PLANTAR SKIN: EXPERIMENTAL AND CONSTITUTIVE ANALYSIS

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Introduction

The skin is made up of three main layers and covers the human body. From a mechanical point of view, it is mainly composed of ground substance, elastic and collagen fibers, which give it a non-linear, time-dependent and anisotropic response [1]. The skin covering the soles of the human feet is highly specialized, and its main functions are to protect the body from injuries and adapt to external stresses during daily activities. Anyway, plantar ulcers, *i.e.* due to diabetes, are one of the most challenging and costly wound types to manage. Although this is a crucial topic, very few studies report on the mechanical properties of the skin, and how disease can modify them. In this context, this work aims to fully describe the mechanical behavior of foot skin through experimental tests and constitutive analysis.

Materials and Methods

Plantar skin was collected from male human donors, (56±18 years) undergoing amputation due to cancer, at the Orthopedics and Orthopedic Oncology Unit, University Hospital of Padova (CESC Code: AOP2649). Mechanical tests were performed with the Biomomentum testing machine (Model Mach-1 v500csst, ©Biomomentum Inc.) considering the posterior and anterior regions (Fig. 1a): uniaxial tensile tests were performed on dog-shaped samples cut according to posterior-anterior (PA) and lateral-medial (LM) directions, while compression tests along craniocaudal (CC) direction were performed on cylindrical samples. Preconditioning was performed before tensile stress relaxation tests (5 ramps of 7% strain; 10%/s strain rate; 600s of resting) and compression stress relaxation tests (5 ramps of 1% strain; 10%/s strain rate; 600s of resting). The mechanical behavior was described using a visco-hyperelastic fiber-reinforced constitutive model [2,3]. The identification of constitutive parameters required the inverse analysis of experimental results, considering both equilibrium response and viscous behavior:

$$\psi\left(\mathbf{C},\mathbf{q}^i\right)=W^\infty\left(\mathbf{C}\right)+\sum_{i=1}^{n}\int_0^t\frac{1}{2}\mathbf{q}^i\left(s\right):\dot{\mathbf{C}}\,ds \tag{1}$$

$$W^\infty\left(\mathbf{C}\right)=W_m^\infty\left(\tilde{I}_1,I_3\right)+W_f^\infty\left(I_4,I_6\right) \tag{2}$$

$$\mathbf{q}^i\left(t\right)=\frac{\gamma^i}{\gamma^\infty\tau^i}\int_0^t\exp\left(-\frac{t-s}{\tau^i}\right)\left(\frac{2\partial W^\infty\left(\mathbf{C}\right)}{\partial\mathbf{C}}\right)ds \tag{3}$$

Results

Tensile tests demonstrate the plantar skin non-linear anisotropic behavior, which was also confirmed by stress-strain curves obtained from compression tests. Experimental results allow us to obtain constitutive parameters for the posterior and anterior regions (Fig. 1b,c). Stress-relaxation results, from both tensile and compression tests, highlighted the tissue time-dependent behavior (Fig. 1d).

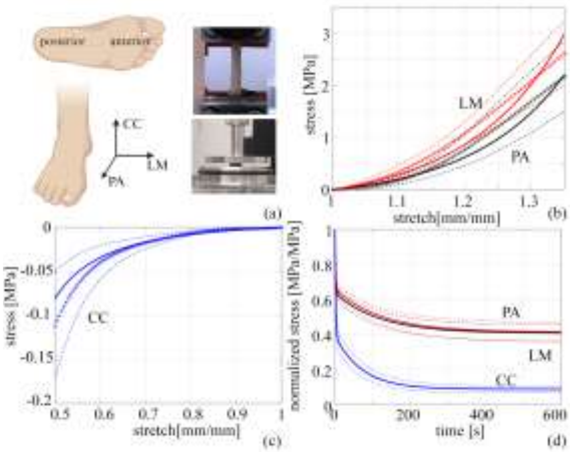

Figure 1: foot region and directions with tensile and compression samples (a). Comparison between experimental data (mean±SD) and constitutive results (continuous lines) for the posterior region: tensile (b) and compression tests (c). Stress relaxation response for tensile and compression loads (d).

Discussion

The experimental findings indicated varying mechanical characteristics in different skin areas and directions. These details can be beneficial in developing *in silico* tools for the foot, which can assist in evaluating the effects of various conditions, e.g. diabetes, or exploring the interactions between the foot and footwear.

References

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