**The impact of balloon-expandable transcatheter aortic valve replacement on concomitant mitral regurgitation: A comprehensive computational analysis**

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**Supplemental Materials and Methods**

**Patient-specific LH model**

The BAV and MV geometries were segmented at mid-systole and mid-diastole, respectively, approximating their stress–free configuration [1]. Similarly, the aortic root and ascending aorta were segmented at mid-systole, while the myocardium was segmented at mid-diastole. The patient-specific MV model used in this study was developed and validated in a previous work from our group that investigated MV dynamics under functional MR [2]. Briefly, the detailed chordae structure (number, position, length, branching, origins of the PM tips, and insertions into the leaflets) was directly reconstructed from the MSCT images. Chordae were classified into five groups: anterior strut (AS), anterior basal (AB), anterior marginal (AM), posterior basal (PB), and posterior marginal (PM). Cross-sectional area values of 0.38 mm2, 0.71 mm2 and 2.05 mm2 were assigned to marginal, basal and strut chordae, respectively [3]. A total of 18 chordae origins were modeled from the PM tips.

3D solid elements (eight-node hexahedral C3D8R/C3D8I elements, six-node wedge C3D6 elements, and four-node tetrahedral C3D4 elements) were used to discretize the ascending aorta, aortic root, BAV, calcification and MV. Stress/displacement truss elements (two-node linear T3D2 elements) were used for the mitral chordae, while shell elements (four-node quadrilateral S4 elements) were used to model the endocardial wall. Two layers of elements were used across the mitral leaflet thickness. For the AML, the average thickness values for the leaflet belly and free edge were 1.26 mm and 2.09 mm, respectively. For the PML, the average thickness values of the leaflet belly and free edge were 1.31 mm and 1.57 mm, respectively [2]. Four layers of elements were used across the ascending aorta/aortic root and BAV leaflet thickness, with a uniform total thickness of 2 mm and 0.7 mm, respectively.

After a mesh convergence study, average mesh sizes for the BAV, MV, chordae, aorta/aortic root and calcification were 0.25 mm, 0.7 mm, 1.5 mm , 1 mm and 0.5 mm, respectively. Leaflet mesh size was refined until stress results were not affected by mesh size, with results showing a variation within 5%. The total number of elements used for the BAV was 48,567, 6550 for MV, 860 for chordae, 183,130 for aorta/aortic root, and 42,650 for calcification. The BAV/aortic root and calcification shared the same nodes on the tissue-calcification interface, thus avoiding contact-related issues during the simulation. SPH particles were uniformly distributed in the domain with a spatial resolution of 0.8 mm, which led to approximately 1 million one-node (PC3D) elements.

**Balloon-expandable** **TAV model**

The stent, which was generated using depictions in the literature, had an external nominal diameter of 26 mm, a frame height of 16.1 mm, and a rectangular cross section of 0.4 x 0.55 mm for the frame struts. 3D solid elements (eight-node hexahedral C3D8I elements) were used to model the stent, while 3D membrane elements (M3D4) were used to model the fully enclosed balloon, which resembled the Edwards RetroFlex 3 balloon geometry. Two layers of 3D solid elements (eight-node hexahedral C3D8R elements) were used to model the TAV leaflets, with a uniform total thickness of 0.28 mm. The skirt was modeled by shell elements (three-node triangular S3 elements).

**Cardiac tissues and TAV mechanical properties**

Supplemental Table 1 lists the fitted material parameters for the cardiac tissues, which were assumed to be homogeneous, non-linear and elastic. The modified anisotropic hyperelastic Holzapfel–Gasser–Ogden material (MHGO) model [4, 5] was adopted to characterize the mechanical response of the ascending aorta, aortic root sinuses, BAV leaflets, MV leaflets, TAV leaflets and myocardium. Local coordinate systems were defined for each cardiac tissue to include local fiber orientation. The MHGO material model was implemented into Abaqus 6.17/Explicit (Dassault Systèmes Simulia Corp., Providence, RI, USA) with a user sub-routine VUMAT. Additionally, the isotropic hyperelastic Ogden material model [6] was used to characterize the mechanical response of the mitral chordae and intervalvular fibrosa. In-house multiprotocol biaxial and uniaxial testing data of healthy human cardiac tissues were used to obtain the material properties selected from an existing human cardiac tissue database established in our lab (age- and gender-matched patient).

Bovine pericardium properties of TAV leaflets were obtained from our recent studies that characterized the mechanical properties of chemically-treated bovine and porcine pericardium [7, 8]. Further details on the determination of material parameters have been described in previous publications [9][10]. Calcification was assumed to be a linear-elastic material with a Young’s modulus of 12.6 MPa and a Poisson ratio of 0.3 [11]. The stent was modeled as an elastic-plastic material with the properties of 316 stainless steel with a Young’s modulus of 193 GPa, a Poisson ratio of 0.3, and initial yield stress of 340 MPa [12]. SPH particles were given Newtonian blood properties with a density of $ρ=1056 kg/m^{3}$ and a dynamic viscosity of $μ=0.0035 Pa∙s$.

**Supplemental Table 1.** Cardiac tissues material parameters

|  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- |
| **MHGO model** | $C\_{10} $($kPa$) | $$C\_{01}$$ | $k\_{1}$ ($kPa$) | $$k\_{2}$$ | $$θ (°)$$ | $$κ$$ | $$D (kPa^{-1})$$ |
| BAV leaflets | 0.017 | 147.262 | 39704.1 | 2352.96 | 0 | 0.317 | 5.0e-4 |
| AML | 0.285 | 61.303 | 9.295 | 99.684 | 0 | 0.333 | 5.0e-4 |
| PML | 0.101 | 33.191 | 10.756 | 48.495 | 27.98 | 0.089 | 5.0e-4 |
| Sinuses | 1.755 | 13.707 | 10.550 | 80.379 | 20.06 | 0 | 5.0e-4 |
| Aorta | 4.175 | 3.464 | 3.771 | 15.927 | 70.95 | 0.086 | 5.0e-4 |
| Myocardium | 0.0374 | 15.387 | 6.079 | 98.366 | 6.78 | 0.144 | 5.0e-4 |
| TAV leaflets | 6.358 | 16.734 | 13.415 | 96.850 | 0 | 0 | 5.0e-4 |
| **Ogden model** | $μ\_{1} $($MPa$) | $$a\_{1}$$ | $μ\_{2} $($MPa$) | $$a\_{2}$$ | $μ\_{3} $($MPa$) | $$a\_{3}$$ |  |
| Anterior marginal | 17.824 | 17.808 | 17.660 | 17.797 | 17.592 | 17.768 |  |
| Anterior strut | 24.342 | 11.338 | 10.332 | 11.167 | 14.914 | 11.188 |  |
| Anterior/posterior basal | 10.256 | 16.579 | 10.654 | 16.554 | 10.671 | 16.554 |  |
| Posterior marginal | 12.995 | 15.651 | 13.083 | 15.683 | 12.870 | 15.662 |  |
| Intervalvular fibrosa | 1.505 | 21.400 | 11.207 | 21.400 | 1.441 | 21.400 |  |

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