Computer Simulations of Two-Component Wheelchair Cushions

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ABSTRACT

A finite-element model of two-component wheel chair cushions is developed, and a systematic study is performed to find the obtained combination of cushion stiffness and radii.

INTRODUCTION

Finite-element computer models have been useful in studying the effectiveness of wheelchair cushions in reducing interior pressures in seated spinal cord injury patients. Sustained high-pressure under the bony prominences known as ischial tuberosities (IT) and the associated loss of circulation is the primary mechanism in the development of pressure ulcers. Since the highest pressures occur directly beneath the IT, it seems that a two component cushion design, with softer cushions beneath the IT should be effective in redistributing pressures away from the IT. In this project, a two-component wheel chair cushion design was studied using a finite element model. The model reveals that reducing pressure under the IT by using softer inner cushions results in higher pressures seat-interface pressures at the outer cushion, in addition to higher interior shear stresses. A systematic study is performed to find the optimal stiffness ratio of the inner/outer -cushions and optimal inner cushion stiffness where the interior pressure under the IT is reduced without significantly increasing the stresses elsewhere.
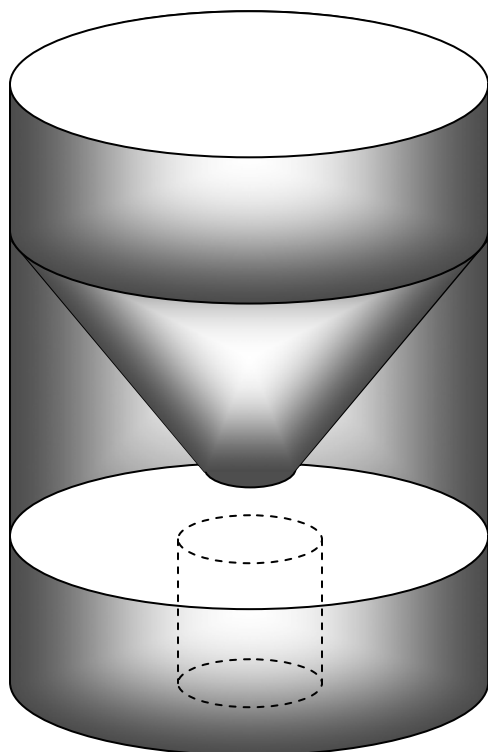

Figure 1. Axi-symmetric seating model. Each half of the pelvis is represented by a bony cone with a rounded IT. The cushion has a circular soft region positioned under each IT (the dashed line).

METHODS

The current model is a refinement of the Ragan et al. (2002) model and is similar to the mechanical model used by Reddy et al. (1982). Figure 1 is a schematic of a single buttock, and Figure 2 is the corresponding mesh. The weight of the upper torso is applied uniformly on the upper surface of the pelvis. The buttocks are 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 et al., 1994). The minimum distance between the point of the IT and the skin was 1.5 cm before loading. The weight of the upper torso was taken to be 65% of the total body weight, and the seat was taken to be a hard, flat, horizontal surface. The cushion is divided into two sections: a circular soft cushion of radius R_1 situated under the IT, and an outer annulus of standard polyurethane cushion with a Young's modulus of 20kPa (see Figure 3). A systematic study was then performed for various combinations of inner cushion stiffness and radius. The computer model revealed the interior compression and shear stresses (Figures4-6), and the seat interface pressures (Figure7). In Figure 8 the maximum interior stress immediately below the IT is shown for various model parameters. In Figure 9 the maximum seat interface pressure that occurs near R_1 is shown for the same parameters.
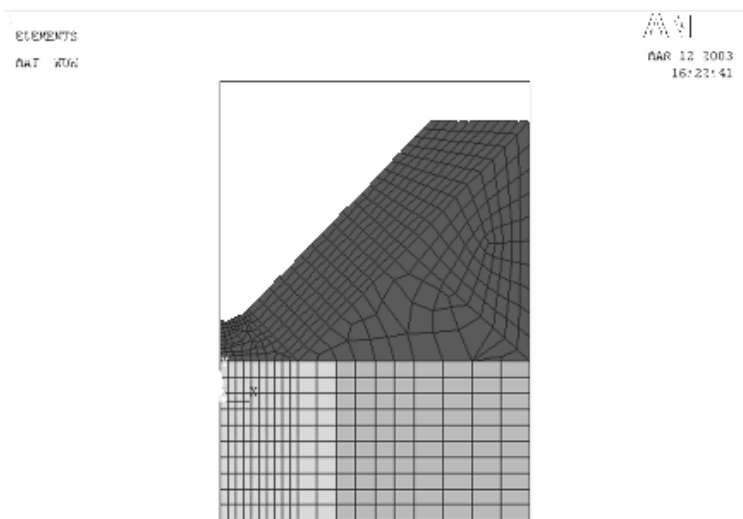

Figure 2: Meshed cross section of the finite element model (white=bone, black=flesh, light gray=inner cushion, dark gray=outer cushion).
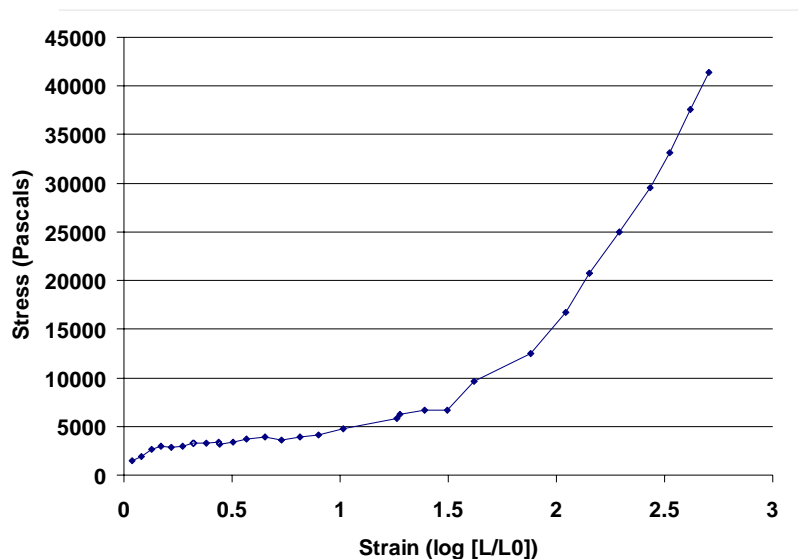

Figure 3: Stress-strain curve for polyurethane cushions obtained with a MiniMat$_{\text{TM}}$ 2000 materials tester. Between 5kPa and 30kPa the Young's modulus is approximately 20kPa.
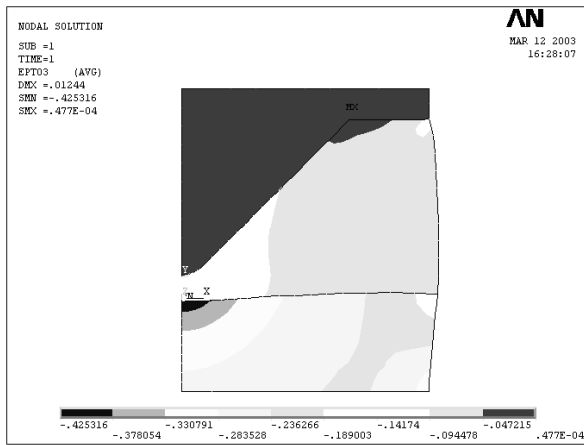
Figure 4: Contour plot of strain deformation for a uniform cushion. Red indicates areas of small deformation and blue indicates areas of large deformation.
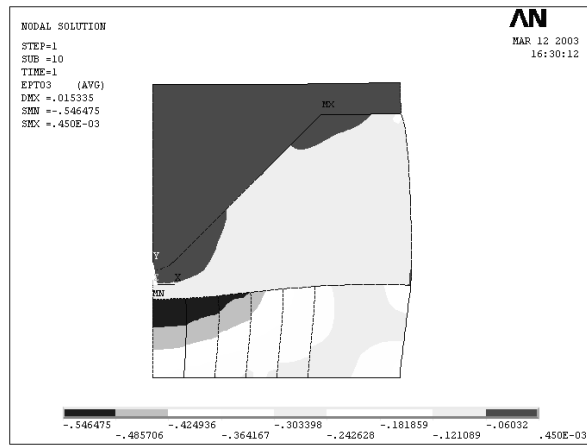

Figure 5: Contour plot of strain deformation for $E_{inner}=0.5/E_{outer}$ and $R_{inner}=4$cm. Note that the interior stress has been reduced below the IT and that the interface pressure has been distributed over a larger area.
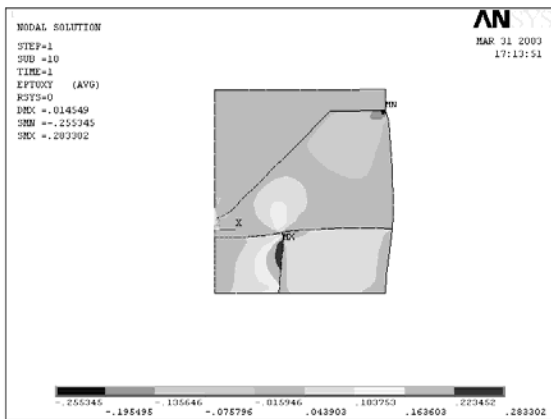

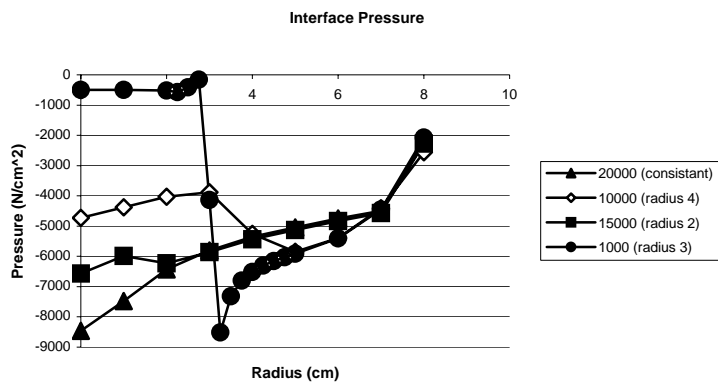**Figure 6**: Coutour plot of shear stresses for $E_{inner}=0.5/E_{outer}$ and $R_{inne}=4$cm.

Figure 7: Seat-interface pressures for various combinations of E_{inner}/E_{outer} and R_{inner}/R_{outer}.
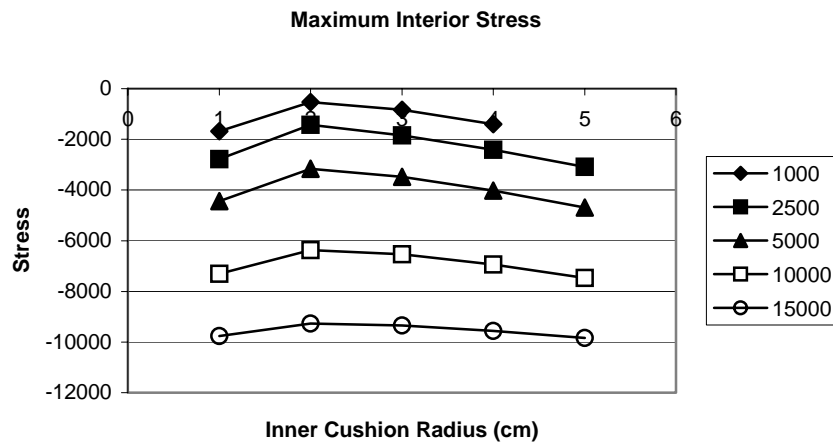
Maximum Interior Stress

Figure 8: Maximum stress below the IT for different inner cushion stiffness and radii.
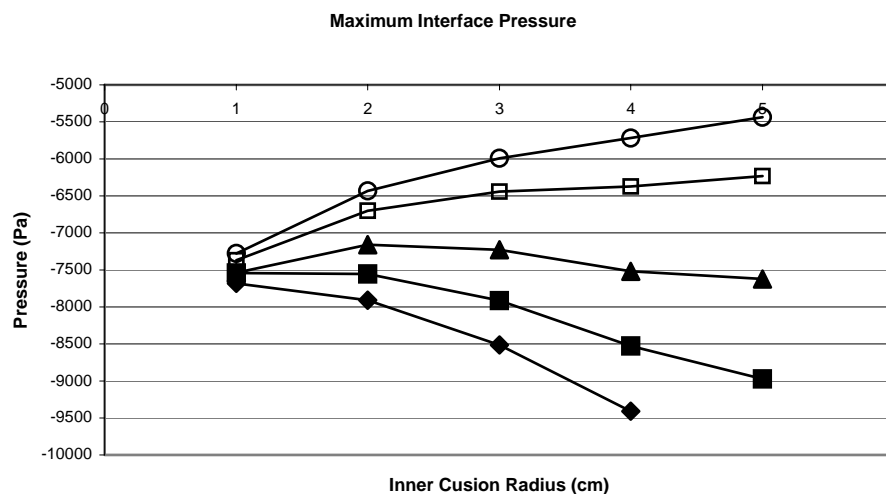
Maximum Interface Pressure

Figure 9: Maximum seat interface pressure for different inner cushion stiffness and radii.

RESULTS AND DISCUSSION

As one can see in Figures 8 and 9 there is a trade off when using a soft inner cushion: it does lower the stress below the IT, but at the cost of raising the seat interface pressure on the inner rim of the outer cushion and raising the interior shear stress. The seat-interface pressure is especially high for the softest inner cushions with large R_1. However, for inner cushions with Young's modulus of 10 kP and radii of 3-4 cm the interior stress can be lowered by 50% without significantly raising the seat interface pressures or interior shear stress. Future studies will concentrate on contoured cushions.

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Todd BA, Thacker JG, Rehabil Res Dev 1994; 31: 111-119.

Reddy NP, Patel H, Cochran GV, Brunski JB, J Biomech, 1982; 15: 493-504.