—**Original**—

Finite Element Analysis of Undermining of Pressure Ulcer with a Simple Cylinder Model

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Abstract

With pressure sores, surface damage indicates that subcutaneous fat tissue necrosis has occurred. We hypothesized that formation of necrosis under a pressure sore changes the stress distribution, which in turn affects further extension of the necrosis. In the present study, two-dimensional finite element models were used to perform analysis under different undermining size conditions. Greater stress concentration was observed in the larger undermining model. This may be the reason that, in clinical situations, a large area of undermining necrosis is sometimes observed under the skin of sores with a small area of damage.

(J Nippon Med Sch 2005; 72: 174–178)

Key words: pressure ulcer, finite element, computer simulation

Introduction

Pressure sore ulcers can be a serious problem for bedridden patients. The first indication of ulcer formation is redness on the skin surface. However, some practitioners have found evidence that ulcers form in deeper tissue and then spread toward the surface of the skin[1,2]. By the time surface damage is noticed, subcutaneous fat tissue necrosis has already occurred. It sometimes manifests as an undermining formation (**Fig. 1**), and it tends to extend.

There have been several studies of finite element analysis (FEA) of pressure ulcers[3-8]. Todd and Thacker[6] demonstrated the consistency of the finite element model in analysis of pressure ulcers.

The present author hypothesized that structural change (i.e., undermining formation) causes worsening of stress distribution of the wound. The finite element model can be used to characterize the extension mechanism of a pressure sore with undermining.

The purpose of the present study was to describe the stress distribution of pressure ulcers under various geometric conditions. The present findings support the hypothesis that, after a small necrosis arises in a deep region of the body, it induces
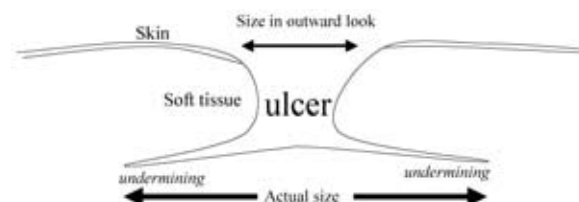

Fig. 1 pressure ulcer with undermining
Cross sectional schematic of a pressure ulcer. Pressure ulcers are sometimes found with deeper tissue necrosis.

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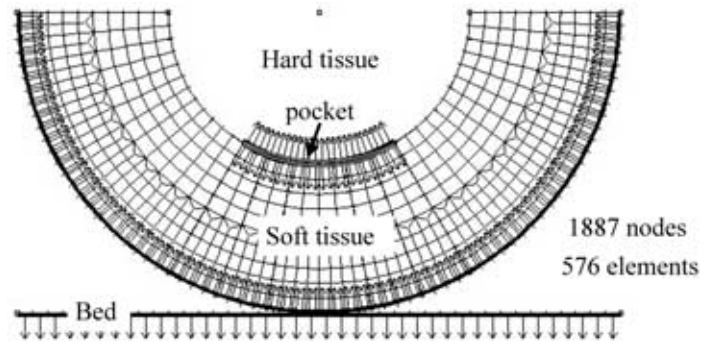Journal Website (http://www.nms.ac.jp/jnms/)

Fig. 2   Basic design of pressure sore model
A hollow half cylinder with a diameter of 20 cm was used to represent the soft tissue. A cylinder with a diameter of 10 cm was used to represent the hard tissue. Undermining was represented by a small gap at the junction of the soft and hard tissue. Model was meshed into 1887 nodes and 576 elements.
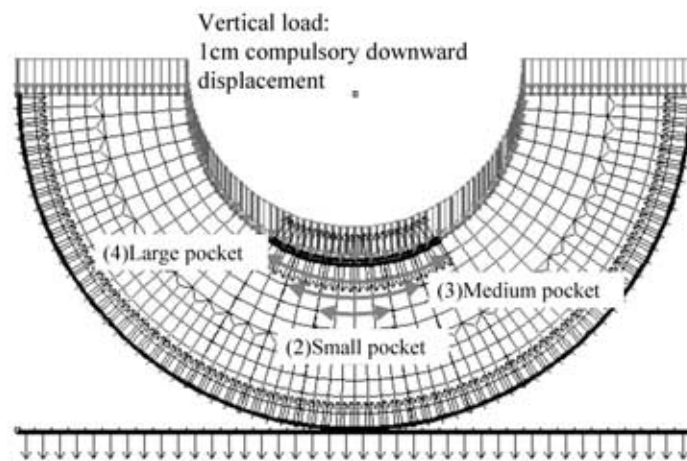

Fig. 3   Undermining size and load condition
Four different sized models were prepared: 1) No undermining (no gap); 2) Small (gap, 1.7 cm); 3) Medium (gap, 3.5 cm); and 4) Large undermining (gap, 5.2 cm).
A 1-cm downward displacement on upper edges to represent gravity.

structural change that results in a structure that facilitates mechanical extension of the necrosis.

Materials and Methods

Analysis was performed using a personal computer (Pentium 4: 2.4 GHz with 1 GB memory) and ADINA analytical software (version 8.08, ADINA R&D, Inc., Massachusetts, U.S.A.).

The first assumption of the model is that the shape of the human body is a cylinder. The second assumption is that the human body consists of two 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 is used. Thus, the cross section of the basic model consists of two concentric semicircles. The outer semicircle functions as the soft tissue, and the inner semicircle functions as the hard tissue (**Fig. 2**). For FEA, the soft tissue is meshed.

Assuming the simplest possible clinical state, the following basic parameters of FEA were assigned values: geometry, material properties, loading
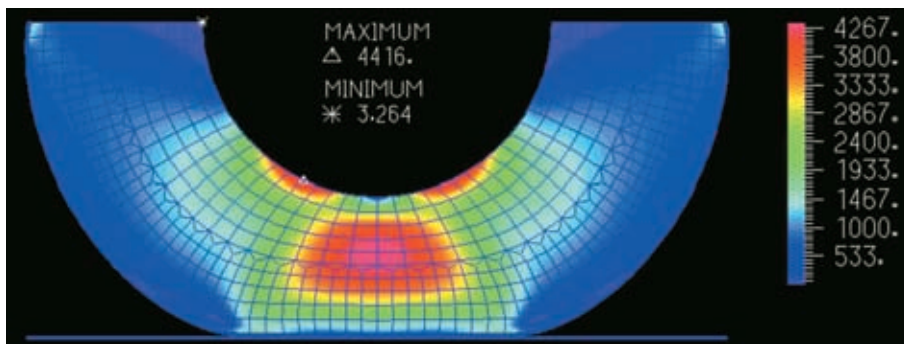
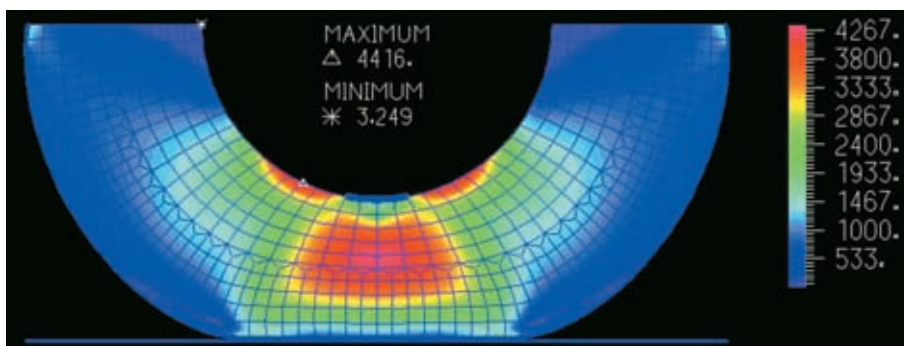Fig. 4   stress distribution of no-undermining model

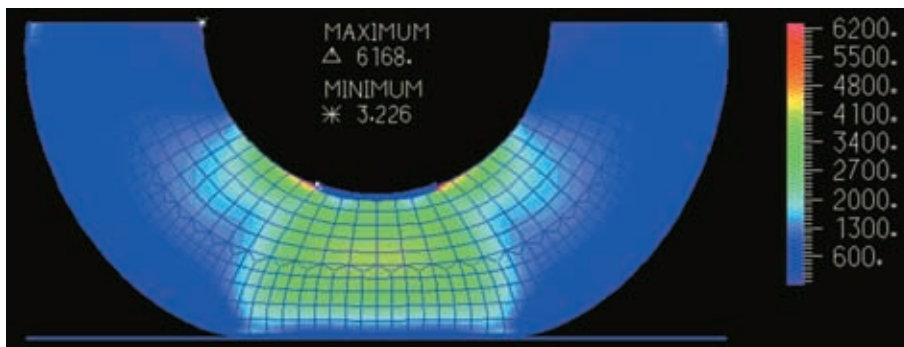Fig. 5   stress distribution of small undermining model

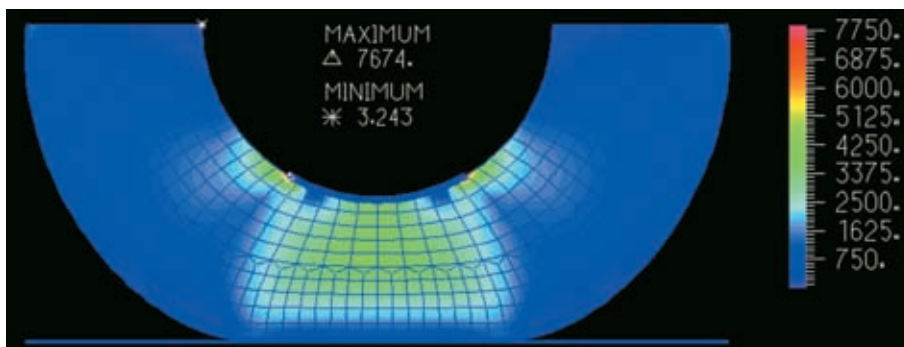Fig. 6   stress distribution of medium undermining model

Fig. 7   stress distribution of large undermining model

condition and boundary condition. Analysis was performed in two dimensions.

Geometry:

A hollow half cylinder with a diameter of 20 cm was used to represent the soft tissue. A hollow half cylinder with a diameter of 10 cm was used to represent the hard tissue. Undermining was represented by a small gap at the junction of the soft and hard tissue. The upper and lower edges of the undermining were designed so that they comprised a contact pair with no friction. For evaluation, four different models were prepared: 1) no undermining (no gap) ; 2) small undermining (gap, 1.7 cm) ; 3) medium undermining (gap, 3.5 cm) ; and 4) large undermining (gap, 5.2 cm) (**Fig. 3**).

Material Properties:

Actual biological tissue is nonlinear, anisotropic and viscoelastic. To simplify the calculations, the particular 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 was set to 15 kPa. Poisson's ratio was set to 0.49. These values were based on previous findings[48] of linear FEA of human soft and hard tissue.

Loading Conditions:

Vertically directed loading was included to represent gravity. This loading is expressed as a 1 cm downward displacement of the upper edges of the model.

Boundary Conditions:

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

For each of the four models used in the present analyses, effective stress was evaluated using a stress distribution map.
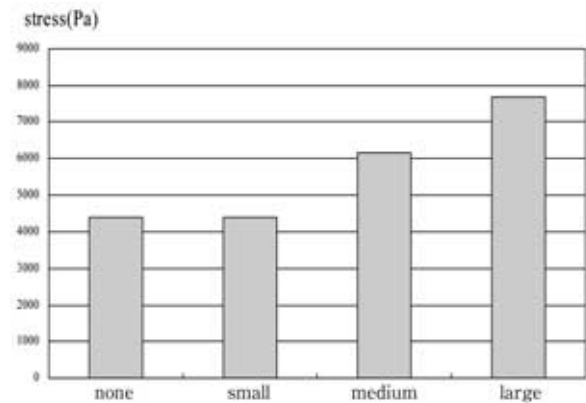

stress(Pa)

Fig. 8   Maximum effective stress in each model
Amount of maximum effective stress increased with increment of undermining size.

Results

On the stress distribution map of the model with no undermining, a large concentration of effective stress was observed at the center just under the hard tissue, and also at the junction of soft and hard tissue. In both regions, the amount of effective stress was approximately 4,000 Pa (**Fig. 4**).

The model with a small undermining had nearly the same pattern of stress distribution as the model with no undermining. Also, the maximum amount of effective stress was the same as that of the model with no undermining (**Fig. 5**).

In the model with medium undermining, the points of maximum effective stress were at the edge of the undermining. The maximum amount of effective stress was 6,168 Pa. Stress was also concentrated immediately under the hard tissue, with a local maximum amount of effective stress of about 4,000 Pa (**Fig. 6**).

In the model with large undermining, the points of maximum effective stress were at the edge of the undermining. The maximum amount of effective stress was 7,674 Pa. Stress was also concentrated under the hard tissue, with a local maximum amount of effective stress of about 4,000 Pa (**Fig. 7**).

A series of examinations revealed two main areas of stress concentration: 1) at the junction of hard and soft tissues, or the edge of the undermining; 2) the center of the soft tissue just under the hard tissue. The maximum amount of effective stress increased

with increasing size of undermining (**Fig. 8**).

Discussion

Chow and Odell[8] made an axi-symmetric finite element model of a human buttock. The purpose of their study was to characterize stress patterns within the soft tissues of the buttock under different loading conditions. They modeled the buttock as a hemisphere of linear elastic isotropic soft tissue, with a rigid core to model the ischium. Honma and Takahashi[4] evaluated the model of Chow and Odell, using the same conditions but with more precise calculation. Although that model was based on a hemisphere and our model was based on a cylinder, the basic design and shape of the 2 models are quite similar. The present results obtained using our non-undermining model are in good agreement with results obtained using the model of Chow and Odell. One of the purposes of the present analyses was to obtain data for use in further refinement of models of undermining. In the present models with gaps (representing undermining), stress was concentrated at the edges of the undermining. The maximum stress value increased with increasing size of undermining. These results suggest that after undermining develops, stress begins to concentrate at the edges of the undermining, and that this stress erodes the edges of the undermining, thus increasing the size of the undermining. Such a process is consistent with the clinical phenomena associated with formation of undermining.

The finite element method can be used to calculate relationships between displacements and pressures or stresses. Thus, it can be used to determine the effects of various positions and motions of a patient on pressure sores, and this information can be used to prevent expansion of pressure sores. In the present study, although a very simple model was used for analysis, the results strongly suggest a particular mechanism for formation of large undermining in pressure ulcers.

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