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A finite element approach for analyzing the effect of cushion type and thickness on pressure ulcer

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ABSTRACT

Immobilization or continuous sitting with a constant posture for a long time in office environment causes sub-dermal tissue damage. Tissue damage occurs because of continuous prolonged compression of buttock soft tissue under body weight. It is treated as the end result of cell death or tissue deformation which ultimately gives rise to pressure ulcer. Although the sub-dermal tissue refers to the tissue beneath the skin, it is the tissue just below the bony portion undergoes maximum deformation because the muscle endures a continuous high stress. In this work, a simple but practical numerical approach has been proposed to estimate the maximum stress beneath the bony structure (ischial tuberosity). The model is validated with experimental data from the literature. Effect of properties of cushion material, loading angle and thickness of cushion has been analyzed. The cushion properties and thickness that can reduce maximum stress at ischial tuberosity have been demonstrated. The effect of sitting posture on maximum stress at ischial tuberosity has also been shown.

Relevance to industry: The study can possibly help the practitioners to select type of cushion and its thickness that can reduce pressure ulcer during prolonged sitting. The simplified but practical model presented in this paper can provide a platform to study the behaviour of different type of cushion material and thickness reducing expensive experimental burden.

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1. Introduction

Pressure ulcer is the localized area of tissue degeneration in sub-dermal tissue as a result of prolonged continuous mechanical load (National Pressure Ulcer Advisory Panel, 1989). External mechanical load (weight of the body) always induces a mechanical deformation in soft tissue (Chow and Odell, 1978). Excess pressure for a long time restricts the blood vessels resulting in the formation of tissue ischemia and ultimately tissue necrosis (Crenshaw and Vistnes, 1987). When a larger pressure is applied to soft tissue, it decreases the time of causing cell death and the tissue damage starts due to impaired capillary profusion giving rise to hypoxia (Kosiak et al., 1958). It has been indicated that the pressure sore mostly occurs at the lower part of body, i.e. 43% at the sacrum and 5% at the ischial tuberosity (bony part). To lower the stress distribution, either the intensity of load or sitting time duration is to be reduced but at the same time the work at an office environment must not be compromised (Peterson et al., 1976). Therefore, design modification of the product (chair seat cushion) or choosing the product with suitable properties should be emphasized to achieve this goal. Sitting comfort for a long time can decrease the rate of cell death. Seat cushion properties can be useful in reducing the deformation of tissues. Polyurethane foam with different properties can be used to investigate stress distribution at ischial tuberosity. Recently, number of studies have reported the effect of foam density, foam compressibility, strain rate and energy absorption of polymeric foam under uniaxial loading. Polyurethane foam under polymeric foam category is mostly used for seat cushion because it can undergo large compressive deformation and not only absorb but also dissipate considerable amount of energy under loading in comparison to solid specimen of equal volume (Avelle et al., 2001). Polyurethane foam exhibits visco-elastic behavior which depends upon the time scale of loading and temperature of material (Gibson, 2012; Lakes, 1999; Briody et al., 2012; Mills, 2007; Schrodt et al., 2005).

As the tissue lying below the bony part exhibits maximum stress under loading and undergoes tissue deformation, the present study focuses on the stress distribution at the tissue near bony

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prominence (ischial tuberosity) through numerical analysis by changing cushion properties. In this context, the mechanical condition of seat is considered by changing seat material properties and parameters to study change in stress distribution at ischial tuberosity. A rigid seat–buttock model is also considered for validation purpose. As the change in cushion properties are alone not sufficient for reduction in stress distribution at ischial tuberosity, further analysis with different thickness of cushion and loading angles has also been carried out. The objective of the present work is to develop a simple two-dimensional finite element buttock–seat model with various material parameters, thicknesses of seat with different loading angle to predict stress at ischial tuberosity in order to provide guidelines to reduce occurrence of pressure ulcer.

2. Literature review

Various experimental and numerical analyses have been carried out on seat–buttock model to find out the contact pressure at seat–buttock interface and stress at bony prominence. Gru-jicic et al. (2009) have examined stress distribution over the seated-human/seat interface through a realistic model of car seat and compared the result with the experimental data. To reflect a real driving situation, Siefert et al. (2008) have proposed a human model interacted with car seat and vibration due to running of vehicle and seating process modeled by the load due to gravity. The static comfort is evaluated by solving the model using finite element analysis in terms of seat pressure distribution. The dynamic simulation is carried out by a unit excitation of the seat slides at the clamping points. Seat cushion is not only used to lower the maximum seating pressure on buttocks but also minimize the transmission of vibration to human body. The effect of varying vertical vibration frequencies on seat-interface contact pressure during sitting on three different seat cushions using a finite element modeling approach has been investigated by Tang et al. (2010) considering a two-dimensional human buttock-thigh model. As the contact interaction between human and seat is an important factor in the comfort sensation of subjects, Verver et al. (2004) have proposed a finite element (FE) model of the human buttocks to predict the pressure distribution between human and seating surface with detailed and realistic geometric description. A parametric study indicates that a pressure distribution at the interface between human and seat strongly depends on variations in human flesh and seat cushion properties. Wang and Lakes (2002) have analytically investigated the contact problems between two homogenous and isotropic soft bodies to simulate the contact of human buttocks and seat cushions allowing Poisson's ratio of seat cushion to be negative. Peak contact pressure is reduced by adjusting the contour curvature of cushions according to Hertz theory. Analysis by both the Hertz model and a finite thickness 3D elasticity model shows that cushions with negative Poisson's ratio can reduce the pressure and prevent pressure sores or ulcers in sick and pressure-induced discomfort in seated people. Lowe and Lakes (2000) have reached a similar conclusion using an FE model. Moes and Horvath (2002) have proposed an FE approach for shape optimization of seats considering interactive force between seat and body. Hobson (Hobson, 1992) has studied the effect of seated posture and body orientation on pressure distribution and shear force acting at body seat interface within and between two study groups made up of subjects with spinal cord injuries and nondisabled subjects. Silver-Thron and Childress (1996) have investigated the effect of parameter variations on the prosthetic interface stresses for persons with trans-tibial amputation using FE approach. In an effort to reduce the incidence of decubitus ulcers among wheelchair users, Todd and Thacker (1994) emphasized on cushion design to minimize the pressure at the buttock–cushion interface. Finite element analysis has been carried out because it shows the stress levels throughout the soft tissue between the cushion and the ischial tuberosity and gives designers a better indication of the effect of a particular cushion. Verver et al. (2005) have outlined a method for the development of seat models by usage of numerically efficient simulation techniques for prediction of realistic responses in human–seat interaction.

Linder-Ganz et al. (2006) have used FE approach for estimating tissue deformation over critical time durations causing pressure injuries using muscle tissue of albino (Sprague–Dawley) rats exposed to pressures. Ceelen et al. (2008) have conducted experiments using Magnetic resonance (MR) and T2-weighted MR imaging to measure the tissue deformation and damage. A finite element model is proposed to calculate the strain in damage experiment. A correlation analysis revealed a linear correlation between experimental and numerical strains. Gefen et al. (2008) have indicated through specialized experiments on planar tissues that there is a 95% likelihood that cells could tolerate engineering strains below 65% for 1 h whereas the cells could endure strains below 40% over a 285 min trial period. The decrease in endurance of the cells to compressive strains occurs between 1 and 3 h post-loadings. In another paper, Gefen et al. (2005) have proved that stiffening occurs in vivo in muscular tissue which undergoes widespread cell death produced by applied bone compression. The local cell death-related stiffening affects the distribution of mechanical stresses and deformations in adjacent (not yet damaged) muscular tissue promoting deep pressure sore. Linder-Ganz and Gefen (2009) have pointed out that the efficacy of wheelchair cushions should be evaluated not only based on their performance in redistributing interface pressures but also according to their effects on stress concentrations in deep tissues,

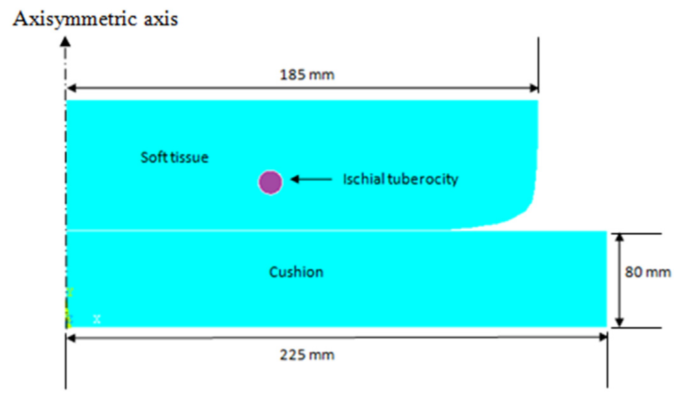

Fig. 1. Finite element model of seat cushion and buttock (soft tissue).

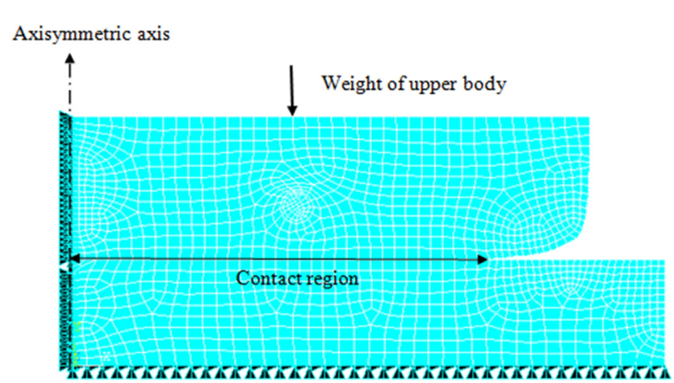

Fig. 2. Finite element model of seat cushion and buttock (soft tissue).

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