

IN VIVO INDENTIFICATION OF THE PASSIVE MECHANICAL PROPERTIES OF DEEP SOFT TISSUES IN THE HUMAN LEG

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Introduction

Compression of the lower leg using medical compression stockings or bandages is a widely used treatment. We submit that the mechanical properties of soft tissues in the lower limb play a major role during compressive treatments of venous deficiency [1] and that predictive biomechanical models could help to better adapt the treatment to the specificity of each patient. A challenging step of the development of such models is to identify the mechanical properties of soft tissues for each patient [2]-[4].

We recently developed a non-invasive and fast inverse approach to address this challenge. In this communication, the approach is described and assessed on several volunteers, showing promising results for an extension to large-size cohort of patients.

Methods

An experimental setup was designed to perform localized compression of the lower leg soft tissues. Displacement and reaction forces were measured while a 30mm diameter cylinder was compressing the calf (Figure 1).

The subject specific leg model was built and meshed in a Finite-Element (FE) software (Figure 1). Four subjects underwent MRI scans and ultrasound acquisitions to provide complete knowledge of leg geometry. Different material properties were assigned to the superficial and deep soft tissues compartments, separated by the fascia cruris. Boundary conditions replicated the experimental compression test.

For the soft tissues, behaviour was described with a 2nd order polynomial strain energy density function:

$$U = C_{10}^p(\bar{I}_1 - 3) + C_{20}(\bar{I}_1 - 3)^2 + \frac{1}{D_1}(J^{el} - 1)^2 + \frac{1}{D_2}(J^{el} - 1)^4$$

Using an optimization loop, the material properties of the FE model were updated until the force / penetration response was in agreement with experimentally measured responses.

The sensitivity of the response to the different material parameters (superficial and deep soft tissues and fascia cruris) was assessed through a design of experiments approach.

Eventually, soft tissue mechanical properties were identified for four subjects.

Results

The numerical model was found to be very sensitive to deep soft tissue mechanical properties, which confirmed that they can be identified using this combined and numerical approach.

Parameters from the 2nd order polynomial strain energy density function were identified for four subjects: $c_{10}=0.19-0.82$ kPa and $c_{20}=0.24-2.61$ kPa. This strain energy function captured the non-linear response observed experimentally.

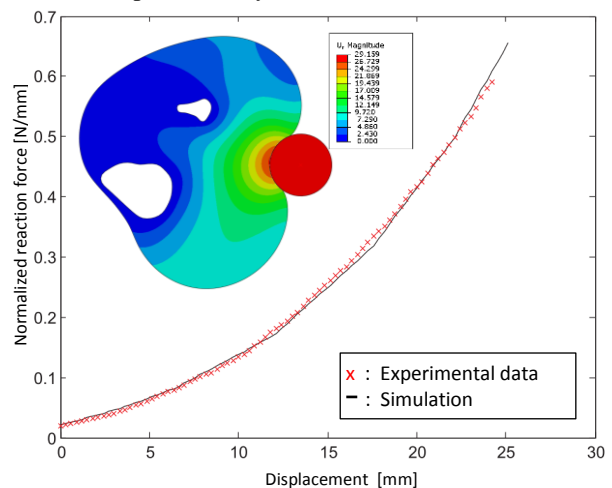


Figure 1: example of force-displacement curve and FE model

Discussion

This method enables the *in vivo* characterization of soft tissue mechanical properties through a simple compression test and an inverse method. With the current arrangement, deep soft tissue 1st and 2nd order parameters C_{10} and C_{20} are well captured, but the system is unable to catch superficial properties or compressive parameters D_1 and D_2 .

A clinical study will be held to investigate the differences in lower leg soft tissues mechanical properties for hemiplegic patients.

In order to be used in a clinical environment, the leg geometry will be obtained by an optical scanner.

References

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