BIOMECHANICAL CHARACTERIZATION OF ASCENDING THORACIC AORTIC ANEURYSMS

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Introduction

An aortic aneurysm is defined as a permanent dilatation of an aorta of at least 1.5 times its expected diameter. Untreated, they may result in dissection or rupture of the arterial wall. Surgical repair is currently advised when the diameter exceeds 55 mm. We investigated the biomechanical properties of ascending thoracic aortic aneurysm (ATAA) tissue to better understand and predict these complications.

Methods

Data from six patients exhibiting ATAA and scheduled for surgery was pre-operatively acquired through non-invasive pressure and diameter measurements, via sphygmomanometer and ECG-gated time-resolved CT-scans, respectively. Epiaortic echocardiography images were acquired during surgery from which the *in vivo* wall thickness (h) was determined using Matlab®. From this data, the maximal outer diameter, the distensibility coefficient (DC) [1], wall stress (WS) [1] and pressure-strain modulus (PS_{mod}) [2] of the ATAA tissue were calculated.

$$\mathrm{DC} = \frac{(d_{sys}-d_{dias})^2}{d_{sys}^2(P_{sys}-P_{dias})} \tag{1}$$

$$\mathrm{WS} = \frac{d_{sys}P_{sys}}{2h} \tag{2}$$

$$\mathrm{PS}_{mod} = \frac{d_{dia}(P_{sys}-P_{dias})}{d_{sys}-d_{dias}} \tag{3}$$

with P_i the pressure and d_i the outer diameter at systole (i=sys) and diastole (i=dias). After surgical repair, the resected tissue was collected and tested mechanically in a planar biaxial and a uniaxial tensile set-up. From these tests, stress-stretch curves and ultimate stress and stretch values were calculated, as well as parameters for the hyperelastic Gasser-Holzapfel-Ogden (GHO) [3] model. The latter were estimated based on the pre-operative data as well as on the postoperative resected tissue.

Results

The different mechanical parameters reported in Table 1 confirm the aneurysmal nature of the collected tissue when comparing to literature. For all patients, a good fit was obtained in the GHO parameter fitting process (the average R^2 was 0.90 and 0.97 for the pre-operative and postoperative data, respectively).

Table 1: Mechanical parameters of the six patients. The patient labels stand for F-female or M-male and age in years. The subscript values in the 4th column are age categories in years. Results reported in literature [1,2,4] are listed at the bottom.

Patient	d_{sys} [mm]	WS [MPa]	PS_{mod} [MPa]	Ult. circ. Stress [MPa]
F74	62.1	0.40	0.16	0.53
F68	51.0	0.52	0.20	0.74
M58	51.2	0.45	0.10	1.10
M60	45.6	0.31	0.23	1.24
M52	45.5	0.30	0.09	-
M55	41.4	0.28	0.14	1.19
Healthy	-	0.093 ±0.006	$_{30\text{-}49}$ 0.08 $_{50\text{-}59}$ 0.11 $_{60\text{-}79}$ 0.17	1.80±0.24
ATAA	-	0.245 ±0.06	-	1.18±0.12

Discussion

F74 was the only patient with a diameter over 55 mm. The others underwent surgery due to confounding factors (e.g. bicuspid aortic valve). Nevertheless, the large spread in ultimate circumferential stress indicates the strong patient-specificity of the rupture risk and the low correlation thereof to the diameter. A more indicative predictor is the ratio of wall stress to ultimate circumferential stress. However, the latter can obviously not be measured pre-operatively whereas the former is highly sensitive to the measured wall thickness and should be calculated more accurately than by using thin-walled tube theory. Though research groups have already identified the need for more accurate calculation of wall stress through finite element simulations on a patient-specific geometry, this study also indicates the strong need for reliable estimation of patient-specific ultimate stress, by identifying correlations with parameters that can be acquired pre-operatively.

References

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Acknowledgements

This work was supported by the Research Foundation-Flanders (FWO).