

Preventive Biomechanics

Optimizing Support Systems for the Human Body in the Lying and Sitting Position

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Chapter 2

The New Approach: Boss-Procedure

Abstract A new approach (Boss-Procedure) to mechanical soft tissue characterization and the generation of human body models (Boss-Models) is introduced. A stepwise procedure is presented to evaluate the mechanical properties of technical support device materials, such as bedding or seating systems or shoes, and to evaluate in vivo properties of human soft tissue materials. Tissue properties are assigned to the human Boss-Models and their interaction with technical support devices is investigated.

2.1 Introduction

An adequate method to quantify and qualify mechanical tissue interaction to determine whether a technical support device (tSD) may negatively effect tissue has, up to the present, not been developed. The newly developed Boss-Procedure combines all relevant data required to realistically, mechanically describe the interaction of single human body regions and any tSD. The data are compiled from three main areas, “experiments”, “imaging techniques” and “constructional data”, Fig. 2.1. Whereas experiments were used to determine the mechanical properties of the tSD material, as well as the biomechanical in vivo properties of human soft tissue (fat-muscle compounds), imaging techniques provided anatomical information for human body modeling (Boss-Models) using 3 D-reconstruction tools.

Experimental procedures to test tSD materials are common in engineering, unproblematic and can be carried out in the regular laboratory environment. In vivo testing of living tissue is a greater challenge since, due to ethical reasons, it must be non-invasive. The testing must also be performed in a defined and reproducible manner.

General Approach

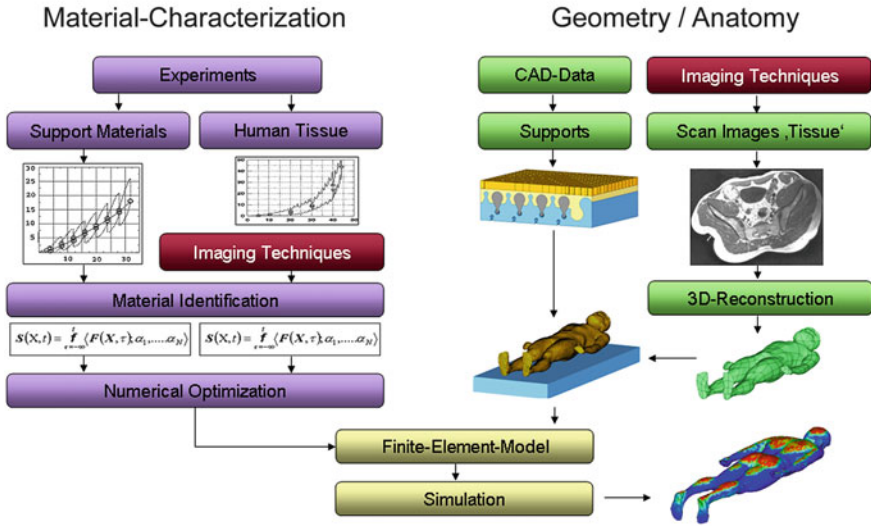


Fig. 2.1 Schematic representation of the Boss-Procedure using the example of the interaction between a Boss-Model and a soft foam mattress

In the method presented here all digitalized data were combined in a numerical finite element model of the total interacting system, i.e. Boss-Model and tSD, to analyze tissue stress and strain during complex interaction.

2.2 Experiments with Technical Support Devices

Depending on the particular materials, quasi and/or transient static and dynamic tensile or compression or shear tests were performed in a defined and reproducible manner, using appropriate material samples. Based on the experimental results, e.g. force–displacement data, parameter optimization was performed employing adequate constitutive equations and numerical optimization algorithms (curve fitting). Where a 3 D stress and strain state under loading is indispensable, e.g. due to extensive lateral straining of the sample, the process of material parameter identification must be accompanied by finite element modeling of the experimental scenario (inverse FEM). In addition, material exhibiting distinct viscoelastic features must either undergo an experimental procedure capable of separating the elastic from the inelastic material properties, or an appropriate material model must be primarily employed, not requiring such separation, cf. [Sect. 4.2](#).

2.3 In Vivo Experiments with Human Tissue

Data acquisition for in vivo experiments on the human body requires a combination of force–displacement testing. This can be achieved with tissue indentation together with simultaneous tissue imaging, such as MRI or CT techniques, to capture the undeformed anatomy at an initial unloaded state and the deformed anatomy under loading. Based on the 2 D-imaging data of arbitrary undeformed tissue regions, 3 D-surface information of the anatomical structures can be reconstructed using 3 D-reconstruction tools. This surface data is used for FE-modeling. Compressive indentation testing is most commonly employed in in vivo force–displacement experiments, due to the high flexibility of fat, connective and muscle tissue. The main challenge was to develop an appropriate experimental design (MRI or CT compatible testing device) and an evaluation procedure to separate the material behavior of the single tissue components, based on the experimental results gained from the tissue compound material. The methods for material parameter determination as well as evaluation of the viscoelastic material properties of biological tissue employ the same procedure (inverse FEM), cf. [Sects. 3.4](#) and [5.2](#).

2.4 Ex Vivo Experiments with Human Tissue

Acquiring in vivo data from mechanical experiments on human ligaments, tendons or blood vessel wall material is not feasible to date. Thus, samples such as aneurysm wall material have been removed from patients during surgery or taken post mortem and then subjected to mechanical characterization. Uniaxial or multiaxial tensile tests are most often performed. The method is based on the experimental results and employed for material parameter identification and is orientated according to the in [Sects. 5.2.2–5.2.5](#) represented procedure.

2.5 Design Data (CAD Data of Technical Support Devices)

Design data of the tSD is used as the basis for finite element mesh generation. If such data is not available, it must be manually generated.

2.6 FE Boss-Models

To simulate the interaction between the human body and a tSD, adequate models of the human body and single body regions, including realistic anatomy as well as in vivo tissue material properties are indispensable. Magnetic resonance imaging

or computer tomography were used as the basis in the modeling process. Each scanned 2 D-slice has to be reconstructed so that the single tissue types, skin, adipose tissue, muscle tissue, bone etc., can be separated and then can be reconstructed with appropriate tools (MIMICS[®] or SIMPLEWARE[®]) to generate 3 D surface data. With the help of pre-processing software (HYPERMESH[®] or ANSA[®]), a finite element mesh is to generate based on these surface data, cf. [Sect. 5.3](#).

2.7 FE Model of the Interaction System

To finally perform simulations of tissue/support interaction, both units, human body model and tSD must be merged, using defined boundary conditions according to the desired loading situation. In addition, the previously established material parameters must be assigned to the specific body regions and the tSD materials, cf. [Chap. 6](#).

2.8 Numerical Simulation of the Tissue-Support Interaction

The final simulation of tissue loading was performed using an appropriate equation solver (e.g. ABAQUS[®] or ANSYS[®]). Post-processing of the simulation data was done by means of processing software such as ABAQUS-VIEWER[®] or HYPERVIEW[®]. Tissue stress and strain were thus evaluated and visualized, cf. [Chap. 6](#) and [Chap. 7](#).