8th. World Congress on Computational Mechanics (WCCM8)
5th European Congress on Computational Methods in Applied Sciences and Engineering (ECCOMAS 2008)
June 30 –July 5, 2008
Venice, Italy

BIAXIAL MECHANICAL PROPERTIES OF INTACT AND LAYER-DISSECTED HUMAN CAROTID ARTERIES AT PHYSIOLOGICAL AND SUPRA-PHYSIOLOGICAL LOADINGS

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Key Words: *Biomechanics, Arterial wall mechanics, Carotid artery, Artery, Biaxial testing, Residual stretch, Cardiovascular disease.*

ABSTRACT

Cardiovascular diseases are routinely treated in an essentially mechanical way, which subjects the vessels to loads that are beyond the physiological range. It is also widely agreed that the mechanical environment and properties of arteries play an important role in the initiation and progression of vascular diseases. Therefore, detailed knowledge of their mechanical behavior is essential for the improvement of surgical and non-surgical procedures as well as for the development of prosthetic materials and artificial tissue equivalents. Since an artery is a heterogeneous structured composite that consists of three layers with different (visco)elastic properties, a thorough understanding of the related mechanical behavior requires experimental data of each layer.

Intact wall tube specimens of human common carotid arteries (CCA), internal carotid arteries (ICA) (n=10, age 76.8 yrs, SD 6.3), and their associated adventitia and media-intima tubes were mechanically examined. Cyclic and quasi-static extension-inflation tests at different axial stretches were performed on the pre-conditioned tube specimens. The intact wall was anatomical separated into intact adventitia and media-intima tubes in a turtle-neck fashion [1]. Correct layer separation was confirmed by light microscope inspection during the separation process, and by histological analysis after testing. Circumferential and axial residual stretches of the adventitia and media-intima tubes of the intact wall were determined, and the stress-free configurations (i.e. curvatures and opening angles) of the intact wall, the adventitia and the media-intima composite in the circumferential and axial directions were determined. Analytical stress estimations in the specimen tubes utilizing a thin-walled model were performed for studying the underlying mechanics of the arterial tubes. Uniaxial tension tests of strip specimens oriented in the axial and circumferential directions of the individual layers, and ultimate tensile stresses and stretches were also performed.

The present study reports novel data on significant residual stretches of the adventitia and the media-intima composite. A residual stress release in the circumferential direction was recorded in the intact wall of the CCA and ICA. In the axial direction, a residual stress release was recorded in the intact wall of the CCA and in the adventitia of the CCA and ICA. Common mechanical features of all investigated tissues are: strong nonlinearity, pseudo-elastic behavior and small hysteresis. The so-called 'inversion'-feature (i.e. negative slopes of the axial stretch-pressure curves at higher axial stretches [1]) was observed only for the intact walls. Adventitias were very compliant at low pressures but they carried significant loads under physiological conditions. The adventitias changed into very stiff tubes at pressures exceeding the physiological range. The burst pressure of the adventitia was beyond a transmural pressure of 250 kPa. A relatively low burst pressure of approximately 60 kPa (450 mmHg) of the media-intima tube was observed. The stress analyses pointed out relatively high anisotropic material properties of all investigated tissues. In addition, high circumferential and axial stresses were occurring in the media-intima tube at physiological conditions. In general, the mechanical data produced in this study emphasize the adventitia and the media-intima composite as 'layers' with very different mechanical properties, and hence different mechanical roles.

The mechanical properties of the arterial wall and the individual layers may accurately be described by a recently proposed three-dimensional hyperelastic constitutive model [2] which was able to capture the characteristic nonlinear and anisotropic material response (see Fig. 1).

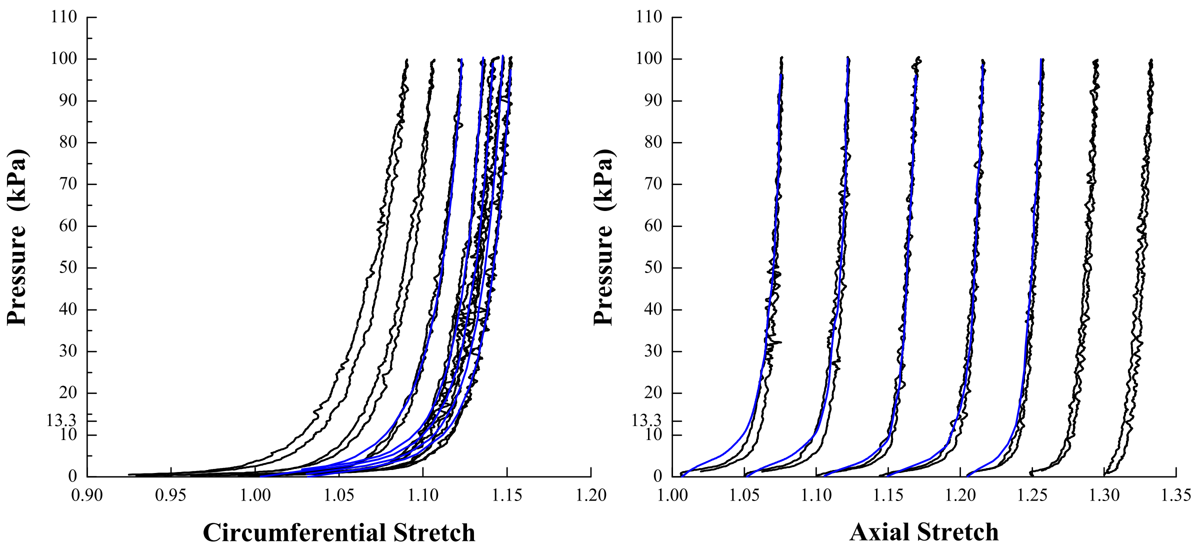

Figure 1: Representative plots showing the relationships between pressure and circumferential stretch (a) and pressure and axial stretch (b) of the adventitia of a human common carotid artery and the related model predictions (blue curves). Each curve is associated with a specific axial stretch. The model provides an excellent fit up to an axial stretch of $\lambda_z = 1.2$.

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