In Silico simulations of functionally graded tricuspid artificial aortic valves

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Cardiovascular diseases are the leading cause of death worldwide. Among them, aortic valve (AV) disorders characterized by abnormal function manifesting as regurgitation or limited leaflets movement become more prominent [1]. Current treatment methods involving the implantation of an artificial valve, despite continuous advances in engineering and medical sciences, are still far from achieving an optimal solution in terms of balancing the implant's cyclic deformation with its fatigue strength. The aim of this study was to investigate the effect of using functionally graded materials (FGM) on the working cycle of the considered synthetic tricuspid AV geometries. A homogeneous reference AV model was also considered [see Fig. 1a]. Using ANSYS Mechanical software (ANSYS Inc., US) and the finite element method (FEM), dynamic simulations were performed under loading conditions corresponding to the isovolumetric contraction phase of the left ventricle with a maximum pressure of 120 [mmHg] and an aortic pressure of 80 [mmHg] [2]. Four conical curve-based rho-driven leaflet geometric variants were considered, with the coefficient ranging from 0.3 to 0.6. Using experimental data obtained from mSLA printed resins, hyperelastic material models were adopted, to which a second-order Ogden model was fitted. Within each geometry, the structure was divided into 4, 6, and 8 sections with varying mechanical properties, assuming a stepwise reduction in material stiffness along the free-edge direction of the valve leaflets [see Fig. 1b].

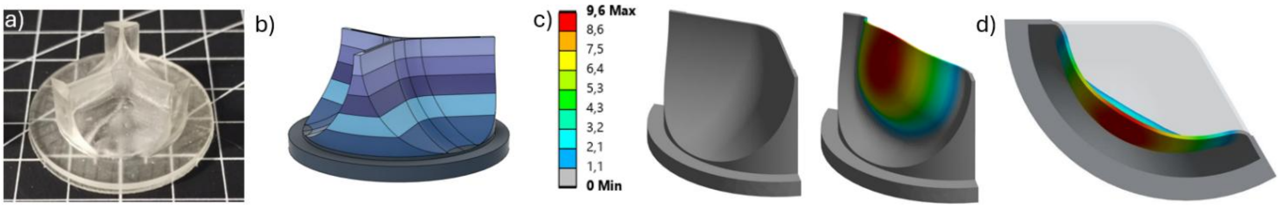

Figure 1. a) 3D-printed homogeneous AV. b) 0.4-rho AV model with six material sections. c) Total deformation [mm] of a one-third section before and after loading (isometric view). d) Top view of the deformation field.

The results of the simulations allowed the estimation of equivalent stress values, leaflet's buckling pressure as well as the displacements of the elements [see Fig. 1c, d], thereby enabling the calculation of both, the cross-sectional areas of the valve at the characteristic points required for Gorlin's equation and the assessment using clinically applied indicators. An additional outcome of this work is the development of a framework that provides a way to tailor the properties of the functionally graded material along the structure to achieve more balanced ratio between the strength of synthetic AVs and their ability to undergo elastic deformation.

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