Evaluation of personalized Human Body Buttock-Thigh Finite Element Models in terms of soft tissue deformation for seat comfort assessment

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Introduction

Finite Element Models (FEM) of the human body (HBM) are used to analyze static seating discomfort mainly in terms of interface pressure distribution on the seat surface (*Savonnet et al. 2018*). However, most of the HBMs are not validated under actual seating conditions due to the difficulty in measuring internal body loads such as soft tissue deformation, intervertebral disc pressures, etc. The rare HBM related studies claiming validation have only analyzed the interface pressure distribution. Recent experiments conducted with and without foam for different seat pan inclinations (Fig 1b) using Open MRI indicate that soft tissue deformation below the Ischial Tuberosity (IT) is affected by both contact pressure and shear and thus could be an objective indicator in seat discomfort assessment (*Wang et al. 2021*). The aim of this present study is to report a preliminary evaluation of FE-HBMs against these subject-specific experimental data in terms of interface pressure and soft tissue deformation.

Methods

FE Model

Mesh. Among four participants (P) in the experimental study, two subject-geometry-specific FEMs were developed for two volunteers, P1 and P2 in *Wang et al. (2021)*. Fat, muscles, skin and bones were manually segmented using 3D Slicer in the MRI acquisition defined for four test conditions, one called ‘unloaded’ and three seated. An automatic tetrahedral mesh with a characteristic length of 5 mm was used for soft tissues (fat and homogeneous muscles) (Fig 1a), while shell layers of 2 mm made of linear triangle elements were used for the boundary of the bones and the skin. A surface-to-surface Type 25 contact with a friction coefficient of 0.4 was used to model the interaction between the skin and the seat. Three seating configurations were reproduced in agreement with experiments: horizontal flat seat pan (Shear), flat seat pan with an inclination of 7° (Reference), and a foam layer added to the reference seat (Foam) (Fig 1b).

Material properties. The pelvis and femur bones were considered as rigid bodies without relative rotation. Hyperelastic materials were distinctly defined per soft tissue type (Ogden material model, law 62 with parameters from *Al Dirini et al. (2016))*. The skin was modelled with a linear elastic material law (Young's modulus of 0.15 MPa and Poisson ratio of 0.49, as recommended by *Verver et al. (2004)*. The geometry and material law for the seat are extracted from *Wang et al. (2021))*

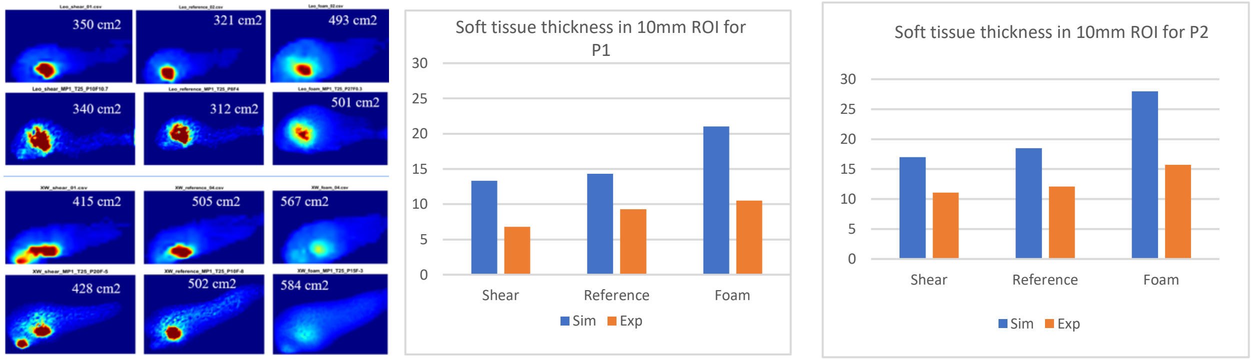
(a) (b) (c)

Figure 1: (a) Mesh of the subject-specific geometric seating model, with the skin, fat and muscle layers made visible; (b) 3 Experimental seating conditions in *Wang et al (2021)*, from left to right: Shear (SC), Reference (RC) and Foam (FC) conditions; (b) ROIs for tissue volume measurement.

Boundary conditions. For each subject, the pelvis and femur positions of the FE model relative to the numerical seat surface were extracted from experimental data identified as the reference posture. The six degrees of freedom of the bones were fixed. The two components of the seat pan reaction force measured experimentally were applied on the seat, free to translate along the force direction. The seat was initially translated to be in contact with the body surface. A quasi-static simulation with an explicit time integration scheme was run using the Altair RADIOSS FE-solver, with dynamic relaxation to avoid artificial vibration.

Post-processing and indicator for seat discomfort. The standard outputs for the FEMs' evaluation against experiments were used: the seat pressure distribution criterion (SPD%) was computed as defined by Ahmadian et al. (2002), and surface contact elements with pressure greater than zero were identified for contact area calculations. For precise focus below the Ischial Tuberosity (IT), cylindrical region of interests (ROIs) with three different diameters (10, 20 and 50 mm) were defined under the IT with their longitudinal axis perpendicular to the seat surface, as illustrated in Figure 1c. The Tissue Volume reduction % (R) was calculated as the variation of soft tissue volumes in the three ROIs and the tissue thicknesses in the ROIs were compared, from both experiments and simulations, as defined by *Wang et al. (2021)*.

Results



(a) (b) (c)

Figure 2: (a) Comparison of seat pan contact pressure distribution with corresponding contact areas of one limb in (left to right) Shear, Reference and Foam conditions for P1 (first two rows) and P2 (third and fourth rows) between experiment (Top) and simulation (Bottom). (b) Comparison of mean bulk tissue thickness (in mm) inside the 10mm ROI for P1, (c) for P2.

First, the pressure distribution from the IT to the thigh is effectively captured (Fig. 2a) in terms of contact surface area for the three different conditions, and SPD% criterion (prediction vs. experiments: 83.5 vs. 68.8, 83.9 vs. 68.0 and 27.9 vs. 33.3 for P1 and 52.4 vs 58, 51.4 vs 57.1 and 17.0 vs 6.26 for P2 in SC, RC and FC respectively). SPD% indicates that pressure is most uniformly distributed in the Foam condition, followed by the Reference. As for the tissue volume reduction (R in %) comparison, R from predictions in all cases is lower than the experimental values; In the 50 mm ROI, the volume reduction error (in %) was 20.5%, 23.7%, 40.3% and 26.2%, 26.9% and 41.9% respectively for P1 and P2 in SC, RC and FC. Whereas, in the 20mm ROI, it was 17.7%, 7.5% and 32.1% for P1 and 15.9%, 14.3% and 33.3% for P2 in SC, RC and FC respectively. Finally, in the 10 mm ROI, it was 18.0%, 10.9% and 32.4% for P1 and 12.3%, 13.4%, 28.3% for P2 in the SC, RC and FC respectively. As the ROI is more focused below the IT, the error in tissue volume reduction and correspondingly the tissue thickness seems to be more. Nevertheless, the predicted tissue thickness trend for P1 & P2 (Fig 2b&c) echo global experimental observations related to soft tissue deformation; the SC led to the highest deformation followed by RC and FC, thus indicating lesser tissue displacement under the IT for shear reduced conditions, especially with added seat cushion foam.

Conclusion

Two Subject specific finite element models of the human body buttock-thigh, personalized only regarding the bones and soft tissue spatial distribution and the external forces, seems to reproduce both the pressure distribution on the seat and the deformation of soft tissue under the IT for the three seating configurations in a discriminating manner. These encouraging results will be strengthened by extending the simulation to other subjects reported in *Wang et al. (2021).*

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