted a comparison study of forefoot off-loading shoes of this type and found less mean peak pressure for plantar metatarsal head ulcers compared with the mean peak pressure with felted foam or ordinary post op shoes. However, when compared with total contact cast and removable cast walkers, the forefoot-off-loading shoe finished last at decreasing plantar peak pressure.¹¹ For rear foot wounds, a HeelWedge™ is available (Figure 4). The design forces the majority of weight onto the arch and forefoot. A locking strap around the ankle increases stability during gait. The concept of this design is to eliminate GRFs and the propulsive elements of gait, thus dispersing the GRFs from the forefoot. The major disadvantage of this shoe is that patients may lean excessively forward or backward when walking and actually increase the pressure to the forefoot. Therefore, the patient must be educated on safe and proper ambulation. A cane or crutch to assist ambulation is often valuable.

Therapeutic shoes and custom inserts are a convenient modality for off-loading and prevention. This is especially true with preulcerative skin or the insensate foot, which is at risk for ulcerative breakdown. However, therapeutic shoes and custom inserts are not appropriate in situations

Figure 3 Forefoot off-loading shoe.

that would warrant total pressure relief, such as active ulcers. Custom inserts completely conform to the foot, responding to body heat and weight, thus eliminating all gaps and pressure points. What makes a shoe therapeutic is the specific design and construction to meet medical needs. The function is the primary design consideration. The therapeutic shoe generally requires greater-than-usual depth and strength and must accommodate foot orthoses. Multiple fabrics, closures, sizes, and widths are available. These shoes also can be modified internally, externally, or both. The practitioner must examine shoes and inserts at each visit and ensure stability and maintenance of appropriate shock absorption and shear force reduction. Proper off-loading can be ensured by testing the recoil of the insert material. At each visit, the practitioner can pinch between the thumb and forefinger the inserts in the areas of the highest points of pressure. This simple test demonstrates whether the insert has bottomed out. It is crucial that the shoes match the shape of the foot and fit the measure of the length of toe to heel and width of forefoot. Proper fit from heel to forefoot is especially important for the patient with accommodative pathologic changes to foot structure who must avoid excess rearward or forward movement. A simple adjunct device is a Hoke ball and ring. This device stretches shoes to accommodate bony protrusions or rigid digits.

Figure 4 Rear foot off-loading shoe.

Extra-depth (also known as depth-inlay) therapeutic shoes are a necessity for those patients with a history of ulceration, neuropathy, decreased plantar fat pad, or rigidly contracted digits. These can be used for patients with propulsive or apropulsive gait patterns. Extra-depth therapeutic shoes come in several types and with modifications. Ankle custom liners or inserts and ankle-foot orthoses are available. A variation is custom-molded shoes with liners. Custom-molded shoes are for patients with gross anatomic deformity but a stable foot and ankle structure. These shoes are essential for patients unable to have reconstructive surgery. Custom-molded shoes replace the extra-depth shoe when modifications cannot meet the patient's needs. It follows that all custom inserts possess different degrees of hardness or resiliency. Custom insoles contain a variety of off-loading materials that are multilayered from a positive mold of the patient's foot. Materials used possess different degrees of hardness, control and conformability. Making the right choice involves factors such as the patient's weight and level of activity and the amount of control required.

Either a closed-cell or an open-cell material that provides different parameters of function is widely used for inserts (Figure 5). Closed-cell materials possess shock absorptive qualities and provide protection. They also possess stability or memory properties. Loss of these properties, or bottoming out, is undesirable and requires regular monitoring. Neoprene, a closed-cell sponge-rubber-based material, is very durable and aids in decreasing shear forces, especially for forefoot pathology. Open-cell materials include Plastizote™ polyethylene foam, which comes in soft, firm, and rigid textures. Implicit in the design is the ability to

Figure 5 Commonly used materials for inserts that provide different parameters of function: Left to Right, PPT™, Plastizote™, combination PPT™/Plastizote™.

provide accommodative characteristics that will compress to the shape of the foot. However, the disadvantage of open-cell materials is their eventual deforming and bottoming out. Use of PPT™ polyurethane foam is common. The density of this material prevents bottoming out or excess compressing. PPT™ acts similar to closed-cell foam. Polyethylene and polyurethane foams are frequently combined for their accommodative, shock absorptive, and protective characteristics. Fabrication of custom inserts of varied thickness is advantageous, especially for the larger overweight patient. Since these inserts add bulk to the shoe, an extra-depth shoe is usually required with their use.

Figure 6 Two views of a custom patellar weight-bearing device attached to custom molded shoe: Used to counter forces placed on the unstable and/or amputated foot or lower extremity.

Other splint devices are available when off-loading of the foot or lower extremity requires total pressure relief and barriers such as morbid obesity, amputation, or neurologic deficits exist that prevent the effective use of a total contact cast, Charcot Restraint Orthotic Walker, or removable walking cast, shoe, or insert. These normally require a prescription to a certified pedorthist or well-versed clinician. The patellar weight-bearing device, ischial weight-bearing device, ankle-foot orthoses, or a prosthetic limb can counter the forces placed on the unstable amputated foot or lower extremity (Figure 6). Customized stump fillers made of conformable accommodative materials placed in shoes aid in decreasing excess linear and shear forces within the shoe and offer stability in ambulation for feet with amputations.

As in any treatment strategy, there are also challenges and barriers to off-loading. With a patient facing major lifestyle changes and decreased activity levels, the practitioner must bear in mind compliance issues, as well as the patient's weight and degree of obesity. Those barriers that directly influence the foot and may present a challenge are large bony protuberances. In devising a strategy for off-loading, one should consider peripheral edema, previous amputations, wound location, and the need for active wound care. One must individualize each situation and each patient's unique needs. Finally, as one considers the multifactorial components of off-loading concepts and how they will best meet the patient's needs, the total integration of these precepts in treatment plans will guide the practitioner to improved outcomes in healing.

In conclusion, successful outcomes for wound healing integrate the strategies and care that best potentiate the increase in oxygen to the ulcer, decrease infection or bioburden, maintain good glycemic control, and create a

favorable environment for wound healing. Along with implementing these strategies, the practitioner must provide adequate pressure and strain relief from the biomechanical and pathomechanical forces that transpire during ambulation.

References

1. Armstrong DG, Wrobel J, Robbins JM: Guest editorial: are diabetes-related wounds and amputations worse than cancer? *Int Wound J*. 2007;4(4):286–287.
2. Frykberg RG: A summary of guidelines for managing the diabetic foot. *Adv Skin Wound Care*. 2005;18:209–213.
3. Krasner DL: *Chronic Wound Care*. Malvern, PA: HMP Communications; 2007;537.
4. Root ML, Orien WP, Weed JH: *Normal and Abnormal Function of the Foot*. Los Angeles, CA: Clinical Biomechanics; 1977;165–167.
5. Snyder RJ, Kirsner RS, Warriner RA III, Lavery LA, Hanft JR, Sheehan P: Consensus recommendations on advancing the standard of care for treating neuropathic foot ulcers in patients with diabetes. *Ostomy Wound Manage*. 2010;56(suppl 4):S1–24.
6. Bus SA, Valk GD, van Deursen RW, et al: The effectiveness of footwear and offloading interventions to prevent and heal foot ulcers and reduce plantar pressure in diabetes: a systemic review. *Diabetes Metab Res Rev*. 2008;24(suppl 1):S162–180.
7. Mueller MJ, Diamond JE, Sinacore DR, et al: Total contact casting in treatment of diabetic plantar ulcers: controlled clinical trial. *Diabetes Care*. 1989;12(6):384–388.
8. Dhawan S, Conti SF: Use of Total Contact Casting in the Diabetic Foot. *Foot and Ankle Clinics. The Diabetic Foot*. 1997;2(1):115–136.
9. Pupp GR, Wilusz PM: Reassessing the impact of diabetic footwear. *Podiatry Today*. 2004;17(3):38.
10. Martin N, Oldani T, Claxton MJ: A guide to offloading the diabetic foot. *Podiatry Today*. 2005;18(9):68–70.
11. Fleischli JG, Lavery LA, Vela SA, Ashrey H, Lavery DC: Comparison of strategies for reducing pressure at the site of neuropathic ulcers. *J Am Podiatr Med Assoc*. 1997;87(10):466–472.