FINITE ELEMENT CALCULATION OF SEAT-INTERFACE PRESSURES FOR VARIOUS WHEELCHAIR CUSHION THICKNESSES

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INTRODUCTION

Seat interface pressures are of interest to both researchers and clinicians since many patients with spinal cord injuries who use wheelchairs develop pressure ulcers. Pressure ulcers unquestionably result from a very complex set of risk factors, but the primary mechanism is sustained high pressure and the associated loss of circulation. The highest pressure occurs beneath the ischial tuberosities (IT) due to the concentration of localized forces. Wheelchair cushions reduce the pressure underneath these bony prominences by redistributing the forces over a larger area. The relatively recent advent of pressure sensitive mats with multiple sensors in a matrix have made it possible to measure seat interface pressures. Producers of cushions use seat interface pressures to assess the effectiveness of cushions in relieving high pressure. However, it is not clear whether the interface pressure provides enough information, since there is evidence that the highest pressures are interior (Reddy *et al.*, 1982) and that pressure ulcers develop internally and spread toward the surface.

Previous studies have used finite-element models of the buttocks and lower pelvis to investigate the interior pressures that occur in a seated human. Previous studies usually focused on isolated seating scenarios (Dabnichki *et al.*, 1994). The goal of the current study is to investigate, in a systematic fashion, the effect of the cushion thickness on these interior pressures.

METHODS

In order to study the interior pressures, a three-dimensional model of the buttocks and lower pelvis was developed using ANSYS® finite-element software. To reduce the computational requirements of the problem, an axisymmetric model was used. Each buttock were taken to be a horizontal circular slab of radius 16 cm and width 8 cm. The buttocks were considered to consist of nearly incompressible "soft" human tissue with a Young's modulus of 47 kPa and a Poisson's ratio of 0.49 (Todd and Thacker, 1994). Each IT was treated as a cylinder of radius 1.5 cm with a hemispherical point. The Young's modulus of the bone was taken to be 10^4 Pa and 0.31 was used for the Poisson's ratio. The minimum distance between the point of the IT and the skin was taken to be 2 cm before loading. Cushion thicknesses of 0 to 16 cm were studied. The elastic behavior of the urethane cushions are known to be highly nonlinear - exhibiting both linear and plastic response (Todd *et al.*, 1998). However, over the range of stresses encountered in this study (0.5 - 3.0 N/cm^2), the response was linear and the Young's modulus of the compressed foam was measured to be approximately 22 kPa with a Poisson's ratio of 0.1. The model mesh size varied from 0.5 cm on the axis of the model to 1.0 cm at the outer radius of the buttock. A no-slip constraint was used at the seat interface.

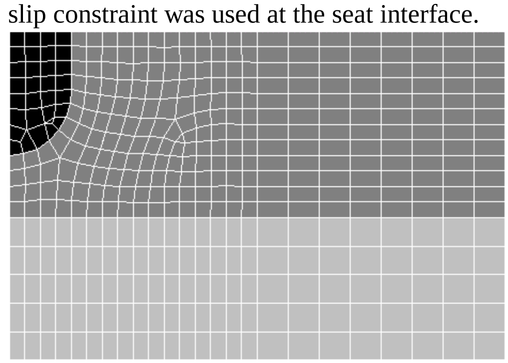

Figure 1 Cross section of the axisymmetric seat -interface model. (black=bone, dark gray=flesh, light gray=cushion)

The weight of the upper torso was divided into two loads; one applied to the top surface of the IT, and the other was applied as a uniform pressure on the top surface of the buttock. The values of these loads were found by fitting the results of the finite-element model to measured values obtained with a Novell Pliance™ pressure sensitive mat (1024 1.5 cm^2 capacitive sensors). Figure 2 shows the resulting fits for both hard seat and soft cushion with P_{IT} = 4.56 N/cm^2, and $P_{buttock}$= 0.37 N/cm^2. Surprisingly, the loads on the ITs were found to be a *small* fraction of the torso weight (15%), with the majority of the weight supported by the buttocks. This disagrees with other studies, where it was assumed that the total upper torso weight should be applied to the IT (Todd and Thacker, 1994). It remains unclear how the load should be distributed on the upper surface of these simple models.

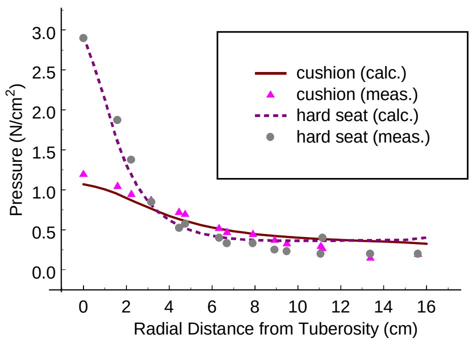

Figure 2 Measured (points) and calculated (lines) radial distribution of the seat-interface pressures for a soft cushion and a hard seat.

RESULTS AND DISCUSSION

Figure 3 shows some typical results for the interior pressures. Within the soft tissue, the area of highest stress is concentrated within a centimeter or two of the IT with the maximum compressive stress just below the bottom surface.

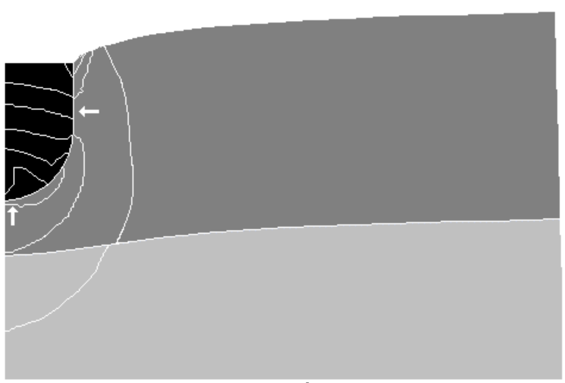

Figure 3 Contour plot of 3rd principal stress for a 16 cm cushion. The arrows indicate the areas of highest compressive (bottom arrow) and shear (top arrow) stress.

Figure 4 shows the dependence of the maximum interior stress, maximum seat interface pressure, and maximum shear stress. As expected, the pressures decrease with thicker cushions. However, almost all of the reduction is obtained with an 8 cm cushion where the maximum interior stress is reduced from 29.3 N/cm^2 for a hard seat to 16.0 N/cm^2. In fact, the shear stress *increases* slightly for thicker cushions. The maximum interior stress is indeed greater than the maximum interface pressure, but they are not in constant proportion. For a hard seat, the interface pressure is 79% of the maximum interior pressure, whereas for a 16cm seat it is 57%.

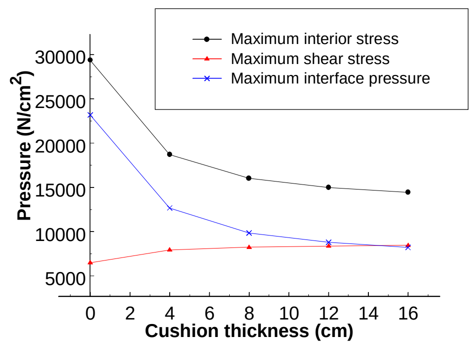

Figure 4 Maximum interior stress, interface pressure and shear stress for various cushion thicknesses.

SUMMARY

A finite element model of the buttocks and lower pelvis was developed to study the effects of cushion thickness on the distribution of stresses near the seat interface. It was found that urethane cushions did in fact reduce the maximum stress below the ischial tuberosity but that increasing the thickness beyond 8cm was ineffective in further reducing stress. It was also found that seat-interface pressures were a good but not a complete measure of internal stress reduction.

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