EVALUATION OF BIAXIAL MECHANICAL PROPERTIES OF MEDIAL LAMELLAE OF AORTIC WALL USING MULTISCALE MODELING

H. Taghizadeh GJ[1], M. Tafazzoli-Shadpour[1], N. Fatouraee[1] & M. B. Shadmehr[2]
[1] Amirkabir University of Technology, Biomedical Engineering Department, 424 Hafez Ave., Tehran, Iran.
h.taghizadeh@aut.ac.ir, tafazoli@aut.ac.ir, nasser@aut.ac.ir
[2] Tracheal Diseases Research Center, National Research Institute of Tuberculosis and Lung Diseases (NRITLD),ShahidBeheshti University of Medical Sciences, Tehran, Iran. mbshadmehr@sbmu.ac.ir

Key Words: *aortic media, lamellar structure, Strain Energy Density Function, multiscale modeling*

Arterial wall is one of the most complicated tissues in both structural and functional aspects. Mechanical properties of the arterial tissue highly depend on wall components. Hence, evaluation of mechanical properties of wall components is necessary for establishing a mechanical model applicable in various physiological and pathological conditions such as remodeling, growth, and plaque formation. Some investigations assumed arterial wall as a composite material consisting of its three main layers, namely Intima, Media and Adventitia [1]. Other approaches have proposed strain energy functions for major wall constituents i.e. elastin, collagen and SMCs [2]. In this contribution, we proposed a new model for evaluation of mechanical properties of wall lamellae based on biaxial testing of the arterial wall to characterize wall behavior.

It has been well established that Tunica media, the mid layer of the aortic wall, is responsible for the main mechanical characteristics of arteries. It consists of a composite structure with two sets of concentric lamellae, namely Sheets of Elastin (Layer I) and interstitial layers composed of mostly collagen fibers, Smooth Muscle Cells (SMCs) and fine elastin fibers (Layer II). A pair of Layer I and Layer II often is called the structural unit of media. Approximately 60 structural units form thoracic aortic media in an adult human.

Samples of human thoracic aortas were provided from brain death patients after organ donation according to ethical committee instructions of Masih Daneshvari hospital, the main site of organ donation and transplant in Iran. The adventitial and loose connective tissues were removed and samples were preserved in PBS prior to tests. Samples of 11x11 mm were subjected to biaxial tension utilizing a custom made device, and force-displacement data were recorded. Additionally, we used histological staining methods to monitor geometrical dimensions of wall microstructure. After quantification of whole tissue properties, optimization algorithms were used to evaluate mechanical properties of layers.

According to the isotropic nature of Elastin sheets, we assumed a Neo-Hookian strain energy density function (SEDF) for layer I [3]. On the other hand, for the interstitial layer a four-parameter exponential SEDF was allocated due to anisotropy resulted from collagen fibers [4] We fitted our experimental results for whole artery wall with by an exponential Fung-type SEDF similar to Layer II [4]. Hence,

$$W_I = c_1(I_1 - 3) \tag{1}$$

$$W_{II} = c_2[\exp(a_1 E_{11}^2 + a_2 E_{22}^2 + 2a_3 E_{11} E_{22}) - 1] \tag{2}$$

Assuming layer forces to be proportional to their volume fraction (Eq. 3), we setup our optimization procedure from equilibrium equations as follows:

$$\begin{cases} f_I\sigma_I^c + f_{II}\sigma_{II}^c = \sigma_{tot}^c \\ f_I\sigma_I^a + f_{II}\sigma_{II}^a = \sigma_{tot}^a \end{cases} \qquad (3)$$

where σ denotes Second Piola stress in circumferential (c) and axial (a) directions for layer I, Layer II and whole wall (tot), f indicates volume fraction of layers, w stands for SEDF The isotropy of Layer I necessitates equality of layer I stresses in axial and circumferential directions. Trust region algorithm was used to solve optimization problem.

The resultant hyperelasitc parameters for the lamellar model and the whole wall are presented in Table 1 and the equivalent stress-strain curves for the whole wall and lamellae are shown in Figure 1 for both axial and circumferential directions. Results are in good agreement with qualitative description of isotropic and anisotropic contributions of elastin and collagen to the whole wall behavior, i.e. elastin fibers are active in lower strains and collagen fibers sustain most of the load in higher strains. Mechanical characterization of wall lamellae assists development of a new generation of arterial wall models which are applicable in different biological situations in which alteration in wall lamellae is required such as morphogenesis, growth, remodeling and arterial diseases.

Table1. Material Parameters found for lamellar model

Parameter	f_I	f_{II}	C_1	C_2	a_1	a_2	a_3
Layers	0.377	0.623	64.671KPa	31.335KPa	1.8890	2.2862	0

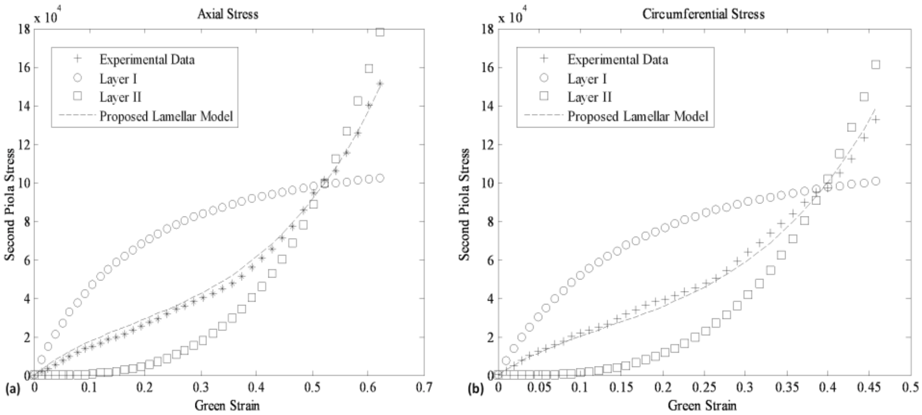

Figure 1. Contribution of Layer I & Layer II on the mechanical behavior of the wall in different Green strains: a) Axial direction b) Circumferential direction

REFERENCES

1. Sommer, G., et al., *Biaxial mechanical properties of intact and layer-dissected human carotid arteries at physiological and supraphysiological loadings.* Am J Physiol Heart Circ Physiol.Vol. **98**(3), pp. 898-912, 2010.
2. Martufi, G. and T.C. Gasser, *A constitutive model for vascular tissue that integrates fibril, fiber and continuum levels with application to the isotropic and passive properties of the infrarenal aorta.* Journal of Biomechanics.Vol. **44**(14), pp. 2544-2550, 2011.
3. Holzapfel, G., T. Gasser, and R. Ogden, *A New Constitutive Framework for Arterial Wall Mechanics and a Comparative Study of Material Models.* Journal of elasticity and the physical science of solids.Vol. **61**(1-3), pp. 1-48, 2000.
4. Humphrey, J.D., *Mechanics of the arterial wall: review and directions.* Crit Rev Biomed Eng.Vol. **23**(1-2), pp. 1-162, 1995.