IN-VIVO DETERMINATION OF PRE-STRESS AND TENSION LINES IN SKIN

Hannah Conroy Broderick (1), Michel Destrade (2), Wenting Shu (1), Aisling Ní Annaidh (1)

1. School of Mechanical and Materials Engineering, University College Dublin, Ireland; 2. School of Mathematical and Statistical Sciences, University of Galway, Ireland

Introduction

Human skin is a difficult material to test and model, as its physical and geometrical properties depend on a host of parameters and conditions: thickness, location, age, health, ethnicity, hydration, etc. Destructive testing of skin samples only gives a partial picture, because harvesting skin dehydrates the sample and releases most of its residual stress, which is likely to alter its behaviour significantly.

In this study, we measure skin tension levels with the Reviscometer™ (CK electronic GmbH, Germany), a commercial device specially designed to test human skin in-vivo, non-destructively and non-invasively. We find that it is possible to determine, in-vivo, not only the orientation of patient-specific tension lines in real time, but also the amount of residual stress at a given location.

Methods

Experimental Protocol:

The Reviscometer™ has two needle sensors placed 2 mm apart: one emits an acoustic wave and the other acts as a receiver. The travel time gives the speed of the acoustic perturbation in all directions (360° in 10° increments). Experiments were carried out at room temperature on the volar forearm.

Analytical modelling:

We modelled the skin as an anisotropic, incompressible material under pre-stress σ, along a family of parallel fibres [1]. The strain energy density follows the Holzapfel-Gasser-Ogden (HGO) model with one family of fibres [2]. A detailed analysis reveals that the formula

$$\sigma = \rho(v_{max}^2 - v_{min}^2),$$

(where $v_{\max}$ and $v_{\min}$ are the extreme values of the wave speed) is valid within an error of less than 9%.

Finite Element simulations:

We used a combination of Abaqus Standard and Explicit to simulate the wave propagating in human skin. The material parameters for the HGO model were as in human skin and taken from [3]. We employed symmetry conditions along both axes of symmetry, to reduce the computational cost. The mesh was refined in the impact region and had approx. 215000 elements. We replicated the in-vivo strains using an initial Static step in Abaqus Standard. We then used a Dynamic Explicit step and applied an instantaneous impulse, allowing the resulting wave to propagate. Finally, we measured the wave speed by tracking a specific identifiable feature of the wave at two points, 2 mm and 4 mm from the centre.

Results

We show that the Reviscometer™ can measure directly the in-vivo stress at a given site on human skin. The direction of skin tension can also be inferred from the Reviscometer™ data, as it corresponds to the fastest observed speed (Fig. 1). Additionally, we show that the wave created by the Reviscometer™ can be modelled as a surface wave propagating on a uniformly pre-stressed half-space, which we validate with Finite Element simulations.

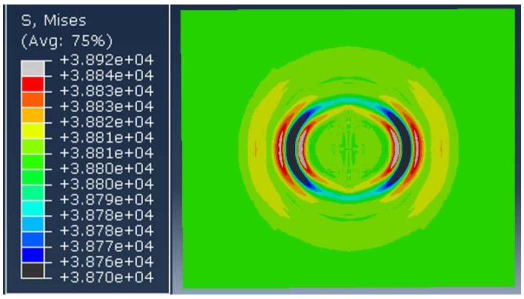

Figure 1: Surface wave propagating on skin under pre-stress from Abaqus Explicit, captured after 250 ms. The initial impact (1000 Pa) was removed after 0.02 ms. The wave travels fastest along the direction of skin tension.

Discussion

This study has clear applications in the identification of tension lines and the prediction of skin tension levels. These indicators are difficult to estimate in general, but they are most important factors in preoperative planning for surgeries, where incisions should be made along lines of maximum tension, to reduce scarring and the possibility for infection.

References

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3. Deroy et al, Skin Research Tech., 23:326-335, 2017.

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