MODELING IN-VITRO MATURATION OF TISSUE-ENGINEERED BIOHYBRID HEART VALVE IMPLANTS

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Background

Biohybrid tissue-engineered implants offer promising possibilities to treat cardiovascular diseases. Tissue-engineered materials ability to grow and remodel can be utilized to produce implants that can adapt to changes within the human body. However, tissue-engineered materials lack enough mechanical strength to withstand physiological loading conditions. One approach to improve the mechanical properties is by using biocompatible reinforcement material. In our work, we focus on textile-based biohybrid heart valves. The embedment of a load-oriented textile scaffold in the implant acts as biomimetic reinforcement and guides the extracellular matrix (ECM) growth direction. Our main objective is to design biohybrid heart valves that can withstand physiological loading conditions within humans for decades. That makes it necessary to develop accurate and computationally efficient numerical models to support the implant design process.

Methods

We developed a macro-mechanical modeling approach for the maturation process of textile-reinforced biohybrid heart valves. Biohybrid heart valves can be modeled as a composite structure [1, 2]. The main valve constituents are (i) the biological tissue and (ii) the fiber-reinforced textile scaffold. The constitutive model defines the total Helmholtz free energy as the sum of energies of the individual valve constituents. The density of collagen is treated as an internal variable. We propose a new energy-based approach to model the densification of protein fibers during the implant maturation process. In this approach, we consider both static and dynamic cultivation processes. First, the model subdivides the densification rate into biologically driven and mechanically driven parts. In the next step, structural tensors introduce materials anisotropy into constitutive equations. Then, we embed the constitutive model into a solid-shell finite element formulation with reduced integration and hourglass stabilization [3]. By using several Gauss points through the thickness of each element, we can significantly reduce the computational costs of our simulations. Finally, we constructed a finite element simulation for an exemplary heart valve with a tubular design [4].

Results

To test the performance of our model, we constructed a shell structure with simple geometries under pressure loading. Then computed the collagen density evolution and the corresponding deformation and stresses. In the second example, we computed the maturation of exemplary heart valve with a tubular design. In the next step, we investigated the influence of scaffold design on the mechanical properties of the implant.

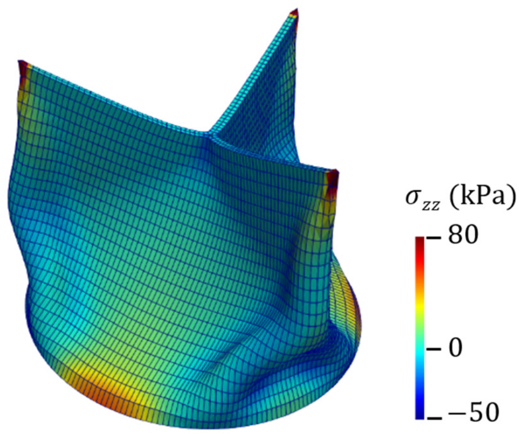

Figure 1: Cauchy stress contour along the longitudinal direction of tubular heart valve implant

Discussion

The model allows us to predict the evolution of collagen density during the maturation process. Collagen fibers distribution influences the stiffness and, consequently, the implant's load-bearing capacity and stress distribution. Through this computational model, we can investigate the influence of the implant's design parameters on the mechanical properties. This can help us to optimize the valve scaffold design and geometry.

References

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