Pressure Point Offloading in the Diabetic Foot

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Summary

The formation of diabetic wounds has been discussed, with an emphasis on the effects of force on the plantar tissues and the theoretical response of those tissues. As pressure reduction is an integral part of the healing process for diabetic wounds, many types of offloading strategies in the medical literature have been examined. All report success – to varying degrees – but not all comparisons have been applied in a similar way and few have controlled for similar variables. This article presents for discussion a range of off-loading methods that wound care practitioners can employ, depending on the site and severity of the presenting wound.

Introduction

Foot wounds are one of the most common and significant complications associated with chronic diabetes. It has been estimated that 5 per cent of those with diabetes will experience a foot ulcer; indeed, 1.5 per cent of diabetic individuals have a foot wound at any point in time [1]. Such wounds can be classed as neuropathic, vasculo-neuropathic or vascular in origin. Since neuropathy is estimated to be present in one in four diabetics [1] and in more than 80 per cent of diabetic patients with foot wounds [2], the majority of diabetic wounds will thus be neuropathic in nature and occur on the plantar aspect of the foot [3-7]. Estimates of the prevalence of plantar wounds range from 25-35 per cent of the first toe through 23-50 per cent of the first metatarso-phalangeal joint to 38 per cent for the lesser metatarsal heads [3-6]. Neuropathy produces changes that include sensory, motor and autonomic components [8], all of which will impact on the diabetic foot. "A key factor in the diabetic foot is that dy-namic pressures are higher than in those without diabetes" [9, 10]. The causes of increases in dynamic pressures are thought to in-clude bony deformity [11], retraction of the toes, pes cavus [12], lack of soft tissue cushioning, callus formation [13, 14] and limited joint mobility [15]. The loss of protective sensation (LOPS) from peripheral neuropathy leads to silent injury from biomechanical stresses when higher pressures are present. Effective pressure reduction strategies are essential in healing and preventing foot wounds.

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Forces Acting on the Foot

On the plantar aspect of the foot, the soft tissue between the epidermis and bone assists as part of the cushioning process, protecting the body from the severe mechanical stress experienced by the skin [16]. In the diabetic foot, with fat-pad atrophy, digital retraction of the toes, LOPS and autonomic changes leading to a reduction in skin tone, these stresses tend to be magnified. In the biomechanics of biological structures, force is independent of the area over which it is applied and pressure is the applied force divided by its area of application. Thus, the same magnitude of force under one foot can result in different forefoot pressures, depending on the area of application. Birke and Sims [17] refer to four variables that interact to produce combined loading under the foot: **magnitude**, **duration**, **direction** (of the forces) and the **area** over which they load.

Magnitude

While the aspect of diabetics having higher foot pressures than non-diabetics has been examined elsewhere [5, 7, 11, 16, 18-22], the minimum pressure threshold thought to cause ulceration is in dispute – estimates range from 40 to >98 N/cm^2 [3, 10, 23], with some pressures measured as >110 N/cm^2 for ulcers already present [10].

Area

The pressure generated through the foot is a function of the force maintained through a defined area, with the pressure directly proportional to the force and inversely proportional to the area [11]. Therefore, as peak pressures are generated in the foot

during forefoot loading and propulsion, high pressure is delivered through a small, rapidly decreasing contact area. If force is reduced at a bony site with an off-loading strategy it must be directed elsewhere, to suitable under-used areas of the foot; that is, to a larger surface area [23].

Duration

Although studies have shown that a relationship exists between moderate repetitive stress and plantar wounds, " ... there is no consensus on the load duration required to cause ulcerations ... no studies have demonstrated a direct mechanism whereby ulcerations are produced in response to a specific, characteristic mechanical load" [24]. Landsman *et al* [24] suggest that diabetic tissues may be more susceptible to mechanical injury and more sensitive to the rate of deformation than the magnitude of the load itself.

Direction

The direction of the forces in tissues is important, since tissue strength is not the same for all loading patterns. While five loading patterns – **tension**, **compression**, **bending**, **shear** and **torsion** – are described for all materials, three have been referred to more often in the diabetic literature [10, 25]. They are described as surface forces: **normal** (tension and compression) and **shear**. Normal forces are applied perpendicularly to a body to cause tension or compression, whereas shear forces cause sliding between parallel planes. When applied, these forces can cause a deformation response referred to as **strain**; like surface forces, there are three types of strain: **tensile**, **compressive** and **shear**.

There is an internal reaction to these external forces, to maintain equilibrium and resist deformation. It is referred to as **stress**; that is, the force per unit area acting in a given plane within a material (expressed in N/m^2 or Kg/cm^2). There are also three types of stress: **tensile**, **compressive** and **shear**.

Normal stresses resist either compression or tension perpendicularly within a body, while shear stresses resist sliding between parallel planes in a body. Stress is the internal force that develops to resist the strain produced by an externally applied force. If the external force overcomes the internal stress, tissue deformation occurs and, if left unchecked, will cause a wound to develop. (**Note**: normal and shear stress always exist in combination, according to the state of the loading [26].)

In the presence of the four variables – **magnitude**, **duration** and **direction** of the forces acting on the same **area** – there are likely to be three types of injury mechanisms in the insensitive foot:

- pressure-induced ischaemia;
- overt trauma, and
- repetitive stress [16].

Concepts of Off-loading

Mechanical protection of the foot is essential for healing [26]; consideration must be paid to either 'unweighting' the foot (that is, no weight on the foot or wound) or 'off-loading' (that is, rebalancing the weight on the foot/leg, with the patient still weight-bearing). Guzman *et al* [27] outline a number of 'ideal' characteristics of successful pressure-relieving strategies. They:

- provide effective pressure reduction from the ulcer at all times;
- have wide application to all patients;
- cause no side-effects or secondary lesions;
- are easily applied;
- encourage patient compliance;
- are cost-effective, and
- allow other treatment goals to be pursued.

Off-loading Strategies

Callus debridement

The formation of callus, a reactive mechanism of the tissues to shearing and normal strain on the skin, is one of the main precursors to ulcer formation [9]. Callus alone has been shown to increase local pressure by up to 30 per cent [28], so effective callus prevention and debridement are vital in reducing the formation of subcutaneous haemorrhaging and ulcer formation. A study of diabetics found there was a relative risk [11] of developing an ulcer under a callused area compared to a non-callused area and the association was much greater than for increased plantar pressures alone [28].

Accommodative padding

Various materials have been used to temporarily off-load pressure on the foot. They can be applied around acute or chronic wounds, depending on the size, site, type and status of the

wound. However, care must be taken not to eliminate pressure in one area merely to overload another [29]. Armstrong, Liswood and Todd [30] examined accommodative padding cut with an aper-ture to fit around an area on the plantar surface of the foot. The results indicated that pressure seemed to be reduced over the aperture but increased at the periphery of the aperture. Coch-rane referred to this phenomenon as 'stress concentration' [25]. A hole introduced in a structure changes a stress line from a maxi-mum value to zero over a small distance, causing the stress lines to be diverted and concentrated at the periphery of the hole. Armstrong and Athanasiou called this the 'edge effect' [31]. Although their measures were not made on diabetics with wounds, and the aperture size and shape of the pad were not defined, the authors urged caution when applying accommo-dative padding adjacent to plantar wounds. An alternative that minimises the edge effect might be total contact padding to off-load the foot [27]. The padding is applied to the entire plantar surface of the foot, with an aperture around the wound, and incorporated with secure outer bandaging and a post-op shoe. Another problem can arise when oedema is present – an aper-ture around the wound can amplify the swelling and concentrate it around the wound.

Footwear

Footwear is seen as an important factor in preventing the recurrence of ulcers. With compliant patients and more than 60 per cent daily usage of custom-made shoes with cushioned insoles, the ulcer relapse rate in one study was reduced by over 50 per cent [32]. Also, when comparisons of pressure variation in various shoe types were made using an in-shoe pressure measurement system, there seemed to be significant pressure reductions at varying plantar sites of the diabetic foot with different types of footwear [4]. Off-the-shelf athletic-style footwear in one study showed a possible benefit in delaying the recurrence of plantar callus [33]. Athletic cross-trainers, therapeutic depth and other 'comfort' shoes have all shown the ability to reduce pressure at specific sites. To prevent the recurrence of wounds, the authors suggest that the site of the previous wound may dictate the style and type of shoe to use [4].

As an adjunct to the use of therapeutic or custom footwear in preventing foot wounds, modifications to the sole profile have also been examined. A totally rigid sole that angles up sharply or gradually at the forefoot has been shown to reduce forefoot pressures in non-diabetic subjects [34]. However, the re-sults are mixed, since other researchers believed an increase in pressure takes place on the lateral column of the foot [35]. These 'rocker or roller' soles may also help prevent wounds by forcing patients to reduce their step length and walk more slowly and by reducing the range of motion at the metatarso-phalangeal joints.

Temporary/post-op shoes

These short-term types of footwear have a rigid sole, are used to cover plaster casts or protect dressings after foot surgery and can be used as a vehicle to carry soft insoles (see Figure 1). However, if gait is not adapted adequately, the habitual walk of the patient can cause the straps to loosen and the foot to shear across any insole or padding in the shoe. Compared with the 'half-shoe' style (see Figure 2) and total contact cast methods of off-loading, these shoes were fifth on the scale in their ability to

Figure 1. Temporary post-operative shoe.

Figure 2. A 'half shoe' style.

reduce foot pressures [36]. The half-shoe style is designed with a negative heel, loads all the weight onto the heel and is useful in off-loading forefoot wounds [37]. The authors believe this style should be used only with crutches and only for short distances, since it may cause gait instability [37, 38]. Compared with other, more mobilising strategies, the half-shoe was rated third in reducing forefoot pressures [36].

Soft, moulded sandal

This and the 'cut-out' sandal are variations of the same temporary shoe, moulded directly to the foot [20]. Birke *et al* [39] reviewed the cut-out sandal, which removes first-toe apex pressure and is appropriate for healing wounds in those areas of the toes. It was thought to be unsuitable for plantar wounds as movement between the foot and shoe might not be adequately controlled, thereby increasing shearing forces at the wound site. Coleman and Plaia [20] describe the soft, moulded sandal more as a pre-ventive measure to use once the wound has healed.

Foot orthoses

The definition of foot orthoses is often quite broad. Indeed, the Australian Podiatry Council's definitions [40] range from 'cushion-ing' to 'functional foot' orthoses. Depending on the clinical requirement, any category could offer the protection required for the healed diabetic foot. Studies examining the pressure-relieving capacities of rigid orthoses on non-deformed feet suggest that they act in the same way as some of the more im-mobilising strategies by redistributing pressure across the foot, especially to the mid-foot and heel [41].

Insoles

Many materials are available for use as insoles after healing of plantar ulceration but the relative merits of each need to be evaluated for their durability and shock-attenuation capabilities. In laboratory testing, some closed-cell polyethylene foams compressed faster than the open-cell urethane foams but moulded better to accommodate bony prominences. The latter materials are reported to be more durable and to resist shock more effectively [42]. Such materials would be used in conjunction with appropriate footwear.

Casting/splinting

A number of casting/splinting methods are used to immobilise the ankle joint and off-load wounds on the foot [43-46], with plaster and fibreglass the materials of choice. Certain methods require some skill to apply, and certain materials need constant mainten-ance [43, 45]. Casting usually involves enclosing the entire foot and leg to just below the knee, with the wound covered; as dressings are changed a new cast is required. Often referred to as 'total contact casting' ('TCC'), it involves minimal padding, to ensure a close fit against the tissues. Considered the most effective off-weighting strategy for diabetic wounds, TCC redistributes pressures across the foot more efficiently and shortens healing times for wounds [47]. Casts that completely enclose the foot and leg are contraindicated where there is dependent oedema, infec-tion, hypotrophic skin or peripheral vascular disease.

Figure 3. Back-slab splint.

A study of five different fibreglass cast types – varying from slipper casts to a short leg cast (with a walking heel) – revealed that forefoot pressure relief was greatest as the form of immobilisation was extended up the leg [44]. Splinting can be achieved with a cast that has been bi-valved or where a 'back-slab' is applied to support the foot and ankle and can be reused daily (see Figure 3). Manufactured splints or walkers, Cam walkers [48], 3-D orthopaedic walkers [49] and DH pressure-relief walkers [36] are also valuable (see Figure 4) alternatives that have proven as effective as casting in reducing forefoot pressures [36], without the need for skilled application. Walkers and splints are easily removed for reviews and patients can walk with them on; however, patient compliance may become a problem if the device is removed too easily.

Other

Cushioned socks [50], gait training [51] and sensory substitution [52] are all referred to in the literature as adjuncts to reducing pressure on the foot, but studies still need to be carried out to assess the clinical value of such strategies.

Conclusion

Many off-loading ideas are available and in practice in wound care. None of the strategies described should be seen as a single solution for off-loading the diabetic foot. Rather, they can form part of a total plan that includes education, control of infection, shoes fitted with appropriate orthoses/insoles and surgery if necessary [53].

Figure 4. Manufactured splint.

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