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Research Paper

Assessment of the in-plane biomechanical properties of human skin using a finite element model updating approach combined with an optical full-field measurement on a new tensile device

G. Boyer[a,b], *J. Molimard*[c,*], *M. Ben Tkaya*[a,b], *H. Zahouani*[a],
M. Pericoi[b], *S. Avril*[c]

[a]*Laboratory of Tribology and Systems Dynamics UMR5513 CNRS/ECL/ENISE/EMSE,*
36 Av. Guy de Collongue, 69134 Ecully, France
[b]*Laboratoire PERITESCO, 18 Avenue de l'Opéra, 75001 Paris, France*
[c]*LGF, UMR 5146, Ecole Nationale Supérieure des Mines, CIS-EMSE, CNRS, Saint-Etienne, France*

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ABSTRACT

Human skin is one of the most important organ of the body. The assessment and knowledge of its properties are very useful for clinical or cosmetic research. Many techniques are used to measure the mechanical properties of this organ, like suction, indentation, torsion or tension tests. The aim of this paper is to present a new device based on tension technique and combining mechanical and optical measurements. The whole procedure used to assess the displacement field as described, and first results of tests performed *in vivo* are shown.

1. Introduction

The skin is the heaviest and the vastest organ of the human body, and certainly one of the most important part. Its function of interface between the body and the external environment is vital. Skin must have very particular properties to permit exchange, for example perspiration, but also to protect the body against different types of attacks (mechanical, chemical or biological). The skin is composed of three main layers, the epidermis, the dermis and the hypodermis with different properties. At a mechanical point of view, skin is a very complex structure: it is an heterogeneous, viscoelastic, anisotropic, adhesive material showing a nonlinear stress–strain relationship (Agache, 2000). Moreover, the skin has a nonzero natural tension. The measurement and the knowledge of these mechanical properties *in vivo* are essential for various domains, example for clinical (assessment of the evolution of a pathology) or cosmetic (assessment of the efficiency of a product) research. Many different devices, using various techniques, have been developed to evaluate

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[*] *Corresponding author.* Tel.: +33 4 77 42 66 48.
E-mail addresses: gaetan.boyer@peritesco.com (G. Boyer), molimard@emse.fr (J. Molimard), mohamed.bentkaya@peritesco.com (M. Ben Tkaya), hassan.zahouani@ec-lyon.fr (H. Zahouani), marc.pericoi@peritesco.com (M. Pericoi), avril@emse.fr (S. Avril).

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the mechanical state of the skin, like suction (Diridollou et al., 2000), contact (Jachowicz et al., 2007; Pailler-Mattei et al., 2008; Boyer et al., 2009), or contactless indentation (Boyer et al., 2012), torsion (De Rigal, 2002) or extension (Thacker et al., 1977; Vescovo et al., 2002; Lim et al., 2008) tests. Extension test principle consists in attaching two pads on the skin and recording the forces induced by a tangential movement of one or both pads.

These previous studies showed that the skin is a visco-hyper-elastic and anisotropic material, with a complex initial tension. A lot of work have addressed in the past hyperelasticity (Manan et al., 2012) or viscosity (Boyer et al., 2009), but few work investigated the anisotropy. If considering the whole in-plane behaviour, with a simplification of the anisotropy to orthotropy, the number of variables should be 14 making very difficult a proper characterisation. This paper aims at a specific characterisation of anisotropy under the hypothesis of linear elastic orthotropy. This is made possible by using a small strain change, representative of skin strain variations during everyday life (10%). Consequently results will be *apparent elastic moduli*. As the sought behaviour is anisotropic, the complete evaluation of its properties with this test considering only forces assessment requires several measurements with different directions. Last, in order to have the best contactless evaluation of strain and to improve the understanding of the skin behaviour, it can be very interesting to evaluate the strain field between the pads in addition to the forces during extension test (Marcellier et al., 2001).

This paper presents a new device specially developed to this aim, the whole method used to assess the displacement field of the stressed area, and a complete analysis of the results using inverse approach (Finite Element Model Updating).

2. Methods

2.1. Device

The device is shown in Fig. 1. It is divided into two parts, the "mechanical" part, which aims to move the pad and to measure forces and displacement, and the "optical" part, whose aim is to visualise and to record images of the deformed area. The whole acquisition chain is described in Section 2.1.2.

2.1.1. Mechanical part

The extensometer is composed of a static and a movable pad attached to the skin by double-sided adhesive. The choice of a static pad permits to measure the force due only to the stressed area. Indeed, the movable pad measures the force of the stressed area in addition to the force due to the surrounding area. The size of the pads can be 10 × 10, 20 × 20 or 20 × 50 mm^2. The gap between the pads ranges from 2 to 27 mm. Extension or compression tests can be performed. Each pad is mounted on a piece fixed onto a tangential force sensor, itself fixed onto a normal force sensor (all force sensors are load cells with full Wheatstone bridge). The normal force sensors allow to control the pressure applied by the pads on the skin. This point has been discussed by (Lim et al., 2008) and seems to be very important to improve the accuracy of the measurement. Ideally, tests are performed with a normal force oscillating around zero. Remaining oscillations are related to the patient movements (breathing and hearth beat). The full scale of normal sensors is 3 N and the full scale of tangential sensors is 10 N. The normal sensor of the static pad is bonded onto the frame, and the normal sensor of the movable pad is bonded onto the movable part of a micrometric motorised translation stage (Polytech Instrument) controlled by computer. This translation stage allows a movement with a velocity ranging from 0.1 to 1.5 mm/s with an accuracy less than 1 μm. The static part of this translation stage is bonded onto the frame. The frame is mounted on a manual translation stage, which permits to control the normal pressure applied by the pads. This manual translation stage is itself mounted on a complete movable frame allowing *X*,*Y*,*Z* movement and rotation using a ball pivot. This frame and a picture of *in vivo* measurement on the arm are shown in Fig. 2.

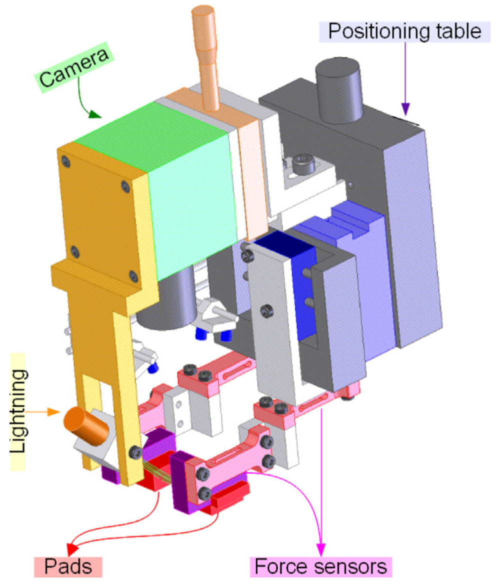

Fig. 1 – Two views of the developed device.

2.1.2. Acquisition chain

Signals of the force sensors are converted into voltage using two bridge conditioners PMI-301B (PM Instrumentation) and recorded using a 16 bits acquisition card NI 6221-M (National Instrument). Images are recorded through USB-2 port. The translation stage is controlled by a supplier card PI C-843 (Polytech Instrument). In order to have the best synchronisation possible between forces and displacement signals, the position of the stage is directly recorded using internal counter of the acquisition card. A programme developed under LabView environment drives the whole system.

2.1.3. Optical part

The image acquisition of the stressed area is performed by an 8 bits camera (The Imaging Source) placed over the pads with high quality optics (deformation less than 0.1%). A micrometric manual translation stage allows to set up the focal