A FEM-BASED INVERSE METHOD TO IDENTIFY THE SKIN MECHANICAL PROPERTIES

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INTRODUCTION

To understand the complex nature of the skin is the driving force behind much clinical research into skin disease and its treatment. Owing to its multi-layer structure which is composed of three main entities, namely the epidermis, the dermis and the hypodermis, and due to its complex constitutive law, the skin mechanical analysis is notoriously a difficult problem. Hence, for a reliable identification of the skin properties, the contribution of each layers have to be discussed as well as its key-behavioural factors. This study aims at using finite element models of the skin to draw conclusions on both its principal structures and mechanical properties.

METHODS

The proposed analysis is divided into different stages which are related to: the skin structure, its behavior law, the inverse identification, and an actual case study example.

Structural aspects. Despite the well-known involvement of the dermis in the mechanical properties of the skin [1], the influence of the other layers (*e.g.* the hypodermis) remains an open-question. The comparison between elastographic images and finite element calculations is first used to observe the hypodermis deformation during an *in vivo* suction test [2]. The later clearly appears to barely impact the measurements. Consequently, a simplified structure which accounts for the dermis and the epidermis thicknesses is considered [3]. Such a thickness is measured through a specific procedure, based on an active contours algorithm [4]. It aimed at identifying the upper and the lower limits of the dermis on 25MHz high frequency ultrasound images.

Behavioral aspects. The dermis composition of collagen and elastin fibers bundled in a proteoglycan matrix gives the skin complex nonlinear anisotropic viscoelastic properties [5-6]. To account for the nonlinear aspect, which is mainly due to the reorganization of the collagen fibers during the stress, a specific behavior is described. The later consist in differentiating the collagen and elastin contributions using individual elastic moduli and a bundle parameter [3].

Inverse identification. The defined input parameters (dermal thickness and mechanical parameters) then stand for the starting point of the inverse calculation. It is based on the comparison between the experimental curves and a simulated data base which is created through variations of the parameters to be identified [7-8]. Hence, this algorithm presents the advantage to be, in its final form, a FEM-free process. A specifically designed stochastic optimization technique which insures the identification of the problem global minimum is finally used to assess the skin mechanical properties [9].

Actual case study. The relevance of the proposed method is then analyzed thanks to an actual case study which aims at distinguishing between photo-induced and chronological skin aging. Suction and ultrasound measurements are performed on exposed and non-exposed body zones: the outer aspect of the forearm and on the upper area of the buttock of 57 volunteers distributed according to sex and to age groups (<25; 40-50; >65).

RESULTS AND DISCUSSION

The results clearly show the relevance of the model. Every identification process presents a low mean error value (<4µm) mostly in relation with measurement uncertainties. According to this work, the studied parameters vary significantly (p<1%) with body region, sex and age-group. The elastin contribution versus the age for example plots increasing values (70kPa to 150kPa) on the forearm whereas it remains constant on the buttock. Hormonal changes can be noticed as well according to the decreasing values of the collagen modulus (150kPa) in middle-aged female subjects. Nevertheless, as both the analyzed regions give similar progression with increasing age, chronological and photo-induced aging cannot be clearly distinguished.

Even if this work presents an original approach to identify skin mechanical properties for dermatological approaches, one can remark that both the skin structure and the mechanical behavior have to be improved for even more reliable results. A generalization of this approach to more complex structures is thus proposed considering a finite element mesh based on the ultrasound images. The constitutive law aspect is raised as well. The interest in considering the dermis fiber reorientation during the test as well as the anisotropic and viscous properties of the skin is pointed out. An Holzapfel [10] hyperelastic behavior law specifically adapted to the skin problem (fiber families and densities) is briefly described to introduce the works we are currently focusing on.

CONCLUSIONS

This work aimed at defining an original case to case method to identify the skin mechanical properties. Giving its specific design, the latter can be easily used by medical practitioners and auto-adapts to experimental measurements. The proposed process was finally successfully used to characterize the chronological and photo-induced skin aging.

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