THICKNESS MEASUREMENT IN MECHANICAL SOFT TISSUE TESTING: VALIDATION AND UNCERTAINTY QUANTIFICATION

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Introduction

Due to the deformable nature of soft biological tissues, the measurement of the sample dimensions is challenging. In mechanical testing, these measurements are used to calculate the first Piola-Kirchhoff stress P from the measured forces f:

$$P = f/(WH), \quad (1)$$

with W and H respectively the undeformed width and thickness of the cross sectional area on which the force is acting. Hence, an accurate measurement of the sample dimensions is crucial for a reliable stress estimation. Moreover, to truly asses the quality of a mechanical test result, uncertainties throughout the complete testing protocol need to be quantified and properly accounted for in the subsequent calculations. Literature is limited to a single study investigating different techniques for soft tissue dimension measurements [1]. In this study, we explore the use of laser technology to measure the sample thickness, quantify uncertainty and biological variability and their effect on the final test result.

Methods

Sample thickness was measured using different techniques: 1) a digital caliper, 2) a micrometer, 3) a tool developed within the framework of C^{4}Bio[i], 4) an in-house developed Micro Laser Scanner (MLS) consisting of a Gocator 2120 line laser and a linear actuator, and 5) MLS combined with a scanning spray (MLSS) applied on the sample. All methodologies were applied on 2 synthetic samples made of different materials, with 10 repetitions in order to quantify uncertainty and to compare the different techniques. Additionally, we measured the thickness of porcine aortas using the MLS to quantify the biological intra- (regional variation within 1 sample) and inter-(average of 10 different samples) variability. The uncertainties and variabilities were then used in an uncertainty propagation framework to calculate the effect on the stress-strain response. To this end, virtual data of a uniaxial tensile test was created, assuming a typical fiber-reinforced hyperelastic material model.

Results

Table 1 gives an overview of the mean and standard deviation for two synthetic samples for each technique. Figure 1 shows the probability distributions for uncertainty (for MLSS and for the C^{4}Bio tool), intra- and inter-sample variability and the effect of uncertainty on the stress-strain curve for 2 different sample thicknesses (H1 and H2).

	Caliper	Micrometer	C^{4}Bio	MLS	MLSS
SYN1	0.842±0.006	0.843±0.002	1.108±0.059	0.773±0.005	0.887±0.006
SYN2	1.020±0.009	1.025±0.004	0.858±0.029	0.870±0.008	1.066±0.002

Table 1: Mean ± standard deviation (n=10) of the thickness of 2 synthetic samples measured with different techniques.

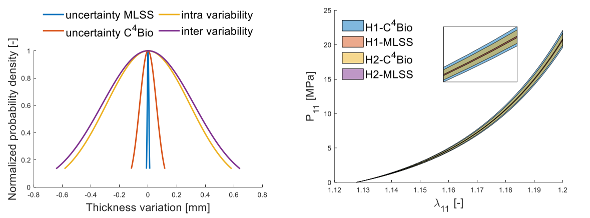

Figure 1: Normal distributions of uncertainty (MLSS, C^{4}Bio), intra- and inter-sample variability (left), and the effect of uncertainty on the stress-strain curves (right).

Discussion

Table 1 shows a large variation between different methodologies, not only in magnitude of the standard deviation differs, but also the actual mean value. We expect an underestimation of the thickness when using contact methods (caliper, micrometer), but also with MLS: laser light penetrates transparent surfaces or the top layer of tissues. The use of a scanning spray will solve this, at the cost of a slight overestimation by adding a thin layer (±11 μm) to the outer surface. A full validation of the different techniques is challenging due to the lack of a ground truth. The measurement uncertainties are relatively low compared to the intra and inter sample variability that was measured (Figure 1, left). The propagation of measurement uncertainties increases with increasing stretch and with decreasing sample thickness. Future work includes to investigate the effect of the scanning spray on the mechanical properties and the quantification and inclusion of other uncertainties throughout the testing protocol.

References

1. O'Leary et al, J Biomech, 46:1955-60, 2013.

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[i] The C^{4}Bio tool is a cheap tool to measure sample thickness using image analysis on a calibrated side-view picture, developed within the framework of c4bio.eu