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A pilot study comparing custom contoured and planar support surfaces for pressure ulcer risk over the heels for night time postural management using interface pressure mapping and discomfort scores

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Purpose: Custom contouring techniques are effective for reducing pressure ulcer risk in wheelchair seating. These techniques may assist the management of pressure ulcer risk during sleep for night time postural management.
Objectives: To investigate the effectiveness of custom contoured night time postural management components against planar support surfaces for pressure ulcer risk measures over the heels.
Method: Supine posture was captured from five healthy participants using vacuum consolidation and 3-dimensional laser scanning. Custom contoured abduction wedges were carved from polyurethane and chipped foams. Pressure mapping and the visual analog scale were used to evaluate the effectiveness of the contoured foams in reducing pressure and discomfort under the posterior heel against standard planar support surfaces.
Results: Custom contoured shapes significantly reduced interface pressures ($p < 0.05$) and discomfort scores ($p < 0.05$) when compared to planar support surfaces. Polyurethane foam was the most effective material but it did not differ significantly from chipped foam. Linear regression revealed a significant relationship between the Peak Pressure Index and discomfort scores ($r = 0.997$, $p = 0.003$).
Conclusions: The findings of this pilot study suggested that custom contoured shapes were more effective than planar surfaces at reducing pressure ulcer risk surrogate measures over the posterior heels with polyurethane foam being the most effective material investigated. It is recommended that Evazote foam should not be used as a support surface material for night time postural management.
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1. Introduction

As a result of the growth of the wheelchair and seating market over the last few decades pressure under the ischial tuberosities (ITs) and the sacral area, its subsequent risk, and management have been studied extensively in relation to postural management during the day - particularly the development and use of custom contouring techniques [1–4]. This has led to advancements in the field of posture and mobility for pressure ulcer reduction with the introduction of new equipment, technologies and materials such as specialist foams, gel inserts, air cell cushions and custom contouring techniques.

During a 24 h postural management programme it is not recommended nor intended that the user remains in wheelchair seating for the whole 24 h; particularly considering that disabled children spend approximately 42% of their day in a lying position [5]. Persons who require the use of night time postural management are typically those most at risk of pressure ulceration due to their limited mobility, bony deformities and muscular imbalances causing high interface forces. A study investigating differences between 15 normally developing children and 15 with severe cerebral palsy (CP) in terms of body position and movement over 24 h found children with CP spent significantly more time in the same position during sleep (5.6 ± 3.5 h) than normally developing children (1.6 ± 1.2 h) [6]. In addition, children with severe CP were significantly less likely to shift position during night time sleep with half of the CP group not changing their position at all during sleep; a result that was reflected in a previous study [7]. This

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presents a pressure ulcer risk during night time positioning as carers who would be available during the day to change position of disabled persons would normally be asleep during these hours. Wheelchair users are at particular risk from pressure ulcers. A study investigating pressure ulcer prevention in the community found that 19.1% (n = 26) of wheelchair users had an existing pressure ulcer and 58% (n = 79) had had at least one pressure ulcer in their lifetime [8], Therefore it is essential that any postural management system, that severely disabled persons are left to sleep in alone, is able to adequately reduce interface pressure.

After the ITs and sacral area, the heels have the highest incidence of pressure ulceration arising from supine lying. Previous studies investigating pressure ulcer prevalence and location have reported the heels to make up anywhere between 10.6% and 18.2% of the total number of pressure ulcer cases [9,10]. In addition, the heel is the area most susceptible to deep tissue injury (DTI) and has been reported to make up 41% of all DTIs [10,11]. As the heels are the most common site of DTIs, which are inherently harder to treat, they experience a high ratio of Grade III and IV pressure ulcers. One study reported the incidence of higher grade pressure ulcers was as much as 43.3% and 34.4% of total heel pressure ulcers when investigating two pressure ulcer databases, respectively [9]. Higher grade III and IV pressure ulcers typically take much longer to heal. Where 75% of Stage II ulcers heal within eight weeks this figure drops to just 17% for Stage III-IV pressure ulcers [12]. This may, in part, be the reason healing times of pressure ulcers over the heels are lengthy with cases often exceeding a year [13].

The unique anatomy of the heel predisposes it to tissue damage with the calcaneus protected only by a thin fat pad in combination with the heel having low blood flow pressure and impaired ability to reperfuse [13,14]. The posterior heel lacks muscular tissue which can provide cushioning and help to distribute loads; such as under the ITs where the gluteal muscles can aid pressure distribution and load attenuation [15,16]. The biomechanics of heel ulceration and the effects of the internal anatomy of the heel in a supine posture on pressure ulcer risk has been explored using computer-aided modelling. Finite element (FE) modelling has demonstrated that atypical foot anatomies are a particular risk factor for heel ulceration; which would be expected for musculoskeletal disabled users of postural management devices [17]. Theoretical modelling indicates that the thin soft tissues that protect the calcaneus are not sufficient to prevent ulceration for sustained periods [17]. Disabled populations are likely to experience muscle wasting which may cause deterioration of the thin padding that is available to the calcaneus, hence, exacerbating tissue damage risk. Due to the sharp posterior heel, the interface pressures are high and it is this area which is in contact with the supporting surface during supine lying. Without the aid of imaging techniques it would be difficult to determine which patients are most at risk of pressure ulceration through assessment of their underlying anatomy. Palpation can be used clinically to gain a practical observation of whether or not the patient is likely to be at risk biomechanically due to the morphology of the calcaneus and structure of the overlying tissues [17].

Despite the posterior heel being a considerable risk area for disabled persons during supine lying the vast majority of night time postural management devices are modular in their design with planar support surfaces. Materials for these devices are typically selected for their rigidity and strength, to enable the postural management goals of the programme by maintaining limbs in a fixed position, opposed to their pressure relieving properties which can cause high external forces and relatively small contact areas for the user. In fact, despite their widespread use among therapists they have attracted criticism in terms of comfort, tolerance and pressure problems among other factors which can lead to their non-compliance [18]. A study investigating the effect of postural management devices on hip subluxation in 14 children with cerebral palsy showed only half of the participants completed the study due to non-compliance. Support surface materials in their design must be able to provide a number of desirable functions for adequate pressure relief. This can be achieved by either using a conformable material to immerse the body or by contouring the shape of the material to envelop the shape of the body. In addition, a material that is able to distort horizontally can absorb the shear forces so the tissues do not have to. Most NTPME systems make use of a foam base; whether this is polyurethane, chipped foam, Evazote, memory foam or other low density foam. Typical set ups include brackets and moveable segments to provide corrective forces whose materials are chosen for their strength such as thermoplastic polymers, e.g. Acrylonitrile butadiene styrene, or rigid foams, e.g. Evazote. Covering materials for NTPME tend to focus on heat dissipation; using mainly thin cotton sheets, gel overlays or lamb wool overlays. However, there is no literature investigating the impact that new techniques and materials have during lying and sleep on pressure ulcer risk for night time postural management.

Interface pressure mapping is routinely used in clinics to assess the efficacy of support surfaces including for wheelchair seating, postural management devices and mattresses. However, in practice pressure mapping only provides a snapshot of the interface pressures that are occurring and its usefulness at predicting deep tissue stresses has been debated in the literature [19]. Poor correlation between interface pressures distally and elevated muscular stresses around internal bony prominences has been highlighted by Ref. [19] and hence its use in predicting deeper tissue injuries is limited despite the widespread adoption of interface pressure mapping as a clinical tool [19]. Alternative methods, specifically imaging techniques such as MRI, can be used to provide a greater insight into the internal mechanical stresses and deep tissue deformations that occur proximally. MRI has been used successfully to provide evidence when comparing the efficacy of various prophylactic heel padding devices on internal soft tissue deformations [20]. Weight bearing MRI has been used by Ref. [21] as a tool for systematically selecting wheelchair cushions. Using MRI the anatomy of the internal soft tissue deformations could be evaluated suggesting that commercial wheelchair cushions were effective at alleviating tissue deformations by 10%. This technique could similarly be applied to night time postural management for aiding selection of devices for clinical prescription. Computational modelling has been used to theoretically demonstrate how support surface properties may influence soft tissue deformations overlying the posterior heel [15]. [15] found that heel pad stresses and strains are considerably reduced when the foot is positioned at a vertical, rather than abducted, position. Although the real world application of FE models in impractical it is useful in fulfilling understanding of the biomechanics responsible for heel ulceration.

Investigations comparing custom contoured seating to standard support surfaces have reported significant reductions in pressure ulcer risk surrogate measures ($p < 0.05$) using custom contouring techniques for wheelchair cushions [22]. In addition, custom contouring has been shown to be effective in reducing heel pressure for heel surgery patients [23]. However, custom contouring is not perfect and does present some potential issues including the system being restrictive on movement and growth, difficulty in transferring between surfaces and humidity; which can ultimately exacerbate ulcer risk. The distribution of gravitational, frictional and shear forces during lying differs from that in a seated posture so further research is required to establish optimum design specifications. The extent to which principles derived from seating can be applied to a lying posture needs to be investigated. Current

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