COMPARISON OF LASTIC (LIGHT ASPIRATION DEVICE FOR IN VIVO SOFT TISSUE CHARACTERIZATION) WITH CLASSIC TENSILE TESTS

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ABSTRACT: LASTIC is a device estimating in vivo soft tissue elasticity. It uses negative pressure to deform the tissue surface and captures several deformation stages to trace the behavioral curve. Using Finite Element inverse analysis and a Neo Hookean constitutive law, the tissue's Young modulus is evaluated. This paper compares LASTIC capabilities with standard tensile tests on four samples with elastic properties ranging from 10 kPa to 100 kPa. Although LASTIC overestimates Young modulus by an average of 24 %, it allows a first estimation of the elastic modulus of different materials.

1. INTRODUCTION

Modeling living soft tissues and their complex specificities (non-linear, inhomogeneous, anisotropic, patient-specific behaviors) is a challenging task, especially during a surgical intervention. The Light Aspiration device for in vivo Soft TIssue Characterization (LASTIC) was, in its first version, used to evaluate the constitutive behavior of skin, tongue and brain tissues [1]. It is based on the pipette aspiration principle: after putting the instrument in contact with the tissues surface, negative pressures are applied and displacement responses are measured. Consequently, the device had to be (1) fully sterilizable and (2) sufficiently fast to provide an interactive estimation of the tissues elastic parameters. These two constraints lead to the new version of LASTIC [2]. It is validated here by comparing it, for in-vitro materials, with usual tensile test machines. This validation is a prerequisite before any intra-operative use of this new version.

2. METHODS

2.1 Elastic samples

Experiments were conducted on four different samples with elasticity moduli ranging from few kilopascals to several hundred kilopascals, to simulate the range of human soft tissues' elasticity. **RTV#1**: a RTV-EC00 silicone (artificina.com), made from a mix of 50 % of base and 50 % of catalyst (also called curing agent). It has a linear behavior up to 25 % of engineering strain. **RTV#2**: the same RTV-EC00 silicone, but made from a mix of 40 % of base and 60 % of catalyst, to create a softer silicone than RTV#1. It has a linear behavior up to 25 % of engineering strain. **Ecoflex**: an Ecoflex® 00-30 silicone (Smooth-on.com) constituted by two bases mixed in equal proportion. It has a linear behavior up to 15 % of engineering strain. **Candle gel**: a gel (glorex.com) that is fluid at temperatures over 95 °C. It has a linear behavior up to 10 % of engineering strain.

Two samples were created for each material in order to perform two different tests: one with LASTIC and one with the tensile tests, see subsections 2.2 and 2.3 for details on the mold shapes. The same material mix was poured in the two molds so that the elasticity measurements were done on the same material for each testing device.

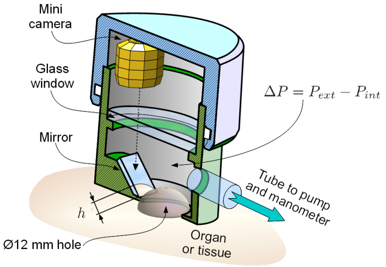
2.2 LASTIC

The current version of LASTIC is designed to be used in vivo and consequently can undergo sterilization. LASTIC is built in a compact metallic cylinder of 33 mm in height and 34 mm in diameter divided in two compartments, see Figure 1. The lower one is airtight, open at the bottom by a circular aperture and closed at the top by a glass window. The upper compartment holds a 9.5 mm × 9.5 mm 2 megapixels camera (model VS6750, STMicroelectronics) with a resolution of 1600 × 1200 pixels. The negative pressure ΔP is created in the lower compartment by a programmable syringe pump (Aladdin AL-1000, World Precision Instruments), while a USB digital manometer (model 8215, AZ Instrument Corp) measures the pressure. As a result, the soft-tissue is aspired inside the chamber, where the deformation is imaged by the digital camera, by means of a 45° inclined mirror. Increasing levels of negative pressure are applied during the measurement, creating larger aspiration height. The deformation, measured as the aspiration height, is segmented on each image of the measurement. It is converted into mm using a basic camera calibration determining the pixel size.

A Finite Element Analysis of the aspiration experiment using a Neo-Hookean constitutive law [3] is used in order to build a library of displacement heights [4].

The library of displacements depends on Young modulus and the applied negative pressure. From this library, a least-square minimization method is used to find, in less than 1 s, the Young modulus in the library that best matches the measurements.

The samples used for LASTIC tests are molded as cylindrical shapes of approximately 20 mm of height, 60 mm of diameter.



Material	Young modulus in kPa		dif in %
	Tensile	LASTIC	
Candle gel	10.5	14	+33
RTV#2	25	32	+28
Ecoflex	55	67.5	+22
RTV#1	90	100	+11

Figure 1 – LASTIC cross section: the upper part contains the camera while the lower part is the aspiration chamber with the mirror (left). Young moduli found by LASTIC and the tensile devices for each material (right).

2.3 Tensile devices

Two extension devices were used for tensile measurements to compare with LASTIC tests. Both apply a given displacement to the material, fixed between two tensile jaws, and record the force needed to reach it. The SYMME Laboratory uses an Instron® machine (Instron, Norwood, MA, USA). The material sample had a rectangular shape of 60 mm x 15 mm x 7 mm. The 3S-R laboratory uses an Eplexor 500N testing device (Gabo Qualiter Testanlagen GmbH, Ahlden/Aller, Germany), with a 25 N sensor. The material had a rectangular shape of 25 mm x 7 mm x 2 mm.

To evaluate the elasticity modulus from the measurements of both devices, the tensile test stress/strain values are studied by fitting a Neo-Hookean constitutive equation [4].

3. RESULTS

The results for LASTIC and the tensile devices are given in details in [4] for each material. Figure 1 (right panel) summarizes the Young modulus estimated by each device. For the candle gel, Young moduli of 10.5 kPa and 14 kPa were found for the tensile devices and LASTIC respectively, resulting in 33 % difference. Similarly, for the other materials, differences of 28 %, 22 % and 11 % were found for the RTV#2, Ecoflex, and RTV#1 respectively. On average, LASTIC thus overestimates the Young modulus by 23.8 % ± 9.5 % SD compared to the tensile devices.

4. DISCUSSIONS

The average discrepancy of 23.8 % in the Young modulus E estimation is relatively high. However, this overestimation seems to be linearly dependent of the value of E and this could be taken into account to improve soft tissue characterization of living tissues with LASTIC. This linear variation could be caused by our digital manometer. It has indeed a precision of ± 6 mbar in measuring the negative pressure created with the pump. Although rather small, this still represents 3 % of the maximum applied negative pressure for the RTV#1, 5 % for the Ecoflex, 7 % for the RTV#2, and 15 % for the candle gel. Since these variations are higher for more elastic materials, our assumption that the manometer is responsible for part of the measurement deviation could be corroborated. A more accurate manometer could help to reduce this error. Nevertheless, for a precise estimation of the Young modulus, we should also improve LASTIC on two other sources of error: the camera calibration and the choice of the constitutive law for the inverse problem solving as explained in [4].

Finally, it is important to keep in mind that, while the tensile tests give the closest approximation available of the elastic modulus of the different materials, they are not gold standards. For example, the estimation of the stress/strain curve of each material with a Neo Hookean constitutive equation is not perfect as the measurements are not exactly reproducible.

5. CONCLUSIONS

Overall, despites an average overestimation of 24 % compared to standard tensile devices, LASTIC gives interesting estimations of the Young modulus of elastic materials by aspirating an area of their surface and recording the corresponding displacement. This device could already be used on patients or even in surgical set up because of the overestimation consistency and because of LASTIC's small size, small cost and capability to be sterilized. Future improvements, presented in the discussions section, should provide accurate in vivo soft tissues measurements.

6. REFERENCES

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