DETERMINATION OF THE HETEROGENEOUS MATERIAL PROPERTIES OF ATHEROSCLEROTIC PLAQUE

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Introduction

The rupture of atherosclerotic plaque causes stroke or myocardial infarction. Studies have suggested that the risk of plaque rupture is determined by the plaque composition and mechanical factors [Falk, 1995]. Therefore, knowledge of the biomechanical properties of the atherosclerotic plaque is essential to predict the rupture risk. In this study, we determined the heterogeneous material properties of the atherosclerotic plaque using a novel approach combining experimental tests, image analysis, and finite element modelling. In future studies, this approach can be used to investigate the effects of drugs on plaque stabilisation.

Methods

Tensile tests were performed on arterial rings harvested from healthy and atherosclerotic human coronary arteries (Figure 1). The images of the ring tests were analysed using the optical flow technique [Sun, 2010] to obtain the deformation strains. Finite element models (FEMs) were then developed for the arterial rings using Abaqus software. The force results of the healthy artery FEMs were matched with those of the experiments to determine their Ogden hyperelastic modulus μ and hardening exponent α. These properties were then fitted in the healthy regions of the atherosclerotic FEMs. In order to obtain heterogeneous properties across the plaque, each element in the plaque was assigned with different μ and uniform α. Properties which match the experiment were obtained using MATLAB software error minimisation.

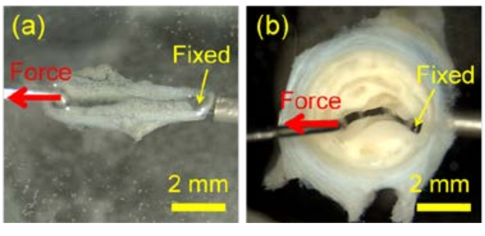

Figure 1: Ring tests of (a) healthy and (b) atherosclerotic arteries.

Results

For the healthy arteries (n = 3), the mean $\mu = 95 \pm 50$ kPa and $\alpha = 25 \pm 4$. Figures 2a and 2b show the experimental strains of an atherosclerotic artery and the corresponding FEM strains obtained using optimised material properties. The heterogeneous μ of the plaque are shown in Figure 3, with uniform $\alpha = 42$.

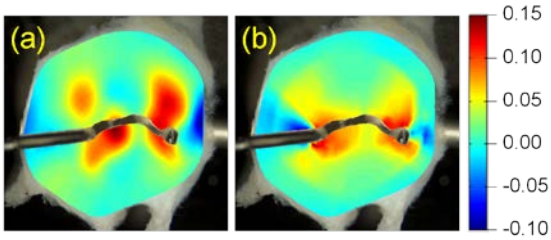

Figure 2: Horizontal strains of the (a) experiment and (b) FEM of an atherosclerotic artery.

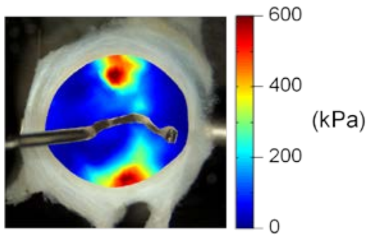

Figure 3: Heterogeneous modulus μ of the plaque.

Discussion

The approach developed allows determination of plaque heterogeneous material properties. The arterial nonlinearity was accounted by assigning hyperelastic functions to both arterial wall and plaque. The high and low modulus regions of the plaque are the calcified and lipid regions, respectively. Combined with future studies, these results will enable us to further understand the biomechanical properties of atherosclerotic artery, thus promoting the development of new treatment strategies.

References

Falk E *et al*, Circulation, 92:657-671, 1995.
Sun D *et al*, IEEE Int Conf on Comp Vision & Pattern Recognition, 2432-2439, 2010.