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Using a 3D biomechanical model to improve a light aspiration device for *in vivo* soft tissue characterisation

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1. Introduction

Estimation of living tissue constitutive law is needed for patient-specific simulations during surgery. However, this task remains very challenging. The device used for characterisation must undergo sterilisation and must give real-time results to characterise tissues that can only be accessed in the operating room (e.g. brain tissues).

The light aspiration device for *in vivo* soft tissue characterisation (LASTIC) device (Schiavone et al. 2010; Figure 1(a)) was designed to fulfil these expectations. It can be sterilised and has already been tested during brain surgery (Schiavone et al. 2009). LASTIC is based on the pipette aspiration principle: it applies a range of negative pressures while measuring the tissue deformation. In order to retrieve the mechanical parameters, those measurements are compared to a library of displacement heights which was built using a finite element analysis (FEA) of the aspiration experiment. A least-square minimisation method is used to find the best parameters which fit the measured displacements (computation times are below 1 s; Schiavone et al. 2010).

The device was compared with standard tensile test for a set of elastic material samples. LASTIC was found to overestimate the Young modulus by an average of 24% (Luboz et al. 2012).

In order to improve the accuracy of LASTIC estimates, we decided to redesign the FEA of the aspiration experiment. In the previous version of LASTIC, the aspiration problem is considered as a 2D axisymmetric problem (Schiavone et al. 2009). However, as the aspiration chamber is not centred in the physical device, symmetrical loading conditions might lead to erroneous estimates (Figure 1(a)).

The focus of this paper is to compare the axisymmetric 2D model with a 3D model of LASTIC's aspiration procedure. The 3D model takes into account the non-symmetry of the device, being therefore closer to the exact geometry of the set-up. To check the impact of this new model, results of simulations using the 2D and 3D models are compared against real aspiration experiments.

2. Methods

The 3D model of the tissue was defined as a parallelepiped with large dimensions compared to the aspiration hole to avoid edge effects. The LASTIC device was defined as a hollowed cylinder. The tissue was meshed with 10 nodes tetrahedra. The mesh was first refined around the device

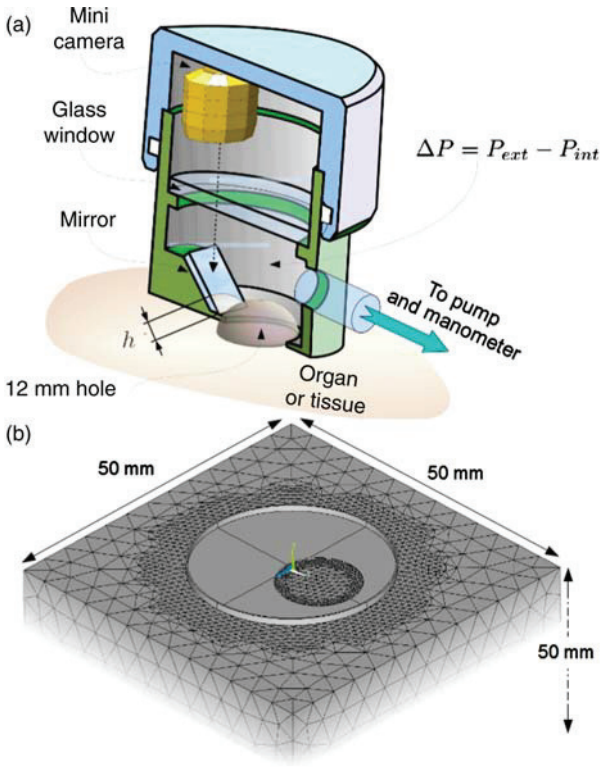

Figure 1. (a) The LASTIC device. (b) The corresponding 3D model.

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base and then refined a second time around the hole, resulting in approximately 55,000 elements (Figure 1(b)). The interface between the device and the tissue was meshed with contact elements so that the tissue can slide without friction on the device. The boundary conditions applied to the model are as follows:

- zero displacement imposed on the lower base of the tissue;
- zero displacement imposed on the device and
- a negative pressure applied on the tissue inside the device hole.

In order to verify the effectiveness of the new model compared to the previous one, we compared the FEA outputs to the deformations measured by LASTIC on four samples:

- RTV#1: a RTV-EC00 silicone with an estimated Young modulus of 75 kPa.
- RTV#2: a RTV-EC00 silicone with an estimated Young modulus of 25 kPa.
- Ecoflex: a RTV 141 silicone with an estimated Young modulus of 55 kPa.
- Candle gel with an estimated Young modulus of 10.5 kPa.

These materials have linear behaviour in the range of deformation considered in this paper (for more details, please refer to Luboz et al. 2012). Their elastic properties were evaluated by fitting a Neo-Hookean law on tensile test measurements as described in Luboz et al. (2012).

3. Results

For each experiment, the simulations were performed for two different negative pressures in both 3D and 2D models, and the maximum vertical displacement was compared to the one measured on the samples. Simulations were performed using the commercial finite element software ANSYS (version 12). The inputs and results are shown in Table 1.

Table 1. Results of the simulations and experimental measurements.

		Deformation (mm)		
	Pressure (mbar)	2D	3D	Experiment
RTV#1	50	0.41	0.40	0.32
	180	1.49	1.50	1.14
RTV#2	10	0.25	0.24	0.19
	90	2.26	2.30	1.72
Ecoflex	20	0.22	0.22	0.18
	130	1.46	1.48	1.18
Candle gel	5	0.29	0.29	0.23
	20	1.18	1.18	0.94

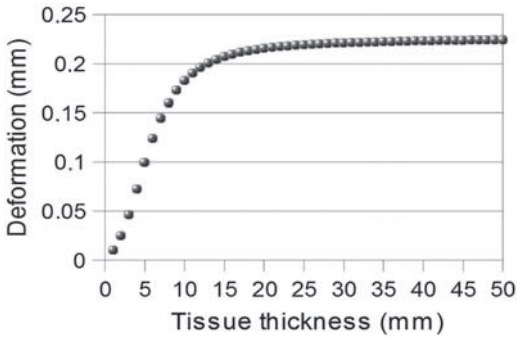

Figure 2. Deformation computed by 2D model as a function of tissue thickness ($E = 55$ kPa, $P = 20$ mbar).

The 3D model performed slightly better results for lower pressures whereas the 2D model is slightly better for higher ones. The average deformation error normalised by displacement is 27.5% for the 3D model and 27.7% for the 2D model, respectively.

4. Discussion and conclusions

The 3D model presented in this paper gives results similar to the 2D model in terms of accuracy, showing that the axisymmetrical geometry of the previous model is not the cause of the errors in LASTIC estimates. The 3D model computation needs 2–5 h on a workstation (Intel Core 2 Quadri-processor Q6600), depending on the tissue deformation. This is much more than the 25 s needed by the previously used 2D model. However, as the inverse solution is deduced from a pre-computed FEA library, this does not affect the real-time estimation of soft tissue parameters.

At this stage, computation results of the 3D model are too similar to the 2D model to be worth the loss in computation time. However, the new model will be more suitable to investigate the effect of friction between the tissue and the device because its geometry better reflects the device shape. Another possible improvement would be to investigate the effect of the tissue thickness. Both models use a tissue with a 50-mm thickness which cannot perfectly predict deformation for the thinnest tissues found in computer-assisted medical interventions, where thicknesses less than 20 mm are common (Figure 2).

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