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# Patient-specific finite element model of the buttocks for pressure ulcer prevention – linear versus non-linear modelling

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## 1. Introduction

Currently available techniques and/or protocols designed to prevent pressure sore formation in persons with spinal cord injury and wheelchair users are mainly based on the improvement of the skin/support interface and on postural and behavioural education. These techniques, however, seem to lack efficiency as the prevalence and incidence of pressure sores still remains very high. Development and validation of efficient solutions to prevent pressure sores is thus strongly needed. Deep tissue sores stem from internal overpressures within the soft tissues (Makhsous et al. 2007). Unfortunately only external pressures, at the interface between the skin and the cushion, can be measured by the available sensors. Yet, internal stresses can be estimated from the values of external interface pressures by resorting to biomechanical modelling. This study outlines a methodology aiming at the definition of an individual and personalised pressure ulcer risk assessment scale based on patient-specific biomechanical modelling.

## 2. Methods

Internal overpressures tend to develop near bony prominences thus the focus is usually made on the ischia and the sacrum when considering wheelchair bound subjects (Makhsous et al. 2007). Our methodology assumes that the shape of these bony features as well as the external surface of the patient's buttocks can be acquired through medical imaging such as CT-scanning or the novel EOS modality (Dubousset et al. 2010). From these data, a hexahedral-dominant finite element (FE) mesh is generated as described below. Hexahedral meshes used in conjunction with the FE method usually yield accurate and numerically stable solutions. However, one of the most common pitfalls in hexahedral meshing is the issue of accurate representation of the inner and outer surfaces of the organ. To produce an accurate FE mesh, our method relies on a small set of simple and synthetic 'template patterns' that describe how the hexahedra intersecting the domain boundary should be optimally subdivided into mixed elements (Yerry and Shephard 1984). The meshing algorithm starts from a hexahedral grid. Each hexahedron intersecting the bone or skin boundary is analysed and the best-suited meshing pattern is applied. Depending on the local surface configuration, the hexahedron is replaced by a combination of prisms, pyramids and/or tetrahedra that maximises the surface representation accuracy. An example of FE mesh produced by our method is shown in Figure 1. Bone and skin surfaces are shown in transparency along with the FE mesh. This model takes into account a number of morphological parameters such as the anteversion or retroversion of the pelvis, the curvature of the ischia, the shape of the sacrum and the soft tissue thickness below the hip level. To reduce computational time the mesh is 'clipped' and only the soft tissues below the patient's hips are modelled (see Figure 1 – right).

Once a FE mesh of the subject's buttocks has been generated, FE analysis can be carried out to simulate the stress concentrations under the ischia and sacrum of the individual based on a 'cine loop' of external pressures recorded during a typical daytime activity session. A TexiSense 'smart cushion' is used to record the pressures at the skin–cushion interface. The embedded pressure sensor is fully made of fabric, which makes it suitable for daily use. Furthermore, the sensor flexibility does not hinder the effectiveness of the ulcer prevention provided by the cushion. Boundary conditions are applied as follows. Mesh nodes lying on bony surfaces (pelvis and femurs) are fixed. Mesh nodes lying on the horizontal clip plane passing through the hips are also fixed. The pressure patterns recorded under the buttocks by the TexiSense sensor are applied as normal pressures on the skin nodes in contact with the cushion. Based on the results of this personalised biomechanical study, a tailor-made ulcer prevention strategy

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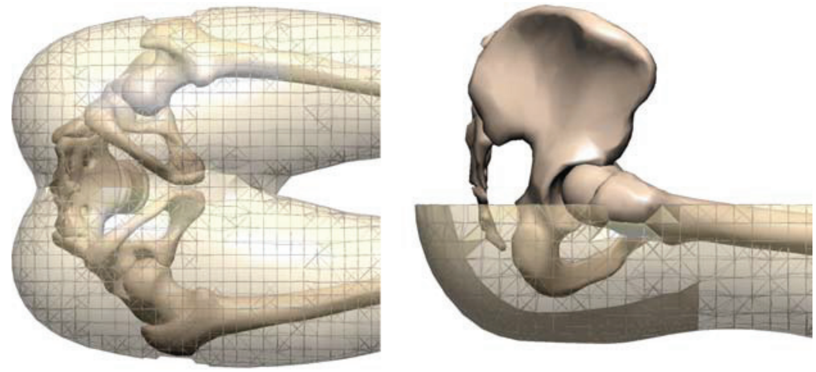

Figure 1. FE mesh of a subject's buttocks in a seated position (axial and sagittal view).

can be designed and implemented in a personalised prevention device (Chenu et al. 2011). FE analysis is a costly numerical method. The mesh shown in Figure 1 comprises 7591 elements and 5279 nodes. Given this number of degrees of freedom, the computation of a fully non-linear simulation (large displacements and large deformations) takes several minutes on a desktop computer. This is clearly not compatible with a real-time prevention strategy. The linear modelling framework (small displacements and small deformations), although less accurate, makes it possible to estimate the internal stresses in real time (Cotin et al. 1999). In this study, a non-linear Mooney-Rivlin material ($C10 = 1.65$ kPa, $C01 = 3.35$ kPa, bulk modulus $K = 500$ kPa (Verver et al. 2004)) was compared to its 'tangent' linear model ($E = 9.9$ kPa, $\nu = 0.49$). The FE analysis was performed using the Artisynth software (http://www.magic.ubc.ca/artisynth).

## 3. Results and discussion

Estimations of von Mises stresses at the ischial tuberosity based on recorded surface pressure values underneath the ischium have been computed. Figure 2 and Table 1 summarise the results for five external pressure values applied to the skin.

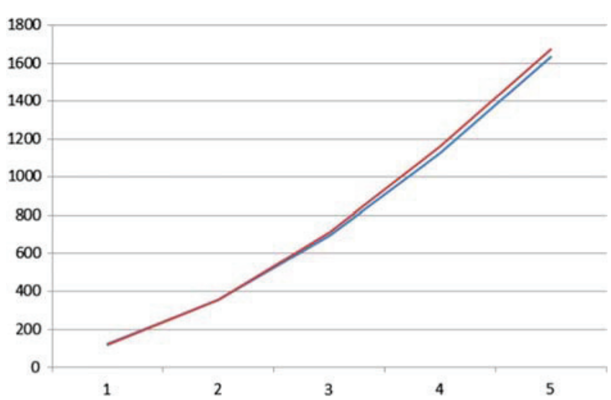


Figure 2. Upper curve, non-linear; lower, linear.

Table 1. Skin pressures and internal stresses (kPa).

| Skin | Lin. | Non-lin. |
|---|---|---|
| 25.1 | 123.6 | 118.1 |
| 68.8 | 355.7 | 357.3 |
| 128.0 | 695.3 | 710.6 |
| 196.6 | 1126.0 | 1159.5 |
| 269.3 | 1633.3 | 1672.8 |

## 4. Conclusions

The linear model underestimates the internal stresses in all but one case, yet the error is smaller than 5% of the non-linear reference value. This indicates that linear modelling of the buttocks soft tissues might be suitable for a real-time personalised ulcer prevention strategy using a von Mises-based indicator of the level of tissue damage. The presented modelling method seems well suited for handling individual morphologies although some limitations exist. First, it is difficult to acquire an unconstrained 'resting shape' of the buttocks. Initial stresses should thus be taken into account to gain accuracy. Second, our model overestimates the buttocks stiffness as it only considers the gluteal muscles and ignores the fat layer. This parameter should be integrated within the model as it affects the outcome of the analysis.


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