Clinical Biomechanics 35 (2016) 7–13

Contents lists available at ScienceDirect

Clinical Biomechanics

journal homepage: www.elsevier.com/locate/clinbiomech

How does lateral tilting affect the internal strains in the sacral region of bed ridden patients? — A contribution to pressure ulcer prevention

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ARTICLE INFO

Article history:
Received 27 December 2015
Accepted 29 March 2016

Keywords:
Pressure ulcers
Repositioning
Lateral tilt
Finite element analysis

ABSTRACT

Background: Repositioning of individuals with reduced mobility and at risk of pressure ulcers is an essential preventive step. Manual or automatic lateral tilting is a way of doing this and the international guidelines propose a 30° to 40° side lying position. The goal of the present study was to determine the internal strains in individuals lying in a supine position and during tilting.
Methods: Based on magnetic resonance imaging (MRI) of the sacral area of human volunteers, subject specific finite element models were developed. By comparing calculated contours of the skin, fat and muscle with MRI measurements on a flat surface the models were validated. A parameter study was performed to assess the sensitivity of the model for changes in material properties. Simulations were performed at tilting angles of volunteers between 0° and 45°.
Findings: Subjects in a supine position or tilted have the highest strains in the muscle and fat. Tilting does affect the strain distribution, taking away the highest peak strains. There seems to exist an optimal tilting angle between 20° and 30°, which may vary depending on factors such as BMI of the subject and is in the current paper investigated only for the sacrum.
Interpretation: The study shows that tilting indeed has a significant, positive influence on internal strains, which is important for the prevention of deep tissue injury. Additional studies are needed to draw conclusions about the greater trochanter area and the tissues around the shoulder.

1. Introduction

"A pressure ulcer (PU) is a localized injury to the skin and/or underlying tissue usually over a bony prominence, resulting from sustained pressure (including pressure associated with shear). A number of contributing or confounding factors are also associated with pressure ulcers; the primary of which is impaired mobility" (NPUAP et al., 2014).

Pressure ulcers constitute a major health problem worldwide. They can be painful; influence the patient's quality of life and lengthen the time for treatment considerably. In many situations pressure ulcers are preventable. Impaired mobility has been reported as one of the primary risk factors (Coleman et al., 2014). Prevalence and incidence values of pressure ulcers are high. Literature shows prevalence values of between 29% and 42% for ICUs, whereas for non-ICUs the corresponding values range between 4% and 33% (Ballard et al., 2008; Bours et al., 2001; Lahmann et al., 2011). Cuddigan (2012) reported a review on prevalence and incidence in critical care settings in various countries, which were published between 2000 and 2011. She reported prevalence rates from 13.1% in the US to 45% in China. Incidence values also have been reported to vary enormously between 1% and 56% in ICUs, when compared to values 1%–11% for non-ICUs (Nijs et al., 2008), indicating that patients in ICUs are at higher risk of developing a pressure ulcer (Baumgarten et al., 2008; Bours et al., 2001; Elliot et al., 2008; Lahmann et al., 2011; Özdemir and Karadag, 2008; Paul et al., 2002).

It is hypothesized that superficial wounds mostly result from a combination of shear forces and pressures at the interface between the skin and supporting surfaces, while deep tissue injury is a result of high internal stresses and strains adjacent to the bone. Many studies, focusing on skeletal muscle cells and tissues, confirmed that two damage mechanisms play a major role in prolonged mechanical-induced damage: occlusion of blood vessels and direct deformation damage (Bosboom et al., 2001; Bouten et al., 2001; Breuls et al., 2003; Gefen et al., 2005; Ceelen et al., 2008; Gawlitta et al., 2007; Gefen et al., 2008; Loerakker et al., 2011; Stekelenburg et al., 2008). Occlusion of blood vessels results in a partial or complete reduction of tissue perfusion at mechanically loaded body sites. This leads to a state of hypoxia. Accordingly, muscle tissue will change from an aerobic to anaerobic metabolism, causing an accumulation of metabolic waste products in the interstitial space, a reduction of the pH and eventually cell death. Healthy subjects will

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http://dx.doi.org/10.1016/j.clinbiomech.2016.03.009

normally adopt pressure relieving strategies, involving changing positions, to minimise any risk of damage accumulation.

The second damage mechanism involves direct deformation at a threshold level, which for maximum shear strain has been estimated to be between 0.5 and 0.6 (50 to 60%) (Loerakker et al., 2011). Beyond this threshold a strong correlation exists between local tissue strain and damage development (Loerakker et al., 2011). Damage can occur by a disruption of the cell membrane and possible involvement of cytoskeletal elements.

The international guidelines for pressure ulcer prevention and treatment (NPUAP et al., 2014) highly recommend repositioning all individuals at risk of developing pressure ulcers. Normal practice is that individuals with reduced mobility are assisted by clinicians and carers to reposition every 2–4 h. A further recommendation in the guidelines is to use a 30° tilted side lying position, if acceptable given the medical condition of the patient. This recommendation is based on tissue-interface pressure measurements (DeFloor, 2000) and on skin temperature and blood flow measurements (Källman et al., 2013), each providing an indication of skin condition under load. The tilting process is labour intensive and time consuming. Some manufactures have introduced tilting mechanisms in association with support surfaces, designed to simulate the effects of manual repositioning and to reduce the burden for health care providers in the absence of health care providers. Woodhouse et al. (2015) compared the performances of such prototype bed systems to conventional manual repositioning. They found no significant difference for either tissue-interface pressures or transcutaneous gas responses between the two protocols. Comfort scores for both groups were similar, but the perceived safety was reduced on the prototype bed systems. However, these physical parameters offer very little information about the deeper layers near the bony prominences.

Numerical modelling using the finite element method (FE) provides a tool to examine internal stresses and strains in loaded tissues. The FE method benefits by accommodating both complex geometries and boundary conditions as found in clinical settings, and patient specific modelling. In the current paper FE models are developed for the sacral area of human volunteers, based on MRI. These models are used to study the internal strains found in the sacral region of an individual lying on a mattress in both supine and tilted positions. Accordingly the following questions were addressed:

- What is the maximum shear strain in the skin, fat and muscle in the sacral region as a function of tilt angle?
- Is there an optimal angle for which the local maximum shear strain is at a minimum?
- How does the distribution of strains change during tilting and what are the locations of the largest strains?
- How does the body mass index (BMI) of an individual influence shear strain?

2. Methods

2.1. Materials and methods

A 2D finite element model was developed based on high resolution MR images of the sacral area of human volunteers (Fig. 1), originally used for a study to analyse the effects of spine boards (Oomens et al., 2013). For each volunteer, MR images were recorded lying in both prone and supine positions. The images in the prone position were undeformed in the region of interest around the sacrum and thus used for mesh generation. The images in the supine (loaded) position were used to tune parameters and to validate the model outcome. Images were segmented using the software package Mimics (Materialise NV, Leuven, Belgium). After segmentation a finite element mesh was developed and transferred to Marc Mentat 2008r1 (MSC Software).

The mesh (Fig. 2) is based on a prone position image and consists of quadratic triangular elements. The mesh is a simplification of the human body, with modelling restricted to the bone, muscle, fat and skin tissues. A part of the area designated to the bone accommodates both ligaments and abdominal tissue. The red ovals in Fig. 1 indicate the areas that exclusively represent bony tissues. A cross-section of a part of the mattress consisting of linear square elements is added in Marc Mentat. In addition, a spring is modelled with one 2D straight beam element. This spring is attached to one node in the centre of the bone and one node in the space left of the body, to avoid rigid body motions of the body. The mesh with the spring and mattress is shown in Fig. 2.

The mesh is used to calculate the deformations within the soft tissues. The skin, fat and muscle tissues are each modelled with the incompressible, nonlinear Ogden material law with strain energy density:

$$W = \frac{\mu}{\alpha}\left(\lambda_1^{\alpha} + \lambda_2^{\alpha} + \lambda_2^{\alpha} - 3\right). \quad (1)$$

In the equation $\lambda_{1,2,3}$ are the principal stretch ratios and μ [kPa] and α [−] the material properties defined in Table 1. The bone in the finite element model is modelled with an isotropic linear elastic material law with a high modulus of elasticity leading to the assumption of infinitesimal deformations within the almost rigid material compared to the soft tissues. Also the spring is modelled with an isotropic linear elastic material law.

A plane stress situation is assumed and contact with Coulomb friction (friction coefficient is 1) is prescribed between the skin and the support surface. First, the mattress is moved upwards until contact

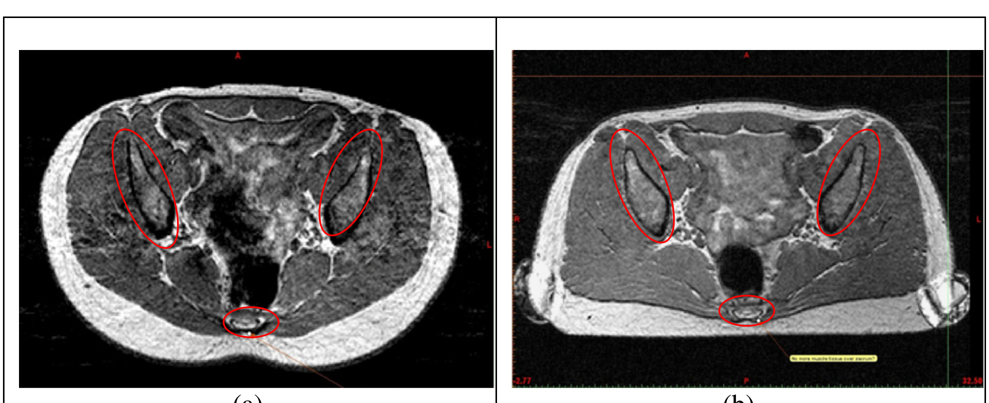

Fig. 1. a) High resolution MRI made close to the sacral area in a prone position, b) resolution MRI made close to the sacral area in a supine position. Red ovals exclusively represent areas with bony tissue.