LAYER-SPECIFIC BIOMECHANICAL CHARACTERIZATION IN ABDOMINAL AORTIC ANEURYSMS

E.P. Kritharis[1,2], S. Sassani[2], J. Kakisis[3], S. Tsangaris[2], D.P. Sokolis[1]

[1] Laboratory of Biomechanics, Biomedical Research Foundation, Athens, Greece; [2] Laboratory of Biofluid Mechanics and Biomedical Engineering, School of Mechanical Engineering, National Technical University, Athens, Greece; [3]Vascular Unit, 3rd Department of Surgery, University Hospital 'Atticon', Athens University Medical School, Athens, Greece

Introduction

Biomechanical characterization of abdominal aortic aneurysms (AAA) is fundamental to our understanding of their modes of rupture, which occurs when hemodynamic stresses overcome the strength of aneurysmal wall. However, all past biomechanical studies have considered the AAA tissue as intramurally homogeneous [Phillipi, 2011], a hypothesis that might lead to erroneous estimates of local stress distributions. Knowledge of the layer-specific properties is essential and this has been the objective of this preliminary report.

Methods

Full-thickness wall specimens were procured from the anterior region of AAA from 5 patients (age: 73±4 y, AAA diameter: 7.2±0.7 cm) during graft replacement, cut into long rectangular strips, and dissected into layers. The strips were categorized by the direction of tissue: circumferential (CIRC) vs. longitudinal (LONG) and by layer: intima (n_{CIRC}=5; n_{LONG}=4) vs. media (n_{CIRC}=6; n_{LONG}=6) vs. adventitia (n_{CIRC}=6; n_{LONG}=9). Uniaxial tensile tests of the layered wall were performed on pairs of orthogonally-directed strips beyond rupture, during which the tensile load, and the axial length and width of strips were recorded. The Fung-type SEF was chosen as a descriptor of the response:

$$W = K(e^{Q} - 1)\,,$$
$$Q = c_{\theta\theta}E_{\theta}^{2} + c_{zz}E_{z}^{2} + c_{\theta z}E_{\theta}E_{z}\,, \qquad (1)$$

where $c_{\theta\theta}$ and c_{zz} represented respectively CIRC and LONG stiffness at physiologic loads, $c_{\theta z}$ the stiffness interaction between axes, and K was a scaling factor; E_{θ} was CIRC and E_{z} was LONG Green strain. Failure stress, peak elastic modulus, and failure stretch were also computed.

Results

Most failure metrics were significantly greater in the adventitia than the intima and media (Table 1). Peak elastic modulus was greater in CIRC than LONG strips from all layers; similar directional variations in failure stress were noted in adventitia. Realistic representations of the stress-stretch data were succeeded by the Fung-type SEF (R^2>0.9, Table 2). Parameters $c_{\theta\theta}$ and c_{zz} were highest in the intima and lowest in adventitia, with $c_{\theta\theta}$>c_{zz}.

		Failure stretch (-)	Failure stress (N/cm^2)	Peak elastic modulus (N/cm^2)
Intima	CIRC	0.23±0.05†	57.2±12.1†	437.1±100.9†*
	LONG	0.28±0.04†	38.8±9.5†	158.3±59.4†
Media	CIRC	0.27±0.04†	137.6±25.3†	966.3±263.3*
	LONG	0.33±0.03†	71.3 ±27.7	386.8±125.3
Adventitia	CIRC	0.58±0.10	240.0±43.1*	1091.6±290.8*
	LONG	0.57±0.05	121.3±30.0	533.0±127.6

*Table 1: * denotes significant directional variations and † denotes variations vs. adventitia.*

	Intima	Media	Adventitia
K (N/cm^2)	0.46±0.21	0.57±0.13	1.53±0.73
$c_{\theta\theta}$ (-)	116.0±17.9*•†	60.7±10.2†	18.5±3.4*
c_{zz} (-)	50.6±23.6†	39.8±11.1†	10.3±0.9
$c_{\theta z}$ (-)	76.4±26.4†	53.3±11.6†	11.2±3.1
R^2 (-)	0.94±0.03	0.97±0.01	0.97±0.01

*Table 2: * denotes significant variations vs. c_{zz}, and •, † denote layer variations vs. media and adventitia.*

Discussion

The present data indicate marked variations in the stress- and deformation-bearing capacity of the individual AAA layers, i.e. reduced extensibility, strength, and maximum stiffness of inner layers, albeit with intima showing greatest stiffness at physiologic loads. Similar layer-specific variations have been shown for ascending thoracic aortic aneurysms by our group [Sokolis, 2012], but the latter were more extensible and less strong than AAA. Knowledge of individual layer properties may be used as input data to heterogeneous finite element models assessing stress distributions more accurately than current homogeneous models.

References

Phillipi J.A. *et al*, In: Studies in Mechanobiology, Tissue Engineering and Biomaterials, Vol. 7. Springer-Verlag, Berlin, 67-118, 2011.

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