INTRODUCTION

Pressure ulcer development remains a costly secondary complication for certain wheelchair users, impacting activities of daily living, employment and overall quality of life [1,2]. Wheelchair users are prescribed cushions in an attempt to prevent the formation of pressure ulcers. Currently, clinicians select cushions based largely upon their clinical experience; limited evidence is available to support their decisions.

Biomechanical and physiological characteristics of individuals may diminish the buttock’s ability to resist damaging deformation and lead to a greater risk of pressure ulcer development. Deformation Resistance (DR) is defined as the intrinsic characteristic of an individual’s soft tissues to withstand extrinsic applied forces. Persons with poor DR require greater attention in finding a cushion that accommodates the buttocks with minimal buttocks deformation. These cushions can be described as having high Shape Compliance (SC). SC is defined as the ability of a cushion to support the buttocks with minimal buttocks deformation. SC can be considered a metric of cushion performance, so is characteristic of the design and material construction of the cushion.

This study sought to study SC and DR in a phantom buttocks model. Specifically, the study evaluated the effects of different wheelchair cushions and buttocks geometry on tissue deformation.

METHODS

Two phantom buttocks models were created based on geometric shapes that reflect the anthropometry of ischial tuberosity (IT) spacing and bitrochanteric breadth (Figure 1). The elastomeric shell was made using Dragon Skin FX-Pro® (Smooth-On, Inc., Easton, PA) mixed with silicone thinner to a stiffness of 30kPa. The models had different tissue thicknesses and sphere diameters (Table 1), representing body types with different DR.

![Figure 1. Foreground: Elastomeric gel buttocks model. Background: rigid substructure.](image)

<table>
<thead>
<tr>
<th>Model</th>
<th>Elastomer thickness under sphere</th>
<th>Sphere diameter (IT Model)</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>35 mm</td>
<td>10 cm</td>
</tr>
<tr>
<td>B</td>
<td>20 mm</td>
<td>20 cm</td>
</tr>
</tbody>
</table>

Deformation data were collected using a Siemens Trio 3T MRI scanner. Coronal, T1 images were collected with a 2mm slice thickness. To document a reference, unloaded condition, the model was scanned upside down. Afterwards, the buttocks was flipped over and placed on top of a wheelchair cushion. Loading was applied to simulate a 70kg and 84kg person. Cushions tested included Roho Hi Profile, Jay2, 3” HR45 foam, Varilite Evolution, Motion Concepts Matrx, Vicair Vector, and a rigid surface.

MRI scans were imported into Analyze AVW v9.0 and converted to isotropic volumetric data (each voxel dimension was 1.68 mm). The model “soft tissue” was segmented using a simple threshold. We computed two different measurements on both the left and right sides: tissue thickness under the sphere (or IT model) and tissue volume under the sphere. Both measures were made through the middle slice of the buttock model. The volumetric measurement was made by...
projecting a 25 mm diameter cylinder through the model from top to bottom, and centered in the sphere. This region was selected to include the elastomer beneath the peak of the sphere. The volume of buttocks model material within this cylinder was calculated by counting voxels in the thresholded region and multiplying by the voxel volume. Two observers performed the analysis, and both were blinded to the model, cushion, and loading conditions. An analysis of repeatability and agreement showed good results.

Data analysis addressed three questions. First, loading conditions were compared in a paired t-test to see if increased load increased deformation. Second, we analysed the benefit of the presence of a wheelchair cushion by comparing the amount of deformation under load on a rigid surface with deformation on wheelchair cushions. This comparison was made across both models using a one-way ANOVA. Finally, we looked at the impact wheelchair cushion and buttocks model design on deformation using a 2-way ANOVA.

RESULTS AND DISCUSSION

A paired t-test across loading conditions revealed no significant differences in linear or volumetric deformation. Therefore, data across loading conditions were combined.

When loaded on a rigid surface (no cushion), Model A had a 65% change in thickness and a 62% change in volume. Model B experienced a 41% change in thickness and 35% change in volume. Not surprisingly, the use of a wheelchair cushion reduced the deformation significantly (p<0.001) (Figure 2). While the model deformation seen on a rigid surface was comparable with thickness changes measured in able-bodied humans, the model deformation when loaded on a cushion was much smaller than published human data [3]. Differences in cushions, loading parameters and/or representativeness of the models may factor into the explanation of differences.

The 2-way ANOVA revealed that both model and cushion design played a significant role in the amount of deformation experienced by the buttocks model, although the interaction effect was not significant (Table 2). Model B, which had thinner tissue but a less peaked sphere, experienced less deformation than Model A on all surfaces.

Figure 2. % Change in thickness (left) and volume (right) in a 25mm diameter region under the sphere (IT model). Figure shows the mean of left and right.

Table 2. P-values from the 2-way ANOVA of percent change in thickness and volume.

<table>
<thead>
<tr>
<th>Thickness/Volume</th>
<th>Left</th>
<th>Right</th>
<th>Left</th>
<th>Right</th>
</tr>
</thead>
<tbody>
<tr>
<td>Model</td>
<td>0.005</td>
<td>0.084</td>
<td>&lt;0.001</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>Cushion</td>
<td>0.060</td>
<td>0.050</td>
<td>&lt;0.001</td>
<td>0.001</td>
</tr>
</tbody>
</table>

CONCLUSIONS

This study represents the first analysis of Shape Compliance of wheelchair cushions. While these methods successfully demonstrate differences in DR and SC, it is difficult to define cushion performance using the models and measurements presented. More complex measures of deformation such as the gradient might be necessary to better stratify cushions. Validation of the approach using human data is planned.

REFERENCES


ACKNOWLEDGEMENTS

The project was supported by the Center for Advanced Brain Imaging and the mobilityRERC at Georgia Tech. Software and hardware for analysis were contributed by Roho, Inc.