MEASUREMENT OF POISSON’S RATIO OF BOVINE AORTA USING DIGITAL IMAGE CORRELATION

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Abstract—Digital Image Correlation (DIC) was adopted to examine the mechanical behavior of arterial tissue from the bovine aorta. Rectangular sections comprised of the intimal and medial layers were excised from the descending aorta and loaded in displacement control uniaxial tension up to 40% elongation. Specimens of silicon rubber sheet were also prepared and served as a benchmark material in the application of DIC for the evaluation of large strains; the elastomer was loaded to 50% elongation. The arterial specimens exhibited a non-linear hyperelastic stress-strain response and the stiffness increased with percent elongation. Poisson’s ratio is observed to increase when specimens are subjected to uniaxial stress in the axial direction, while Poisson’s ratio is observed to decrease when specimens are subjected to uniaxial stress in the circumferential direction.

Keywords—Speckle Correlation Method, Biophotonics

I. INTRODUCTION

The prevalent cause for stroke is the rupture of unstable atherosclerotic plaque within the sinus of the carotid artery that provides blood to the brain. Plaque rupture can be attributed to a number of possible factors, most of which are mechanical in nature [1]. Nevertheless, there is currently a limited understanding of the mechanics of plaque rupture. In order to understand the mechanical conditions and consequent stress-strain distributions in arterial walls that facilitate plaque rupture, we have adopted the use of Digital Image Correlation (DIC) [2]. DIC is a full-field, non-contact optical method of displacement measurement that requires just two digital images to acquire displacements. In contrast to point measurement techniques DIC can provide the complete in-plane displacement distribution over a finite area of observation. In this study DIC has been adopted to measure the strain distribution in sections of bovine aorta subjected to uniaxial tension.

II. METHODOLOGY

Bovine aorta and descending artery (total length from aortic arch of approx. 20cm) were obtained within 1/2 hr post mortem. The arteries were maintained in an EGTA enhanced passive physiologic solution except during transport, dissection and testing. Rectangular sections of artery were excised, oriented either axially or circumferentially, measuring approximately 25 mm by 100 mm. The adventitial and part of the medial layer of the specimens were removed using a microtome blade, yielding specimens with uniform thickness of approximately 2.0 mm. Prior to loading each specimen was sprayed with a spotted coat of black paint. The spray deposits a high contrast speckle pattern on the specimen’s surface necessary for precise displacement measurements.

The specimens were placed within a dedicated load frame and subjected to uniaxial monotonic tensile loads under displacement control actuation. Displacement increments of 1.27 mm (0.05 in) were applied to the aorta sections until reaching a maximum axial deformation of 25 mm (1 in). The reaction load resulting from elongation was determined using a precision load cell with full-scale range of 22.5 N. An image of the specimen’s surface was recorded prior to loading and at each step of axial displacement. The tension experiments for the arterial specimens were comprised of loading the specimen to 25% nominal elongation and unloading 12 times consecutively. The 13th and 14th cycles consisted of loading to 30% and to 40% elongation and unloading, respectively. The first 12 cycles were conducted to condition the samples and achieve a steady state mechanical response. Speckle images were documented during the 1st, 4th, 8th, 12th, 13th, and 14th cycles at every 2% elongation; the axial load at each of these increments was documented as well. A typical experiment comprised of the 14 load-unload cycles with one specimen required about 30 minutes.

To validate results obtained from using DIC to evaluate properties of the bovine artery, benchmark tests were performed with silicon rubber sheet (40 Durometer). Rectangular sections were obtained from the rubber sheet (1.27 mm thick) with dimensions of 25.4x85mm.

To illustrate the DIC optical arrangement, Figure 1 shows a diagram of the setup. The optical arrangement used for DIC in this study consisted of a digital camera with 7.5x zoom lens, an incoherent light source, and a computer (Fig. 1). An image size of 25 mm by 18 mm was utilized and digitized into a sample of 1280 by 960 pixels with 256 gray levels. A comparison of the digitized speckle distributions captured at each load step was conducted to determine the full-field displacement distribution.
III. RESULTS

A typical series of stress-strain curves was obtained from axial and circumferential sections during specific cycles of the conditioning routine. The estimated elastic modulus of an axial specimen was 186 KPa at the 12th cycle. The average elastic modulus of the second component of the stress-strain curve for an axial specimen was 880 KPa.

One of the primary benefits of using DIC is that the displacement and corresponding strain can be determined in two orthogonal directions. Thus, both the elongational and transverse strains were available from a comparison of the speckle images obtained for the arterial specimens at each load increment. Poisson’s ratio was determined from the ratio of transverse and elongational strains of each arterial section over the load history. The change in Poisson’s ratio of a representative arterial specimen with elongation is shown for axial strain in Fig. 2 and circumferential strain in Fig. 3, respectively. Poisson’s ratio increased with the magnitude of axial stretch but decreased with each cycle of the conditioning phase of loading. The change in response of the representative specimen for the 14th load cycle is apparent in Fig. 2; Poisson’s ratio decreased from 0.15 to near 0.23. Poisson’s ratio decreased with the magnitude of circumferential stretch but increased with each cycle of the conditioning phase of loading. The change in response of the representative specimen for the 14th load cycle is apparent in Fig. 3; Poisson’s ratio decreased from 0.47 to near 0.33.

A comparison of the stress strain response of the bovine artery and silicon rubber resulting from uniaxial loading reveals that the constitutive behavior of the two materials is different. Furthermore, the strain dependent Poisson’s ratio of the bovine artery and elastomer, respectively, are also unique. Poisson’s ratio of the arterial specimens increased with axial strain while that of the elastomer decreased with axial strain. The elastomer exhibits incompressible behavior ($v = 0.5$) at the onset of loading and then becomes increasingly compressible with the increase in magnitude of elongation.

IV. DISCUSSION

Based on the observed trend in Poisson’s ratio of the elastomer it is apparent that there are some errors contributing to the experimental results, particularly at lower strain ($\varepsilon \leq 8\%$). To maintain conservation of volume Poisson’s ratio of the elastomer should be less than or equal to 0.5; the calculated value obtained from the displacement field using DIC exceeded this quantity indicating at least 2% error. The primary source of error in the experimental analysis results from out-of-plane displacement of the specimen during the onset of loading. Behavior with a non-constant Poisson’s ratio. Sources of errors are also present in the calculated strains for the arterial specimens due to the nonlinear behavior and large compliance. Nevertheless, the constitutive behavior and elastic constants determined for the arterial specimens and elastomer in this study agree with those reported in the open literature [3,4].

V. CONCLUSIONS

Digital Image Correlation (DIC) was used to measure Poisson’s ratio of bovine aorta under both axial and circumferential strain. DIC provides a useful method for evaluating deformations in bovine arteries. Additional experiments were conducted with silicon rubber sheet for benchmarking results obtained using DIC under large strains. Measurements show that Poisson’s ratio of bovine aorta varies with the load cycle, % elongation, and direction of the applied uniaxial load.

REFERENCES