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Simulation and Design of Aortic Valve Repairs: A 3D Parametric Geometric Anatomy and Fluid-Structure Interaction Biomechanics.

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Brief Summary:

Stenosis and other type aortic valve (AV) pathologies are major contributors to aortic insufficiency that require replacement or repair. The construction of patient-specific and accurate 3D geometry was the focus of this research. An extensive database (n=100) was investigated using imaging software to construct the AV geometry of older patients candidates for Transcatheter Aortic Valve Replacement (TAVR/TAVI). Calcific aortic valve disease (CAVD) is a progressive pathology characterized by calcification mainly within the cusps of the aortic valve (AV). As CAVD advances, the blood flow and associated hemodynamics are severely altered, thus influencing the mechanical performance of the AV. This study proposes a new method, termed reverse calcification technique (RCT) capable of re-creating the different calcification growth stages. The RCT is based on three-dimensional (3D) spatial computed tomography (CT) distributions of the calcification density from patient-specific scans. By repeatedly subtracting the calcification voxels with the lowest Hounsfield unit (HU), only high calcification density volume is presented. RCT posits that this volume re-creation represents earlier calcification stages and may help identify CAVD initiation sites. The technique has been applied to scans from 12 patients (36 cusps) with severe aortic stenosis who underwent CT before transcatheter aortic valve implantation (TAVI). Four typical calcification geometries and growth patterns were identified. Finite elements (FE) analysis was applied to compare healthy AV structural response with two selected CAVD-RCT configurations. The orifice area decreased from 2.9 cm^2 for the healthy valve to 1.4 cm^2 for the moderate stenosis case. Local maximum strain magnitude of 0.24 was found on the edges of the calcification compared to 0.17 in the healthy AV, suggesting a direct relation between strain concentration and calcification geometries. The RCT may help predict CAVD progression in patients at early stages of the disease. The RCT allows a realistic FE mechanical simulation and performance of calcified AVs.

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1. Halevi, R., Hamdan, A., Marom, G, Mega, M., Raanani, E., and Haj-Ali, R., Progressive aortic valve calcification: Three-dimensional visualization and biomechanical analysis, Journal of Biomechanics, 2015, In-Press, DOI: http://dx.doi.org/10.1016/j.jbiomech.2014.12.004