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In Vivo Mechanical Characterisation of Human Buttock Fat and Muscle Using Inverse FEM

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ABSTRACT

Introduction. The most common complication associated with immobilization is pressure sores caused by sustained localized tissue strain and stress. Computational simulations have provided insight into tissue stress-strain distribution, subject to loading conditions and thus can contribute to help design more efficient anti-pressure sore patient body supports. In the simulation process, a suitable material law as well as adequate soft tissue material parameters are indispensable.

Methods. Measurements to characterise deeper human soft tissue regions do not permit the classical experimental set-up using isolated test specimen as employed e.g. in tensile or shear testing.

An in vivo method to characterise material parameters of human gluteal skin/fat and passive muscle tissue has been proposed. It employs a magnetic resonance imaging (MRI) compatible loading device (Fig.1a) to produce well-defined tissue deformation (Fig.1b) while recording corresponding force-displacement data together with a MRI scanner to gain visual information of the displaced tissue layers under loading.

(a) (b)

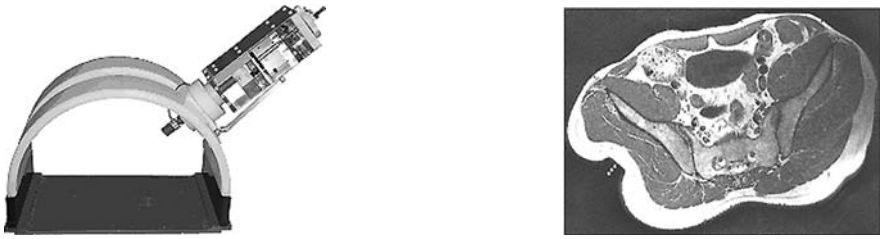

Figure 1: (a) Tissue loading device, (b) Transversal MR-image of buttock loaded with a cylindrical indenter head.

A defined tissue loading procedure as well as indentation position guaranteed reproducibility in the computational model. A stepwise loading of the gluteal tissue was performed and MR images of the entire buttock were recorded at every deformation step. The derived MRI data were digitalized and three dimensionally reconstructed. Individual long-term force-displacement relations for gluteal skin/fat and muscle

(Fig.2a) were postulated based on the current positions of their enveloping surfaces as well as on the assumption of unique force transmission through both tissue layers.

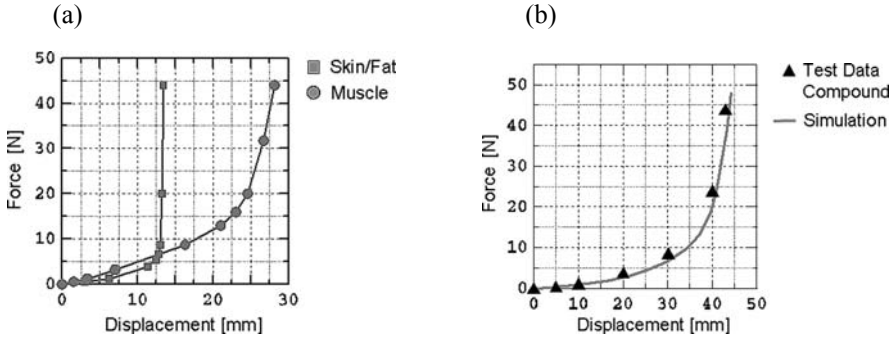

Figure 2: (a) Separated long-term skin/fat and muscle force-displacement curves, (b) Simulation vs. experimental data of the gluteal tissue compound.

Finite element (FE) models of skin/fat and muscle layers at the initially undeformed state were built. Postulated force-displacement data as well as reconstructed surface data served as constraints in an iterative optimization process. Herein, using the Ogden form for slightly compressible materials, the material constants describing skin/fat and muscle tissue were parameterized following the inverse FE-method with the objective of minimizing the deviation of test data and simulation result.

Results. Separate parameter sets for human gluteal skin/fat and muscle were established. The long-term shear modulus for skin/fat was $G_{\infty, S/F}$ = 1182 Pa and for muscle $G_{\infty, M}$ = 1025 Pa. To verify the approach, the skin/fat-muscle tissue compound was simulated using the derived material parameter sets and the simulation result was compared to empirical values (Fig. 2b). A correlation factor of R^2= 0.997 was achieved. In addition, a visual comparison between MR-images at maximum deformation and the corresponding simulation result showed reasonable accordance (Fig.3).

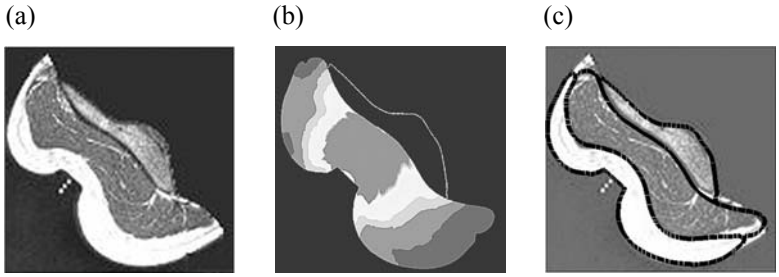

Figure 3: Comparison of the MR image at maximum indenter displacement with the simulation result: (a) MR image, (b) Simulation (v. M. stress), (c) Superposition of MR image with simulation (borderline).

Discussion. Beyond other investigations e.g. [1, 2], the presented approach yields in in vivo gluteal soft tissue material parameters valid for finite deformations for, both, gluteal skin/fat and muscle tissue. In addition, the derived results correspond with the value range based on ex vivo experiments proposed in the literature [3, 4].

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