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## Finite element models to assess static sitting discomfort – Numerical simulations to investigate the modeling options from the literature

S. Duprey<sup>a</sup>, S. Savonnet<sup>a</sup>, F. Cotton<sup>b,c</sup> and X. Wang<sup>a</sup>

<sup>a</sup>Univ Lyon, Université Claude Bernard Lyon 1, Univ Gustave Eiffel, LBMC UMR\_T9406, Lyon, France; <sup>b</sup>Department of Radiology, Centre Hospitalier Lyon-Sud, Hospices Civils de Lyon, Lyon, France; <sup>c</sup>CREATIS, CNRS UMR 5220, INSERM U1044, Université Lyon 1, Lyon, France

### 1. Introduction

Seating discomfort thresholds relying on seat pressure variables have been experimentally determined (Mergl 2005). These thresholds combined with pressure outputs from simulations performed with human body models enable to provide seat discomfort prediction. A large number of studies have developed whole body or thigh-buttock finite element (FE) models for seating discomfort assessment (Savonnet et al. 2018). However, there is no consensus yet on the modeling options and few models are actually validated. This points to a need to quantify the dispersion and the error in contact pressure results from different existing FE models, in comparison with in vivo experimentations.

### 2. Methods

#### 2.1. Data collection

First, Magnetic Resonance images of the thigh-buttock complex (1.5 T, T1 weighted, resolution of 0.853\*1.1\*1.0mm) of a healthy male subject (24 years, 174 cm, 66 kg) were acquired. The subject was lying on one side with his legs bent to form a trunk-thigh angle close to 90°.

Then, seating pressure data for this same participant were acquired using a pressure map (X3, Xsensor, Calgary, AB) with the seat pan angle at 5° and a backrest angle of 130° (backward from the horizontal). Positions of skin markers on the participant's pelvis and trunk were captured using an optoelectronic system (Vicon Motion Systems, Los Angeles, US). The contact forces on the seat pan were measured.

#### 2.2. FE model

##### 2.2.1. Geometry

The medical images were manually segmented with 3D slicer 4.4.0 (Fedorov et al. 2012) to reconstruct:



Figure 1. The three different meshes.

the bones (sacrum, pelvis and femur), soft tissues (fat tissue and skin together) and muscles. *Mesh composition* – All the models were meshed with tetrahedral elements of equivalent size, a prior mesh convergence study having defined characteristic length as 5 mm. Then, three meshes were defined (Figure 1):

- *Mesh1* included the bones and all the soft tissues segmented as a whole.
- *Mesh2* included the bones, all the soft tissues segmented as a whole, but with the skin separately represented as a layer of 2 mm shells.
- *Mesh3* included the bones, two distinct parts being generated to represent the fat tissue and the muscles. The skin was modeled as in *Mesh2*.

#### 2.2.2. Material properties

Bones were considered as rigid bodies. Skin, when represented, was modeled according to an elastic linear law with a Young's modulus of 0.15 MPa and as nearly incompressible with a Poisson coefficient of 0.49, in line with past studies (Verver et al. 2004). The three laws most frequently used in the literature to model the thigh-buttock soft tissues were selected, together with their parameters:

- a linear elastic law with parameters from (Zheng and Mak 1999)
- a 1<sup>st</sup> order hyperelastic law or Neo-Hookean law with parameters from (Brosh and Arcan 2000),
- a 2<sup>nd</sup> order hyperelastic law or Mooney Rivlin law with parameters from (Verver et al. 2004).

#### 2.2.3. Seven models from the same geometry

Models were generated by combining the three material properties with the three meshes described above. The 3<sup>rd</sup> mesh was not combined with the linear elastic or Mooney Rivlin laws, in accordance with the literature (Table 1).

### 2.3. Simulations

The models were positioned on the numerical seat surface such that the numerical pelvis position matched the experimental one based on skin markers. Simulations were performed using the explicit solver RADIOSS (Altair, Troy, Michigan). The boundary conditions consisted in applying an upward motion of

**Table 1.** Experimental and simulated (7 models) contact area, mean pressure, maximal pressure and maximum gradient in the tissues.

			Area cm <sup>2</sup>	Error %	Pmean kPa	Error %	Pmax kPa	Error %	Gradmax kPa/cm	Error %
Experimentation			465		4.6		14.6		9.9	
Model 1	Mesh1	Linear elastic	209	55	10.1	121	45.9	214	4	59
Model 2	Mesh1	Neo-Hookean	256	45	6.2	36	31.0	112	4.2	57
Model 3	Mesh1	Mooney Rivlin	315	32	6.7	46	30.0	105	4.5	54
Model 4	Mesh2	Linear elastic	204	56	10.3	426	28.8	96	4.1	58
Model 5	Mesh2	Neo-Hookean	247	47	8.5	86	34.3	134	4.4	55
Model 6	Mesh2	Mooney Rivlin	312	33	6.7	48	28.4	94	4.6	53
Model 7	Mesh3	Neo-Hookean	248	47	8.5	86	36.9	152	3.2	68
Mean error				45		121		129		57
Standard Deviation				9.5		138		43		5

the seat pan in the direction of the measured contact force, while the FE model was fixed. Simulations were stopped when the simulated and measured contact forces matched. The outputs were contact surface area, mean and maximal pressure and maximal gradient on the rigid seat surface. The dispersion (standard deviation divided by the mean) were calculated.

### 3. Results and discussion

Simulations showed that material properties had a stronger effect than mesh composition on mean and maximal pressure, maximal gradient and contact area. Dispersions of 27.6%, 25.0% and 20.4% respectively in mean pressure, maximal pressure and contact area were observed when material properties were varied (models 1, 2, 3), much higher than the dispersions generated by varying mesh composition (models 2, 5, 7), which were 17.1%, 16.7% and 8.6% for mean pressure, maximal gradient and maximal pressure.

Simulated surfaces were lower than the measured ones and thus simulated pressures were higher than experimental ones; this could be explained by the material laws coefficients that are not personalized. Contact area produced the lowest errors (from 32% to 56%) while the discrepancies in pressure ranged from 36% up to 214% (Table 1). When comparing, in the one hand results from models 1, 2 and 3 (based on *Mesh1*), and on the other hand, results from models 4, 5 and 6 (based on *Mesh2*), it was models 3 and 6, based on a Mooney-Rivlin law, that yielded some of the lowest errors as for contact area and mean pressure.

### 4. Conclusions

Material properties have to be chosen with care since they are responsible for the highest dispersion in the


mean pressure results. Since the substantial errors observed here cannot result from geometrical issues nor from boundary conditions, they are thought to derive from erroneous material law parameters. Thus, personalizing material parameters through an optimisation, for instance, appears as a mandatory step.

### Disclosure statement

No potential conflict of interest was reported by the authors.

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**KEYWORDS** Discomfort; sitting; buttock; finite element  
 [sonia.duprey@univ-lyon1.fr](mailto:sonia.duprey@univ-lyon1.fr)