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EFFECT OF DEFORMATION RATE ON THE MECHANICAL PROPERTIES OF RECTANGULAR AND CRUCIFORM ARTERIAL SAMPLES: UNIAXIAL AND BIAXIAL TESTING

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INTRODUCTION

The elastic behavior of arteries is nonlinear when subjected to large deformations. In order to measure their anisotropic behavior, planar biaxial tests are often used. Uniaxial tests are also commonly used due to simplicity of data analysis, but their capability to fully describe the in vivo behavior of a tissue remains to be proven. Mechanical behaviour of arteries submitted to uniaxial or biaxial testing has been done previously [1-4]. Each one of these works was performed only at one deformation rate: 1 %/s [1, 3], 10 %/s [2], 1 Hz [4]; but those works do not show the behaviour of the arterial wall when it is submitted to different deformation rates. Thus, in this study we present the effect of deformation rate in the material properties (i. e. loading forces) of uniaxial and biaxial tests.

MATERIALS AND METHODS

Five thoracic aortas were harvested within the day of death of pigs from a local slaughterhouse. Then the artery was cut open along its length, and cut out in rectangular and cruciform shapes (Fig. 1). The rectangular samples were tested uniaxially while the square and cruciform samples were tested biaxially. A total of 12 samples were obtained from the 5 aortas. Thickness was measured with a vernier caliper. Samples were stored in saline solution at 4 °C for no longer than 24 hours prior to testing.

Eight rectangular samples were tested uniaxially: four in the circumferential direction and four in the longitudinal direction. Preliminary destructive tests revealed that failure rarely occurs below a nominal stretch ratio of 2.0. Therefore a 1.5 nominal stretch ratio was applied to avoid any plastic deformation on the tissue. The forces were measured with one load cell. The original length of the sample was taken as the distance between the pair of grips (Fig. 1.a).

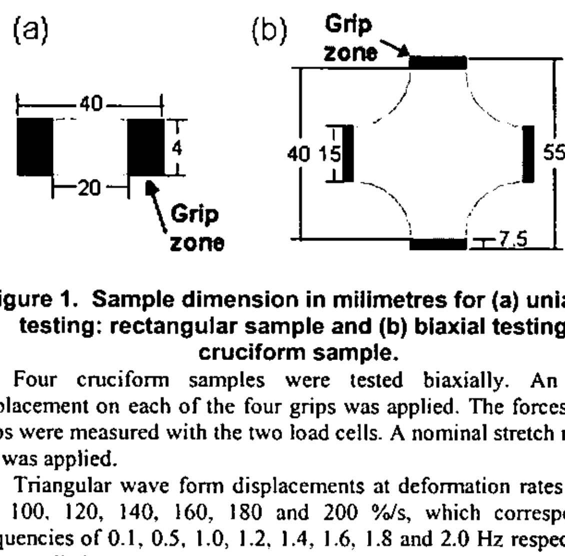

Figure 1. Sample dimension in milimetres for (a) uniaxial testing: rectangular sample and (b) biaxial testing: cruciform sample.

Four cruciform samples were tested biaxially. An equal displacement on each of the four grips was applied. The forces at the grips were measured with the two load cells. A nominal stretch ratio of 1.5 was applied.

Triangular wave form displacements at deformation rates of 10, 50, 100, 120, 140, 160, 180 and 200 %/s, which correspond to frequencies of 0.1, 0.5, 1.0, 1.2, 1.4, 1.6, 1.8 and 2.0 Hz respectively, were applied randomly or in progressive order to each sample tested. Five pre-conditioning cycles [5] and five steady-state cycles were used for each deformation rate. The sampling rate of the force measurements was set so that forces were measured at the same deformations values in each cycle, therefore allowing to average the force-deformation data over the last 5 cycles. For all the samples tested, the experimental data obtained in uniaxial and biaxial testing, were statistically analyzed and are represented as the mean value ± one standard deviation. A $p < 0.05$, indicating statistical significance, was obtained using Student's t-test.

RESULTS

The mean thickness of all the specimens tested was 2.4 mm. Figure 2 shows the experimental force data plotted against time. Each curve shows the behaviour of the aorta at a particular deformation rate (i.e. the open square data is the loading-force vs. time curve at a deformation rate of 50%/s). The deformation rates chosen were used in the following order: 160, 120, 50, 200, 140, 100, 10 and 180 %/s. 10 triangular wave cycles were performed for each deformation rate. Figure 2 data points represent the average force-time curves of all the samples tested. As expected, the time needed to reached the peak deformation (50 %) was the highest for a deformation rate of 10 %/s. It is also seen that the loading force is slightly lower when the higher deformation rate (200 %/s) was used than using the lower deformation rate (10% s). This behaviour is shown much cleared in figure 3.

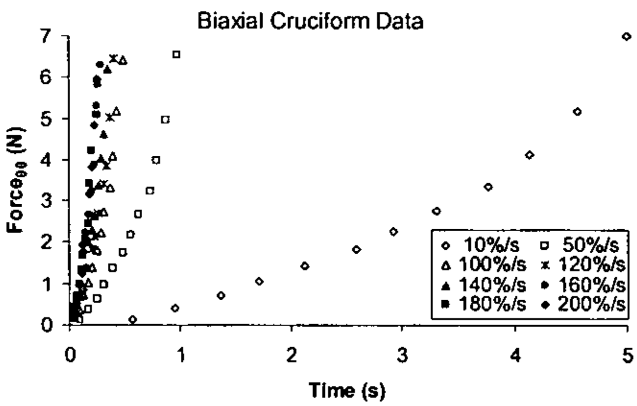

Figure 2. Effect of deformation rate on the mechanical properties of a cruciform sample: Circumferential forces plotted against time.

Figure 3 shows the effect of deformation rate on the peak force value. The peak stretch was 1.50. It is seen that the loading force is slightly reduced when the deformation rate is increased. This means that higher forces are applied to the material when it is stretched at a lower deformation rate. Meanwhile, if the sample is stretched at the highest deformation rate, then the loading force will be smaller.

When a balloon is inflated inside the artery to treat atherosclerosis, is important to minimize the forces (tension) suffered by the arterial wall to reduce the probability of developing a reduction in the lumen (restenosis) after a few months post-surgery. Our findings might suggest that a rapid inflation-deflation of the balloon, using a high deformation rate, could minimize the applied forces and the stress distribution in the vessel wall.

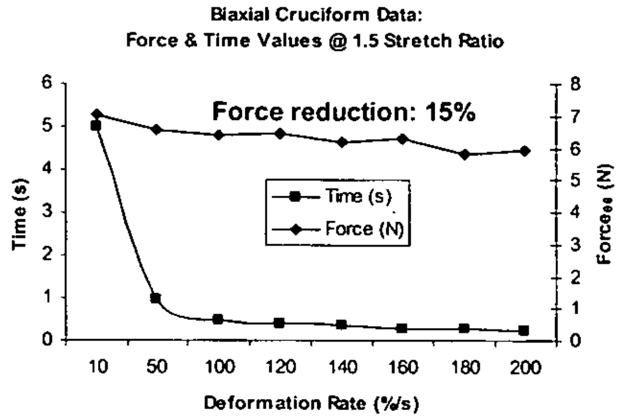

Figure 3. Peak circumferential force and time data points measured at the maximum stretch ratio reached (1.50).

CONCLUSION

We have reported uniaxial and biaxial experimental data of porcine aortas *in vitro*. We found that the loading force is been reduced up to 15% when the deformation rate is been increased from 10 to 200 %/s. This means that when the tissue is extended applying the lowest deformation rate, the measured force will be lower than its value if the quickest deformation is used instead. In other works, the tissue seems to withstand lower force values when the deformation rate is higher (i.e. 200 %/s). This finding might be useful in medical teckniques such as angioplasty.

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