ANISOTROPIC NON-LINEAR FINITE ELEMENT MODELS OF AORTIC ROOT FOR THE STUDY OF BICUSPID AORTIC VALVE

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Object. Bicuspid aortic valve (BAV), the most common cardiac congenital malformation, frequently causes aortic stenosis and/or regurgitation. BAV is often associated with early development of aortic aneurysms [1]. Realistic finite element (FE) models could provide a valuable tool to investigate BAV-related alterations and to convey predictive information to clinicians. Here, we present a novel structural FE modelling strategy for simulating the function of the aortic root throughout the cardiac cycle.

Methods. Aortic root geometries with normal tricuspid aortic valve (TAV) and BAV was based on measurements from 2-D magnetic resonance images. Aortic leaflets were discretized with shell elements (ABAQUS type S4) and their mechanical response was modelled through a transversely isotropic incompressible hyperelastic model [2]. The aortic wall was discretized with solid elements (ABAQUS type C3D8); different thickness and collagen fiber orientations were assigned to each arterial layer (intima, media, adventitia) [3]. Layer-specific mechanical properties were defined using an anisotropic non-linear hyperelastic model able to represent collagen fibers dispersion [4]. Two load steps were implemented. The first one loaded the aortic root to its telediastolic configuration, the second one simulated the physiological pressure time-course over a complete cardiac cycle. The numerical simulations were performed within the finite element commercial code ABAQUS/Explicit 6.9-1 (SIMULIA, Dassault Systèmes).

Results. Abnormal leaflet stresses were observed in the BAV model, located particularly in the central basal region of the conjoint leaflet. Both cusps underwent more flexure as compared to the normal TAV, and were abnormally stretched to maintain coaptation (fig.2a). Peak maximum principal stresses on Valsalva sinuses were 48% higher in BAV model than in TAV and they were mainly located in the non-coronary sinus. An overstressed intimal layer, compared to media and adventitia, was highlighted both in TAV and BAV, the latter showing higher stress values (fig.2b).
Fig.1 a) Max principal stresses on leaflets in the main instants of the simulated cardiac cycle. b) Colorimeter maps of circumferential stresses [MPa] in the three layers of ascending aorta for the TAV (up) and BAV (down) models.

Conclusions. In BAVs aortic valve function is altered and characterized by abnormally high stresses on aortic leaflets and also on the surrounding aortic wall tissue, with possible implications in the development of tissue degeneration or damage.

References

