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Design of Artificial Mitral Valves by Shape Memory Alloys

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Abstract

The cardiac valve surgery replacements take place worldwide about 300000 times a year, of them, more than 50% involve mechanical valves. Bileaflet valves, among other mechanical valves, having higher physiological compatibility and longer shelf life, account for about 60% of the valve replacement surgeries, however, due to the occurrence of non-physiological blood flow passing through the valve, the replacement should be exercised accompanying with anticoagulant medications. Based on previous research works, due to the occurrence of complicated and stagnant flows around the mitral valve, the hinge area in these valves could be a place prone to blood clots and embolism. In this study, an attempt is made to improve the performance of these valves with the help of smart materials compatible with the human body to replace the hinges. The super elastic property of SMA smart material is used to rotate the leaflet inside the ring. The leaflets leave the full semi-circular geometry found in conventional bileaflet valves, and the axis of rotation of the leaflets is transferred from the center of the ring circumventing the valve, toward the ring edges. The shape memory material replaces the hinge material and provides the leaflet rotations, permitting the one-sided blood flow from left atrium to left ventricle. The geometry of this proposed valve is designed as an SMA bileaflet in SolidWorks software. The maximum hydrostatic pressure that is applied to the mitral valve from the atrium chamber, would be a basis for designing the valve opening as much as 90 degrees. By applying the resultant force to the pressure center of the leaflet and assuming a rigid mechanical valve in comparison with the super elastic property of the SMA hinge, this hinge has a double-clamped beam boundary condition, with one end clamped to the ring edge and the other end clamped to the rigid mitral valve, providing a maximum 90-degree rotation of the mitral valve for the blood flow from the atrium to the ventricle with minimum vortex and turbulent flow. A finger-of-thumb estimate shows that in this range of bending axial stresses, the shape memory hinge remains in the elastic range in terms of a material behavior, however, the assumption of small deformation theory is violated and large rotations and large strains emerge the geometric nonlinear behavior of the beam-type hinge. This beam is formulated and analyzed by 1D three-node finite elements based on the Lagrangian formulation of continuum mechanics, and finally, the design of the SMA beam-type hinge is followed by parametric studies.