A novel technique for assessment of mechanical properties of vascular tissue

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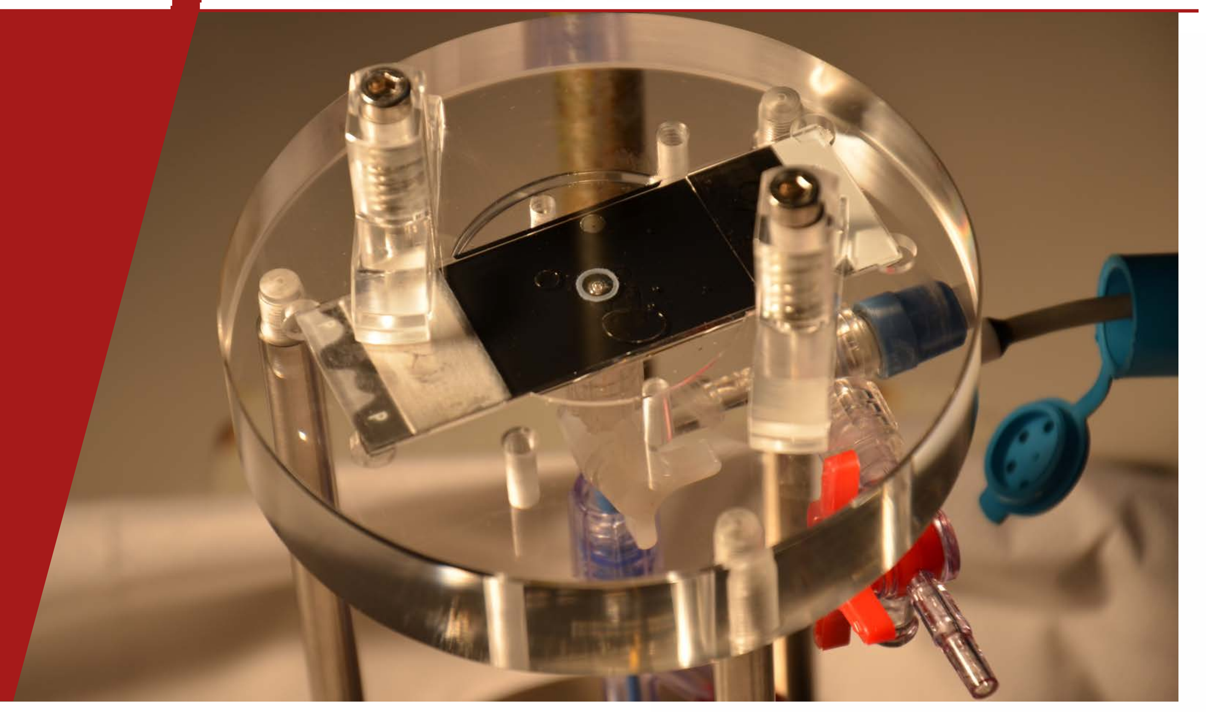

Introduction

Rupture of atherosclerotic plaques in the carotid artery is a major cause for stroke. Currently, the severity of the stenosis is used to estimate the risk of plaque rupture. However, plaque rupture occurs when the mechanical stresses in the cap of the plaque exceed the local tissue strength. Therefore, a biomechanical model of the plaque may help to better assess rupture risk.

Objectives

To determine the risk of rupture, mechanical properties of plaque components and cap strength are measured in 2D inflation experiments and inverse numerical modelling. In this study, we develop a method to assess material properties of (diseased) vascular tissue in a quasi 2D setting.

Materials & Methods

Thin slices of healthy porcine carotid arteries were cut and slightly compressed between two glass plates, as shown in figure 1 and the top right corner of this poster.

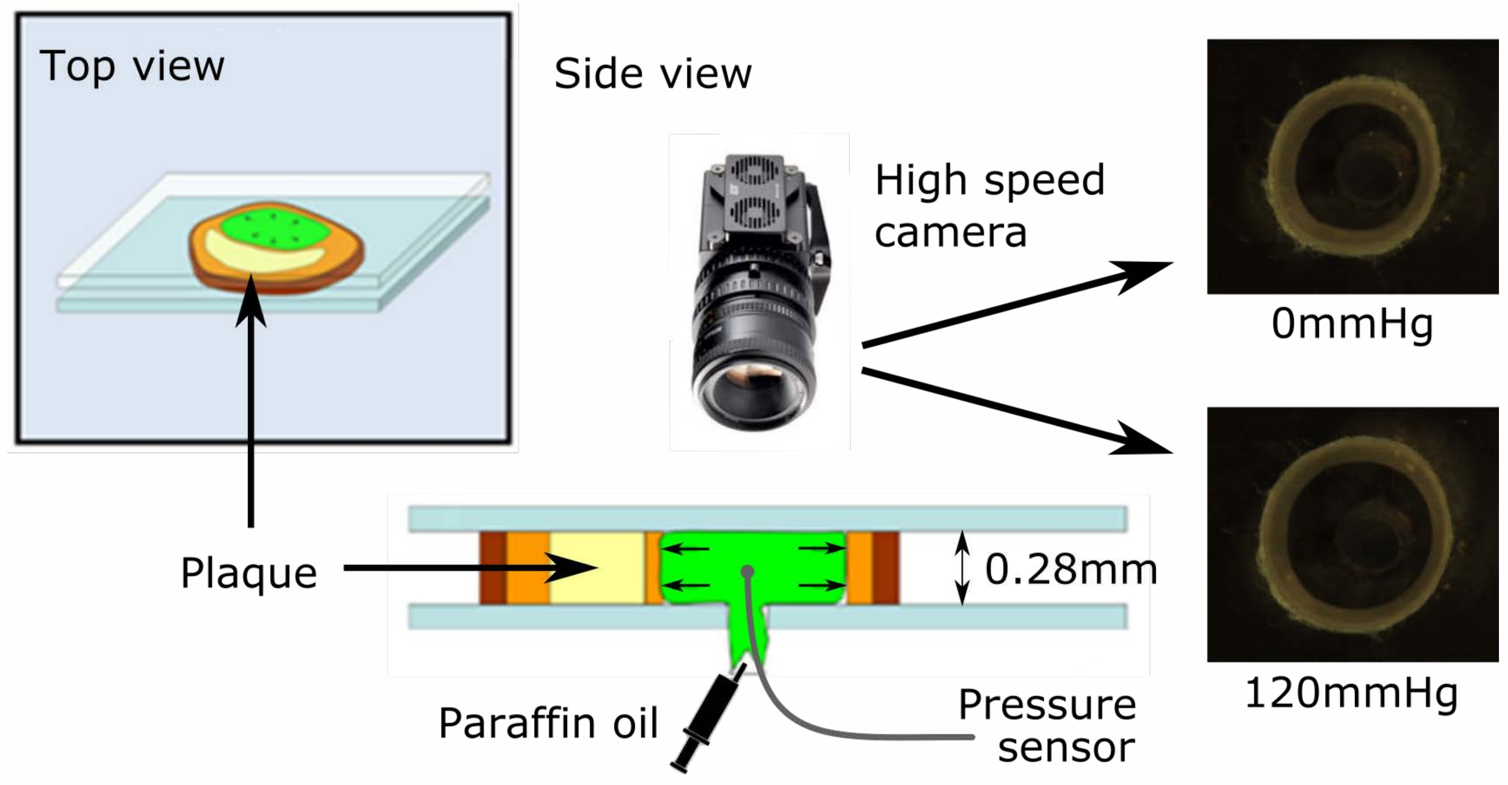

***Figure 1*:** Schematic overview of the experiment.

For validation purposes, ultrasound measurements[2] have been performed on 4 healthy porcine carotid arteries three times (figure 2). The arteries were under a physiological axial stretch of 60%.

***Figure 2*:** Ultrasound experiment setup.

The well known Gasser-Ogden-Holzapfel[1] (GOH) material model was used to assess the behavior of the carotid samples during pressurization.

$$\Psi = \Psi_{mat} + \Psi_{coll}$$

$$\Psi_{mat} = \frac{1}{2}c(I_1 - 3), \qquad I_1 = \lambda_r^2 + \lambda_\theta^2 + \lambda_z^2$$

$$\Psi_{coll} = \frac{k_1}{2k_2}\left(e^{k_2(\kappa I_1 + (1-3\kappa)I_4 - 1)^2} - 1\right), \qquad I_4 = \lambda_z^2 sin^2\gamma + \lambda_\theta^2 cos^2\gamma$$

The stiffnesses c (matrix), k_1 (fibre) and stiffening parameter k_2 were fitted using a 1D model, describing radial displacements. The fibre angle was fixed at 36°, while pressure varied between 80-120mmHg[2].

Phantom validation

Thin rings ($n = 7$) of silicone rubber (Wacker elastosil M 4601 A/B), were inflated in the experiment. The obtained material properties, using a Neo-Hookean model, were compared to the properties calculated from tensile tests on rectangular samples of the same material.

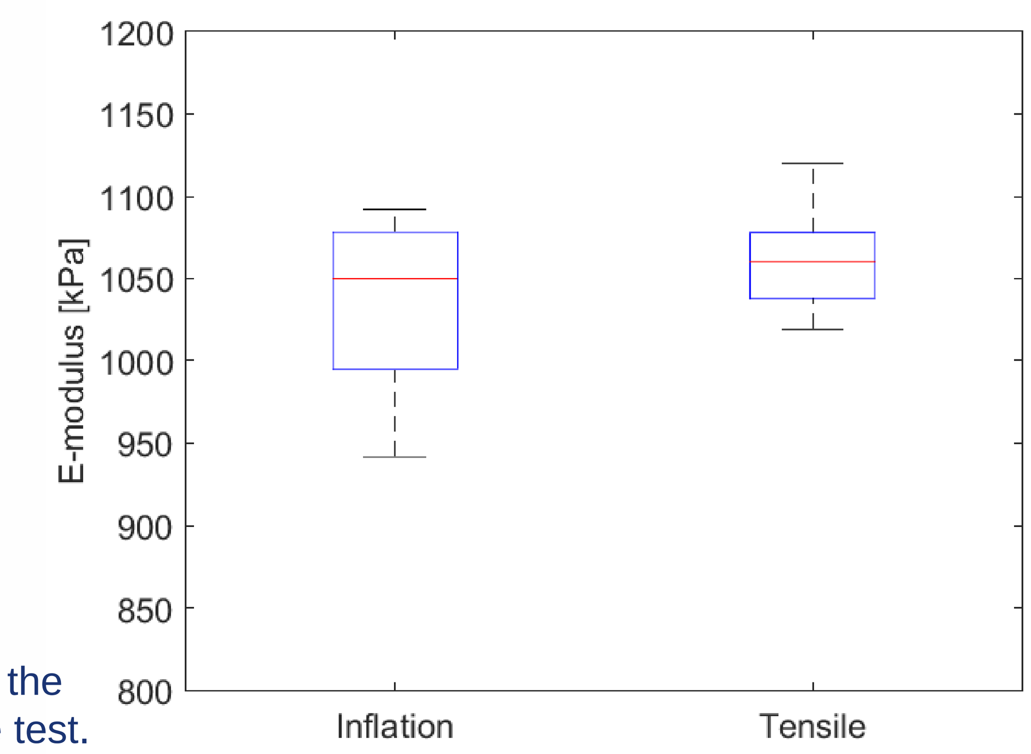

***Figure 3*:** E-moduli obtained in the inflation experiment and tensile test.

Similar E-moduli are obtained in the inflation- and tensile tests (figure 3). The means of both groups are the same (Student's t-test, $p = 0.2 > 0.05$).

Results

Strain stiffening is observed at higher pressures in all carotid samples in both the ring inflation and ultrasound experiments (figure 4).

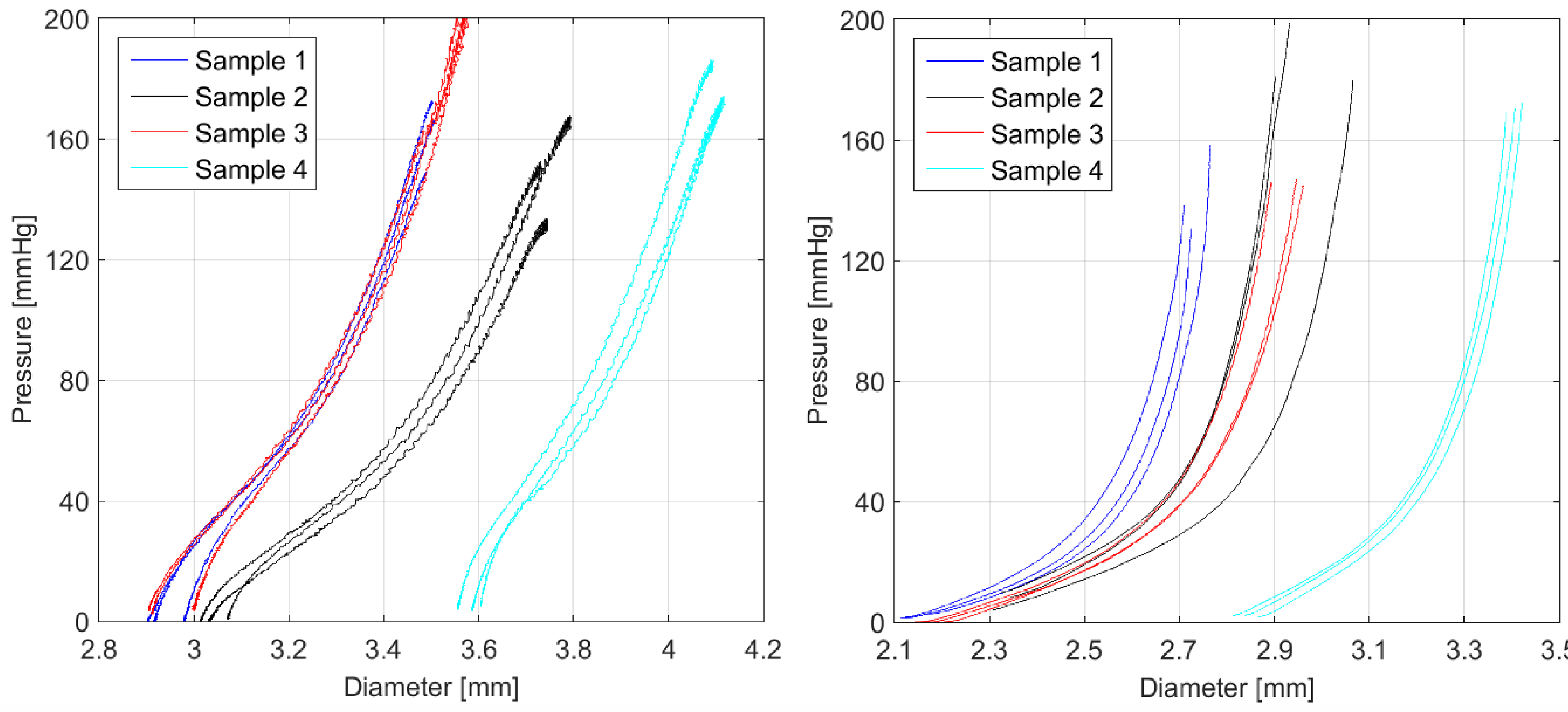

***Figure 4*:** Pressure-diameter curves from the ring inflation (left side) and ultrasound (right side) experiments. Measurements on all four samples were repeated three times.

Both methods show reasonable reproducibility. The pressure range of 0-120mmHg was used to evaluate the material parameters. For this poster the results from the first measurements of sample 1 are shown (table 1 and figure 5), the other samples gave similar results.

	c [kPa]	k_1 [kPa]	k_2 [-]
INF	63,9	1,2	25,3
US	13,9	17,5	28,9

***Table 1*:** Material properties from best fit of GOH model on the ring inflation (INF) and ultrasound (US) measurements of sample 1.

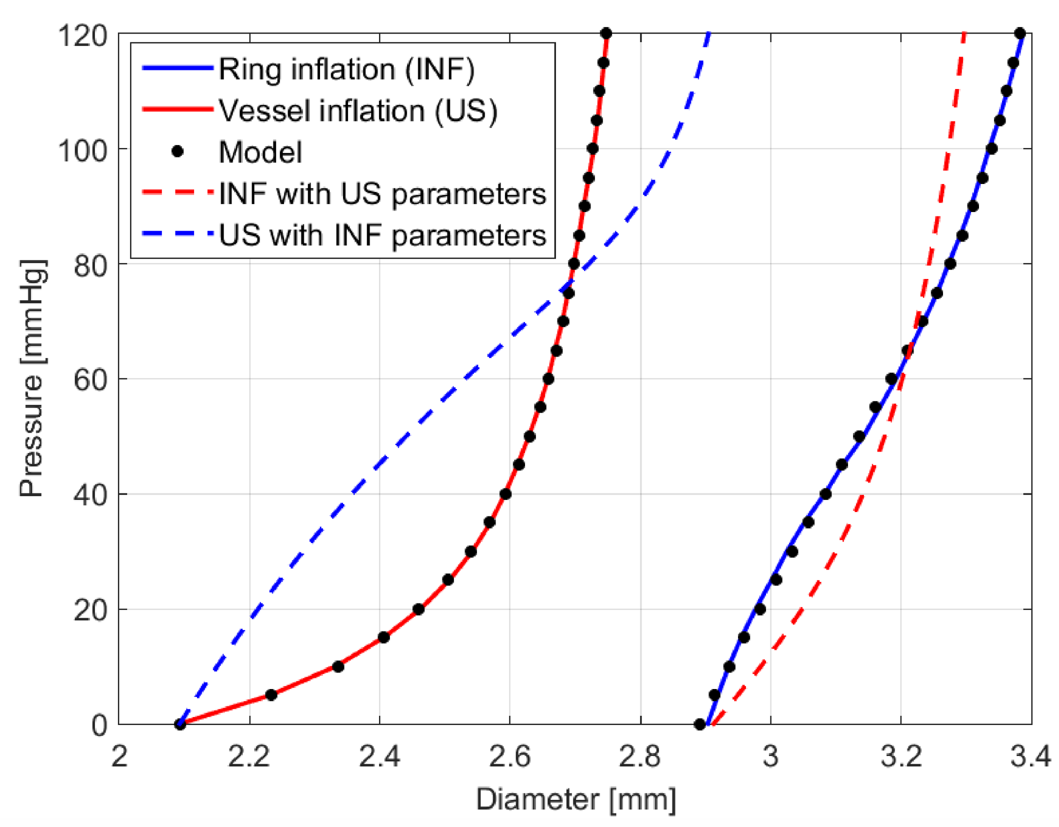

***Figure 5*:** Pressure-diameter curves of the experiment data and model fits. **Solid lines:** INF in blue, US in red. **Black dotted lines:** Best fit of the FEM on the experiments. **Dashed lines:** Model results with interchanged parameter sets.

The GOH-model fits both experiments well, giving different sets of parameters for each experiment. Exchanging the fitted parameters between the two cases gives the same average displacement over the whole loading range, with a very different shape of the pressure-diameter curve.

Conclusions and future work

We developed a method to reproducibly assess vascular material properties, in a quasi-2D experiment. Application of the Gasser-Ogden-Holzapfel model gives parameter estimations that depend on the experimental boundary conditions. This needs further research.

In future applications, heterogeneous properties, like in atherosclerotic plaque material, may be assessed as well, using vital staining techniques to distinguish different tissue components without affecting their mechanical behaviour.

Acknowledgment

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/ Department of Biomedical Engineering

References

[1] T.C. Gasser, R.W. Ogden, G.A. Holzapfel. J. Biomech. Eng., 126 (2004), pp. 264–275.
[2] A. van der Horst, C.N. van den Broek, F.N. van de Vosse, M.C.M. Rutten. Biomech Model Mechanobiol (2012) 11:533-542.