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Patient-specific FEA of the aortic valve: an approach based on structural constitutive models

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Abstract

Cardiovascular diseases represent a major worldwide health care issue. In particular, a considerable amount of diseases is represented by heart valves failure. Surprisingly, surgical treatments aiming at restoring valve functionality remain nowadays “more art than science” [1]. For this reason, in this last decade, the use of computational tools to investigate heart and valvular mechanics has gradually grown and, in particular, finite element analysis (FEA) has been frequently adopted as an innovative approach to support the operation planning procedure.
In order to perform realistic simulations, appropriate constitutive material models have to be considered, such a model should be able to reproduce the mechanical behavior of the cardiovascular tissue as appear through experimental evidences. The complexity of the constitutive model increases the more it take into account the histological structure of the tissue. Complex constitutive laws including anisotropy and non-linearity are necessary to represent the mechanical response of cardiovascular tissues since it depends on the contribution, composition, and interaction of different constituents such as collagen fibers, smooth muscle cells and the elastin network.

The aortic valve is made of three leaflets and three sinuses which form cavities behind the leaflets. The sinus wall consists of circumferentially oriented smooth muscle cells in a matrix of randomly oriented elastic fibers and few small collagen fibers leading to little anisotropy. In contrast, the valve leaflets can be seen as a fiber-reinforced composite material with collagen fibers largely running in the circumferential direction [2]. As a consequence of the microstructure, the leaflets of the aortic valve exhibits a non-linear and anisotropic behavior with a markedly stiffer response in the direction perpendicular to blood flow [3].

Recognizing the importance of the geometrical and material modelling in the field computational biomechanics, this work focuses on the definition of a patient-specific geometry and a realistic characterization of the mechanical behavior of the aortic valve. A non-linear anisotropic hyperelastic material model, possible motivated by the tissue histology, is adopted to simulate the performance of patient-specific valve models obtained directly from medical images. The material parameters of the constitutive model are identified with respect to specific experimental results available in the literature.

References

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