Identification of material parameters through inverse finite element modelling

Sam Evans, Stéphane Avril

To cite this version:

Sam Evans, Stéphane Avril. Identification of material parameters through inverse finite element modelling. Computer Methods in Biomechanics and Biomedical Engineering, London : Informa Healthcare, 2012, 15 (1), pp.1-2. <10.1080/10255842.2012.650321>. <hal-00732931>

HAL Id: hal-00732931
https://hal.archives-ouvertes.fr/hal-00732931

Submitted on 17 Sep 2012

Computer Methods in Biomechanics and Biomedical Engineering, 2012, 15(1) 1-2,
doi :. 10.1080/10255842.2012.650321

Identification of material parameters through inverse finite element modeling

SAM EVANS[(1)]*, STÉPHANE AVRIL[(2)]†

(1) School of Engineering, Cardiff University, The Parade, Cardiff CF24 3AA; United Kindgom
(2) Ecole Nationale Supérieure des Mines de Saint Etienne, Centre CIS ; Département D2BM ; LCG - UMR CNRS 5146, 158 Cours Fauriel, 42023 Saint-Étienne Cedex 2, France

In the past, the mechanical behavior of soft tissues has not received the attention it deserves, because their highly nonlinear behavior requires numerical simulations that were beyond the power of all but the most advanced computing facilities. However, with the rapid development of computers and imaging techniques such as MRI and digital image correlation, it is now possible to make real progress in soft tissue modeling and interest in this important field is growing rapidly. There are many exciting applications in medicine, in the design of products such as razors and in other areas such as animation and computer graphics. In addition, there are many fields such as dermatology and cosmetics where accurate measurements of tissue properties are needed. In general, it is difficult to measure the mechanical properties of these materials directly and some kind of inverse approach is needed, where an experiment is simulated and the material parameters are adjusted until the model matches the experiment.

'Consider a nonlinear material with large strains . . . The task of interpreting the experimental tensile test then becomes nontrivial . . . Probably this task will eventually be taken over by computer-aided experiment, "backcalculating" by trial and error using finite elements...' – Irons and Ahmad (1980) [1].

There are many challenging problems involved in this approach. The mathematical framework required to describe large deformations is complex, and the development of appropriate constitutive models is in its infancy. Experimental measurements also present many practical and theoretical difficulties. Before the mechanical properties of a material can be measured, it is first necessary to define the parameters that are to be measured, by choosing or developing an appropriate constitutive model, and to devise a suitable test method and a computational model that can be solved repeatedly with different material parameters. This requires a model that can be solved quickly and reliably; these are not attributes one usually associates with large deformation, highly nonlinear finite element models (FEMs). Once the necessary experimental data and computational models are in place, it is necessary to implement an appropriate optimization strategy to adjust the material parameters to give the best match with the experimental results, and to consider issues of uncertainty and uniqueness of the identified parameters.

Where only a single parameter is optimized, for example the stiffness of the material, it is relatively easy to ensure that a global optimum has been found, but for complex models with many parameters there are often many different parameter sets that will produce equally

---

* Corresponding Author: EvansSL6@cardiff.ac.uk
† Corresponding Author: avril@emse.fr

good results. Experimental and numerical errors also increase the uncertainty, as does an inadequate constitutive model.

The papers presented in this issue address many of these issues. Several of them address the issue of parameter identifiability, and more specifically solution uniqueness. For instance, Badel *et al.* present a paper entitled 'Mechanical identification of layer-specific properties of mouse carotid arteries using 3D-DIC and a hyperelastic anisotropic constitutive model'. This paper discusses the identifiability of the passive mechanical properties of a mouse carotid artery, taking into account the orientation of collagen fibers simultaneously in the medial and adventitial layers. Another similar study is presented by Stüder *et al.* It is entitled 'Importance of multiple loading scenarios for the identification of material coefficients of the human cornea'. The aim is to show that inverse problems may be ill-posed when material models are fitted with multiple coefficients to a limited number (usually one) of experimental data. Using multiple sets of experimental data for the fitting process is proposed as a possible solution. Similar problems arise also for the identification of permeability parameters, as presented by Riches *et al.* in their paper entitled 'Sensitivity analysis of permeability parameters of bovine nucleus pulposus obtained through inverse fitting of the nonlinear biphasic equation: effect of sampling strategy'. This paper describes the determination of strain-dependent permeability using the Nelder–Mead simplex method. As multiple solutions may exist, it is shown that permeability parameter estimations arising from inverse methods should be utilized with the knowledge that they come with large confidence intervals.

A few papers are focused on the optimization approach itself. For instance, Delalleau *et al.* present a paper entitled 'Dual-parameters identifications of skin elastic properties'. This paper aims at proposing a stochastic inverse identification of the skin mechanical properties. It is based on the minimization of a cost function relative to the comparison between experimental suction experiments and their corresponding FEMs. In another paper entitled 'Identification of the material parameters of soft tissues in the compressed leg', Franquet *et al.* compare different algorithms and their parameters for estimating elastic properties from medical images in the framework of vascular mechanics. In many studies, the main difficulty is to model the actual boundary conditions. This difficulty is a major concern in solving inverse problems. It has been emphasized for instance by El Masri *et al.* who present a paper entitled 'Apparent Young's modulus of vertebral cortico-cancellous bone specimens'. The goal of this study is to assess the apparent Young's modulus of vertebral cortico-cancellous bone specimens using an inverse method. To compute the apparent Young's modulus of the specimen from the inverse method, the boundary conditions of the biomechanical experiments are faithfully reproduced in a FEM, and an optimization routine is used. Gras *et al.* also mention similar difficulties in a paper entitled 'The non-linear response of a muscle in transverse compression; assessment of geometry influence using a finite-element model'. The aim of this study is to assess the possibility of modeling muscle behavior in compression with a parametric model and a simple, constitutive law. A multivariate analysis is carried out to assess the effects of geometry on muscle response. The effects of boundary conditions on the resolution of the inverse problem are even more important in the paper presented by Dubuis *et al.*, entitled 'Identification of the material parameters of soft tissues in the compressed leg'. An inverse method is applied to identify the properties of soft tissues from 3D medical images. The principle is to calibrate the constitutive properties using CT scans obtained with and without the presence of a compression sock onto the leg. The mechanical action of the compression sock being partly unknown, the inverse problem is highly complex. Other inverse problems arise when modeling soft tissues in particular conditions, such as skin indentation or ulcer compression. Such applications are presented in two other papers. One is presented by Groves *et al.* and it is entitled 'Quantifying the mechanical properties of human skin to optimize future microneedle device design'. This study aims to develop a representative stratified model of human skin, informed by in vivo data. A multilayer FEM incorporating the epidermis, dermis and hypodermis was established. This is correlated with a series of in vivo indentation measurements, and the Ogden material coefficients were optimized using a material parameter extraction algorithm.

The other one is presented by Gefen *et al.* and it is entitled 'Identification of capillary blood pressure levels at which capillary collapse is likely, in a tissue subjected to large compressive and shear deformations'. This study employs a reverse engineering method to identify capillary blood pressures at which capillary collapse is likely to occur, by solving large deformation FEMs of capillaries with complex geometries in an extracellular matrix, which are subjected to compression and shear.

These papers represent the current state of the art, and it is apparent that none have fully solved the various problems. Different groups have progressed in different areas so that, for example some have excellent optimization procedures but use simple constitutive models, whilst others have excellent experimental techniques but limited numerical models. The most important conclusion we can draw from this is that if we are to progress, it is essential to communicate and to collaborate in order to combine the best of these various approaches, and we hope that this special issue may play some part in facilitating this.

References

[1] Irons B, Ahmad S. 1980. Techniques of finite elements. 1st ed., Chichester: Ellis Horwood.