3-DIMENSIONAL PHANTOM BUTTOCKS TISSUE DEFORMATION ACROSS CUSHIONS

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INTRODUCTION

Pressure ulcers (PUs) are a leading secondary complication of spinal cord injury (SCI), affecting 24% of people with SCI during their initial hospital stay [1]. Furthermore, more than 50% of people with SCI experience PUs during their lifetimes [2-5]. PUs are associated with increased clinic or home-health visits and hospitalizations [6]. Yet the costs of PUs extend far beyond the medical costs incurred for treatment. These can have a devastating impact on the quality of life due to the need for prolonged bedrest, resulting in social isolation and loss of independence. The continued high rate of readmission to hospital indicates that there is a continued need for clinical techniques to determine individualized pressure ulcer risk status and provide appropriate preventative interventions.

Current clinical assessment of seating-related PU risk focuses almost exclusively on interface pressure measurement. The primary reason for this choice is pragmatic, namely that interface pressure mapping systems are widely available and established in both research and clinical settings. Interface pressure mapping is currently the only commercially available and clinically viable method for assessing tissue loading, and it provides some insight into the loading at the buttock-cushion interface. However, interface pressure mapping assesses the effects of applied seating loads only at the surface and not in the deeper soft tissue which may be more susceptible to damage [7]. It is thus not surprising that many decades of research have failed to determine either a consistent predictive relationship between interface pressure and PU development or a clinically valid threshold of acceptable interface pressure [7,8].

Recent evidence suggests that it is actually internal tissue deformation resulting from external interface pressure that is the primary biomechanical factor responsible for PU development [4-6]. Therefore, persons that experience less soft tissue deformation are at lower PU risk than those with greater amounts of deformation. Extending this to wheelchair seating, we recognize that tissue deformation will occur as a person sits on a cushion, but the amount of deformation will vary across people and will directly relate to their PU risk. Stated differently, people with certain biomechanical and physiological characteristics will resist damaging deformation better than others. Individuals with SCI exhibit many intrinsic factors that heighten PU risk and influence deformation resistance, including disuse muscle atrophy, altered muscle tone, and changes in muscle composition [8]. In order to provide effective interventions to prevent PU development, we must understand how individuals' buttocks tissue responds to loading when seated on different commercially available cushions.

This goal of this pilot study was to demonstrate that 3-dimensional measurements of a phantom buttocks tissue deformation could be collected from MRI data. Testing of human subjects will follow in a future study.

METHODS

Model

To simulate a human buttocks, a realistic phantom buttocks model was created. The model included a molded pelvis and femurs (3B Scientific) embedded within a gel-based buttocks and thighs (Figure 1). The soft tissue was modeled using Dragon Skin FX-Pro® (Smooth-On, Inc., Easton, PA), a platinum cure silicone rubber that was made more elastic with silicone thinner.

The phantom soft tissue was validated according to its stiffness. Actual estimates of the elasticity of human buttock soft tissue vary considerably, but tend to be on the order of 10-100 kPa [e.g., 9, 10]. We tested a 28.6mm diameter puck (12.5 mm thick) according to ASTM D 575-91, a test for rubber properties in compression. The puck was loaded and unloaded at 12 mm/min, and we measured force and deflection.

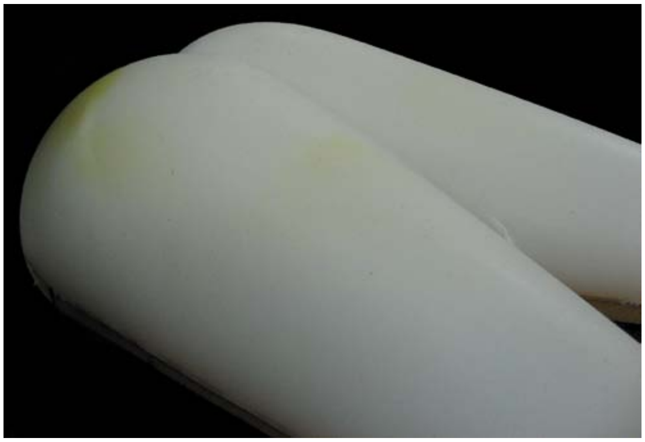

Figure 1. Phantom buttocks model.

Data Collection Protocol

Data was collected using a Siemens Trio 3T MRI scanner. Coronal, T1 images were collected with a 4mm slice thickness.

To document a reference, unloaded condition, the buttocks was scanned upside down with no loading applied (as pictured in Figure 1). Afterwards, the buttocks was flipped over and placed on top of three different surfaces: HR45 foam, a Jay Extreme cushion, and on a rigid surface. 58.4 kg were applied on top of the buttocks and thighs to simulate a 70kg person.

Data was processed using Mimics (Materialise, Inc.). The pelvis from each scan was registered to the unloaded scan in order to align the soft tissue for relative comparison. The peak of the ischial tuberosity was identified as the MRI slice in which the ischial tuberosity was closest to the rigid surface below. Tissue thickness was measured as the distance from the peak of the ischial tuberosity to the skin in the vertical direction.

RESULTS

Over the linearly elastic range of the material (approximately 0-25% deformation), the stiffness was 3.3 N/mm and elasticity was estimated to be approximately 70 kPa (Figure 2).

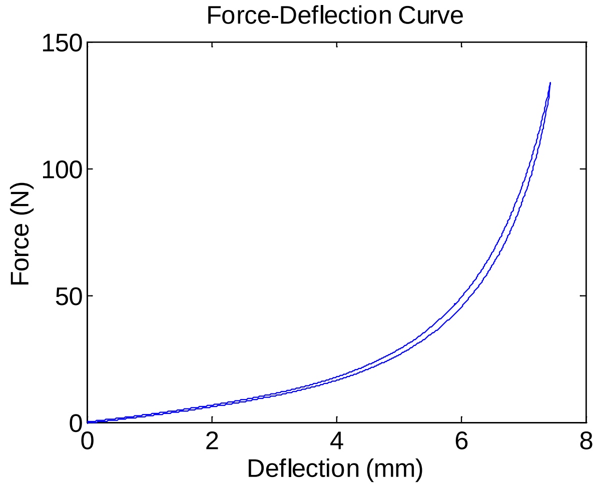

Figure 2. Force-deflection curve of phantom gel.

Tissue thickness at the peak of the ischial tuberosity varied by support surface (Table 1). As one would expect, the greatest deformation was seen with a rigid surface. A small difference in deformation was seen between the cushions studied.

Multiple perspectives of the 3-dimensional deformation are presented in Figure 3. Contours of the unloaded buttocks can be compared with the MRI of the deformed buttocks to illustrate compression of the tissue nearest the ischial tuberosities and expansion of the tissue laterally (Figure 3, rows 2 and 3). Deformation maps illustrate a steeper gradient of deformation near the ischial tuberosities on the rigid surface, whereas the Jay Extreme and HR45 foam have a fairly consistent deformation in the ischial tuberosity region. Both the contours and overall distribution of deformation differ across surfaces.

Table 1. Tissue thickness and % deformation underneath the ITs varied widely across cushion.

Cushion	**Thickness (mm)**	**% Deformation**
Unloaded	22.3	0%
Jay Extreme	21.2	5%
HR 45 Foam	17.7	21%
Rigid	6.0	73%

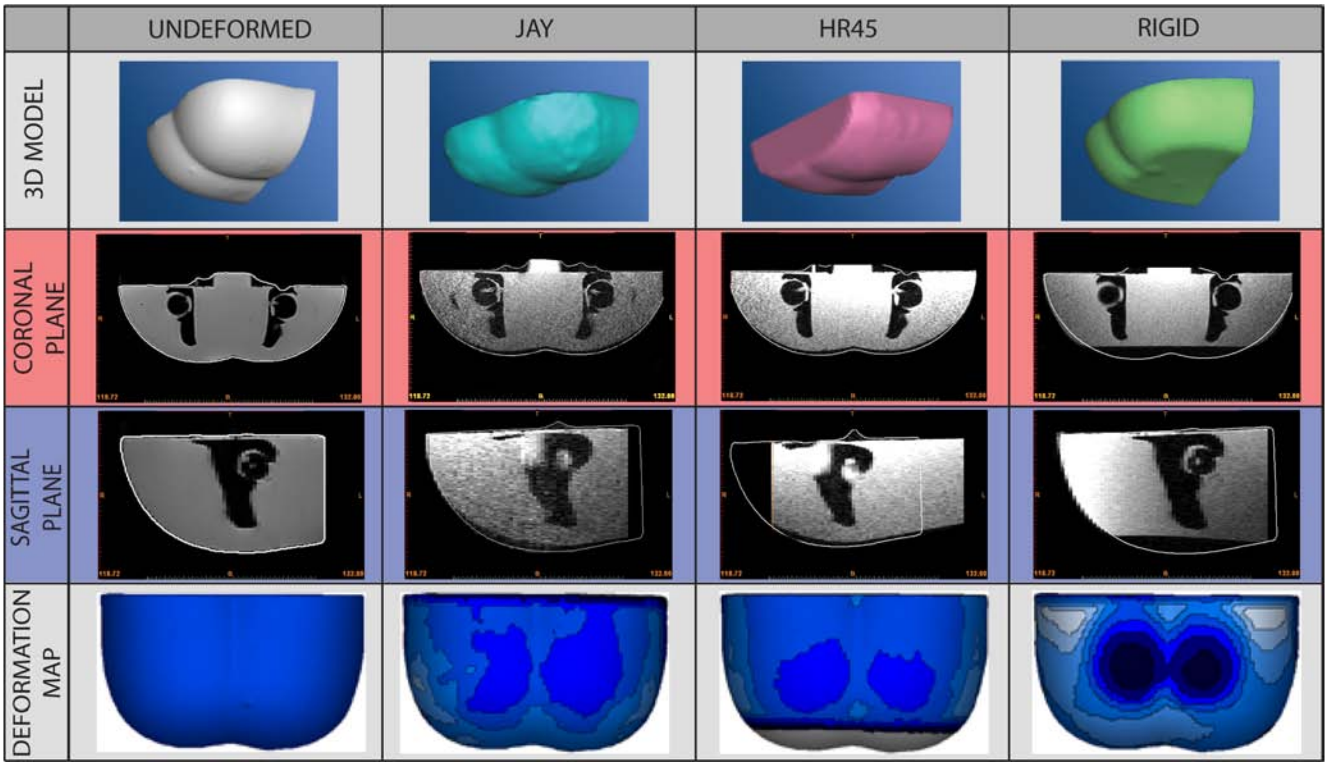

Figure 3. Results of 3-dimensional deformation analysis. Models of the soft tissue are illustrated in the first row. The second and third columns present a slice of the MRI scan at the peak of the ischial tuberosity on each cushion. The white outline represents the contour of the unloaded buttocks at the same location. The bottom row presents deformation of the buttocks as viewed from beneath. Darker colors indicate greater compression with the lightest colors indicating the greatest expansion.

CONCLUSION

The data presented demonstrate that differences do exist in the deformation of buttocks tissue across cushions. Although not at all surprising, the greater deformation seen when loaded on the rigid surface as compared with cushions supports the study goal to demonstrate that MRI is a suitable methodology with which to analyse 3-dimensional buttocks deformation. The implications of the differences in deformation presented here require additional study to understand the effect they will have on pressure ulcer development.

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