

Finite Element Analysis of Effect of Softness of Cushion Pads on Stress Concentration Due to an Oblique Load on Pressure Sores

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Abstract

The concentration of mechanical stress in soft tissue can cause or worsen pressure sores. We have previously reported the results of analysis of stress concentration in soft tissue using a finite element model. In the present study, we hypothesized that even if a cushion pad was thin, it would effectively reduce horizontal loads that can increase stress concentration in soft tissue. To our knowledge, there have been no previous reports describing stress distribution in soft tissue attached to a thin cushion pad with a horizontal load. In the present study, we performed mechanical analysis of a model of a human seated on a thin cushion pad with a range of hardness values (i.e., Young's module). Two-dimensional finite element models were used to perform this analysis. Loads were applied at the upper edge of the model as oblique compulsory displacement. In all of the cushion pad models, the peak value of effective stress was less than that of the control model without a cushion pad. Also, the peak value of effective stress decreased as Young's module of the cushion pad decreased. These results suggest that use of a thin cushion pad is an effective way to prevent the development of pressure sores. (J Nippon Med Sch 2007; 74: 230–235)

Key words: pressure sore, finite element method, simulation surgery, prevention, management

Introduction

Pressure sore ulcers can be a serious problem for bedridden patients. The first indication of ulcer formation is erythema on the skin surface. However, some practitioners have found evidence that ulcers form in deeper tissue and then spread toward the surface of the skin³⁴. By the time surface damage is noticed, subcutaneous fat tissue necrosis has already occurred. This necrosis sometimes manifests as an

undermining formation, which tends to expand.

Finite element analysis (FEA) is a powerful tool of engineering physics⁵⁻⁷ that can compute and display anatomic predictions of the human body. Computationally unfeasible before the advent of digital computers, FEA can be used to model human tissues and organs, by discretizing them into many small components termed elements, the most fundamental unit of the finite element model. An element is connected to adjacent elements at points termed nodes. Collectively, the elements comprise

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what is termed a mesh, with each element containing a specific set of equations that govern the local material's unique biomechanical properties. A thoughtfully constructed finite element model can simulate the stretching and elasticity of tissue. In the final step in construction of the model, it is subjected to loading conditions that include forces, displacements, pressures, and any other factors that are associated with the simulated event.

There have been several studies of pressure ulcers using FEA⁸⁻¹³. Todd and Thacker¹³ have demonstrated the consistency of a finite element model in the analysis of pressure ulcers. These studies have addressed the effects of only vertical directional loads, which represent gravity. Horizontal loads emerge when a patient is moved or rotated. The combination of vertical and horizontal loads creates an oblique load. In a previous report, we observed¹ stress distribution caused by oblique loading and concluded that oblique loads play an important role in the formation of stress concentration in deep tissue.

Thick cushion pads are sometimes used for prevention of pressure ulcers. A thick cushion pad is useful for reduction of stress concentration caused by a vertical directional load. We hypothesized that even if a cushion pad were vertically thin, it would effectively reduce oblique loads, which can increase stress concentration. To our knowledge, there have been no previous reports describing stress distribution of soft tissue attached to a thin cushion pad with an oblique load.

The purpose of the present study was to analyze the stress distribution of a model of the human body attached to a thin cushion pad with a range of hardnesses, to assess the effectiveness of the cushion pad in reducing stress concentration.

Materials and Methods

In the FEA, 5 models that differed in values of softness of cushion pads were used. As a control, a model without a cushion pad was also analyzed. Effective stress was evaluated using a distribution map.

All data analysis was performed using a personal

computer (Pentium 4 : 2.4 GHz with 1 GB RAM) and ADINA analytical software (version 8.3, ADINA R&D, Inc., Watertown, MA, USA)

The first assumption of the model was that the shape of the human trunk is a cylinder. The second assumption was that the human body consists of 2 categories of tissue: soft tissue and hard tissue. Soft tissue corresponds to structures such as skin, fat, and muscle. Hard tissue corresponds to bone. To simplify the calculations, only the lower half of the cylinder model was used. Thus, the cross section of the basic model consists of 2 concentric semicircles. The outer semicircle functions as the soft tissue, and the inner semicircle functions as the hard tissue. As a representation of a cushion pad, a thin structure was added to the outer layer of the model (**Fig. 1**). For FEA, the soft tissue and the cushion pad were combined into a mesh with a basic geometry of 2,010 nodes and 624 elements.

Assuming the simplest clinical state, the following basic parameters of FEA were assigned values: geometry, material properties, loading condition, and boundary condition. Analysis was performed in 2 dimensions.

Geometry

A hollow half cylinder with a diameter of 20 cm was used to represent the soft tissue. A half cylinder with a diameter of 10 cm was used to represent the hard tissue. The cushion pad was represented by a thin additional outer layer of soft tissue. It was assumed that the skin and the pad were in tight contact.

Material Properties

Actual biological tissue is nonlinear, anisotropic, and viscoelastic. To simplify the calculations, the specific microstructure of the tissue was not taken into account. It was assumed that the soft tissue was linear, isotropic, and time-independent. Young's module of the soft tissue was set to 15 kPa. Poisson's ratio of the soft tissue was set to 0.49. These values are the same as the values we used in a previous study. Poisson's ratio of the cushion pad was set to 0.49 (same as the soft tissue value). Five different values were used for Young's module of the cushion

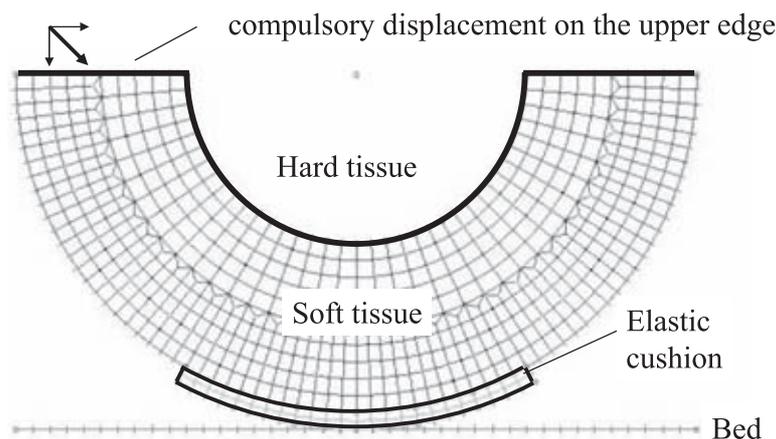


Fig. 1 To simplify the calculations, only the lower half of the cylinder model was used. Thus, the cross section of the basic model consists of 2 concentric semicircles. The outer semicircle functions as the soft tissue, and the inner semicircle functions as the hard tissue. The model consists of a mesh with a basic geometry of 2,010 nodes and 624 elements.

pad: 15 kPa (same as the soft tissue value), 7.5 kPa (1/2 the soft tissue value), 3.75 kPa (1/4 the soft tissue value), 1.87 kPa (1/8 the soft tissue value), and 0.93 kPa (1/16 the soft tissue value).

Loading Conditions

Under actual clinical conditions, patients do not generally remain in the same position at all times. They are moved or rotated during nursing care. To simulate these conditions, the present model was subjected to horizontal displacement. The model conditions included 1 cm of horizontal movement and 1 cm of vertical movement, representing horizontal and vertical displacement resulting from horizontal and vertical loads, respectively.

Boundary Conditions

The patient was assumed to be lying on a flat, hard, non-slip bed. For this purpose, a tangential line was drawn adjacent to the lower edge of the soft tissue. This line was fixed in all directions and formed a contact pair with the edge of the soft tissue or the edge of the cushion pad. The coefficient of friction was set to 1.0 for these contact pairs.

Results

Results of the FEA were summarized and visualized using a von Mises stress distribution map. In the model without a cushion pad, 2 regions of concentration were observed (Fig. 2). One region was at the boundary between the soft tissue and hard tissue, and the other was at the center of the soft tissue immediately below the hard tissue. The maximum values of effective stress were 5.83 kPa for the region at the boundary and 4.64 kPa for the region at the center.

All models with a cushion pad had a stress concentration pattern that was similar to that of the model without a cushion pad (Fig. 3a~c). That is, they each had 2 regions of concentration: one at the center and one at the boundary. The maximum values of effective stress decreased as Young's module of the cushion pad decreased (Fig. 4). Thus, although the stress concentration pattern was similar to that of the model without a cushion pad, the stress distribution became more diffuse as the cushion pad softness increased (i.e., as Young's module decreased).

FEA of Cushion Pads on Pressure Sore

a. stress concentration at the soft/hard boundary

b. stress concentration at the soft tissue center

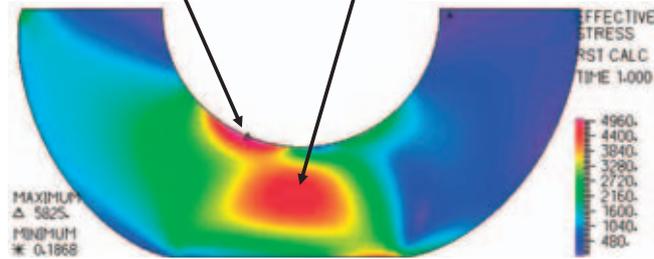


Fig. 2 Results of the calculations were summarized and visualized using a von Mises stress distribution map. Areas with a high concentration of stress are shown in red. The blue areas have low stress levels. Two regions of stress concentration were observed: a) at the boundary between soft tissue and hard tissue and b) in the center of the soft tissue immediately below the hard tissue. The maximum values of effective stress were 5.83 kPa in the boundary region and 4.64 kPa in the center region.

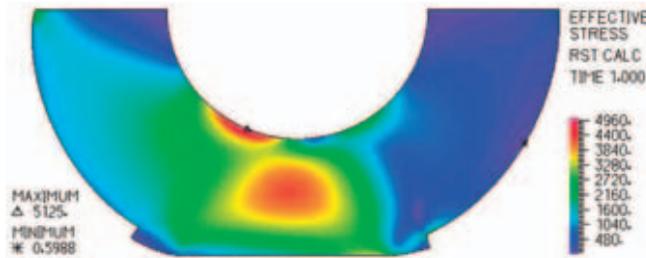


Fig. 3a The maximum values of effective stress were 5.13 kPa in the boundary region and 4.20 kPa in the center region.

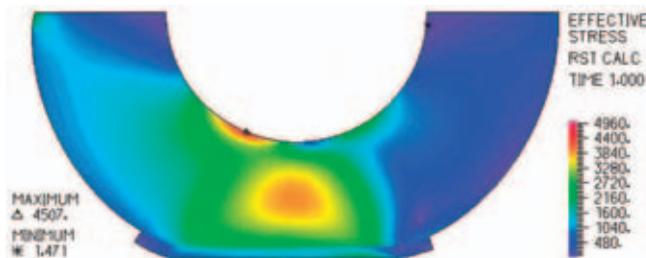


Fig. 3b The maximum values of effective stress were 4.51 kPa in the boundary region and 3.91 kPa in the center region.

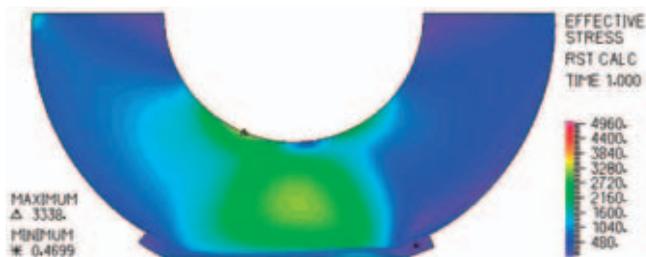


Fig. 3c The maximum values of effective stress were 3.34 kPa in the boundary region and 3.17 kPa in the center region.

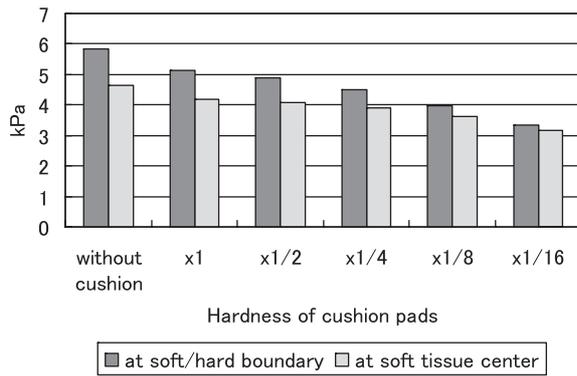


Fig. 4 The maximum value of effective stress decreased as Young's module of the cushion pad decreased.

Discussion

Chow and Odell⁹ have made an axisymmetric finite element model of a human buttock. The purpose of their work was to characterize stress patterns within the soft tissues of the buttock under different loading conditions. They modeled a buttock as a hemisphere of linear elastic isotropic soft tissue, with a rigid core to model the ischium. Honma and Takahashi¹⁰ evaluated Chow and Odell's model using the same conditions but with more precise calculation. They observed stress concentration in the middle of the soft tissue and at the junction between the soft tissue and hard tissue. In the present study, we improved that model by converting it from axisymmetric to nonsymmetric, allowing analysis under nonaxisymmetric conditions, such as with an oblique load. The present findings indicate that an oblique load increases stress concentration, thus increasing the likelihood of the development of a pressure ulcer.

A thick cushion pad is useful for reduction of stress concentration. There have been several studies^{12,14-17} of the effectiveness of various cushions in reducing seat-interface pressures. The conclusion of these studies was that there seems to be a maximum effective cushion thickness for reducing stress concentration. These studies dealt mainly with vertical loads and cushion thickness.

Actual loads on patients are not limited to vertical loads due to gravity but also include horizontal

movement. A cushion that is thin in the vertical direction is not thin in the horizontal direction. In the present study, we simulated conditions in which a human is seated on a thin cushion pad with a variety of values of softness. The present results suggest that a thin cushion pad reduces stress concentration, thus supporting the present hypothesis. The results also indicate that softer material is more effective at reducing stress concentration.

The finite element method can be used to calculate relationships between displacement and pressure or stress. Thus, it can be used to assess how the development of pressure sores may be affected by various conditions, such as cushion softness, cushion shape or position, and motion of a patient.

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