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IMAGING VIGNETTE

CT Image-Based Engineering Analysis of Transcatheter Aortic Valve Replacement

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DESPITE THE INCREASED GLOBAL EXPERIENCE WITH TRANSCATHETER AORTIC VALVE REPLACEMENT (TAVR), there remain 3 major adverse events. Aortic rupture (Fig. 1), coronary artery obstruction (Fig. 2), and paravalvular leakage (PVL) (Fig. 3) may occur with valve implantation. Oversizing or excessive radial expansion force with the TAVR stent may cause aortic rupture, whereas insufficient dilation may lead to PVL and device migration. During TAVR implantation, native leaflet material may produce occlusion of the coronary ostia. A reliable prediction of the biomechanical interaction between native tissue and device in TAVR is crucial for the success of this procedure.

In this study, an image-based engineering analysis (Fig. 4) and prediction of transcatheter aortic valve deployment was performed using computational models reconstructed from multislice computed tomography images obtained from patients undergoing pre-TAVR evaluation. Four patients with tricuspid aortic valve stenosis subsequently received 23-mm transcatheter aortic valves (Sapien, Edwards Lifesciences Corporation, Irvine, California) (Table 1). Finite element models of the patients included aortic root, aortic leaflets, calcification, mitral-aortic intervalvular fibrosa, anterior mitral leaflet, fibrous trigones, and left ventricle. Simulations of the balloon deployment of the Sapien valve were utilized to evaluate the potential for the aforementioned complications (Online Video 1). The models presented in this paper assumed an optimal height and angulation of the stent, which is not necessarily true in all cases and is dependent, among others, on the angle between the ventricle and the aorta.

The method presented herein could be utilized as a pre-procedural planning tool to virtually predict device performance for TAVR and improve clinical outcomes.

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Table 1. Summary of the 4 Transcatheter Aortic Valve Replacement Cases Examined in the Current Study

	Age, yrs	Sex	Annulus Size From Perimeter Measurement (mm)	Results
Case 1	94	Female	19.6	Aortic root rupture
Case 2	72	Female	22.9	Normal implant
Case 3	89	Female	23.9	Paravalvular leak
Case 4	65	Female	23.7	Coronary occlusion

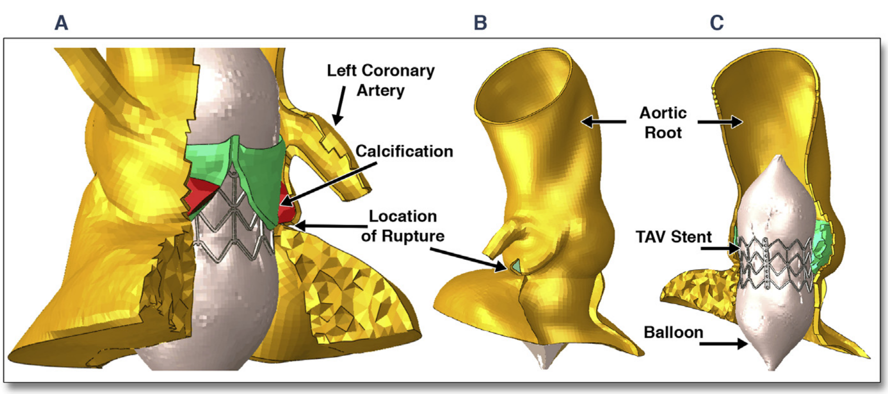

Figure 1. Aortic Annulus Rupture

During the transcatheter aortic valve replacement (TAVR) procedure in Case 1, tearing and rupture occurred below the left main coronary artery. Simulation: local **(A)** and full **(B)** views of the deformed aortic root and balloon deployment **(C)** show annulus tearing under the left coronary ostium due to dislodgement of calcification into vulnerable part of the aortic sinus. (For illustration purposes, the **yellow** geometry in our finite element models represented the aortic root, the **green** geometry represented native aortic leaflets, the **red** geometry represented calcification, and the **grey** geometry represented the TAV stent.)

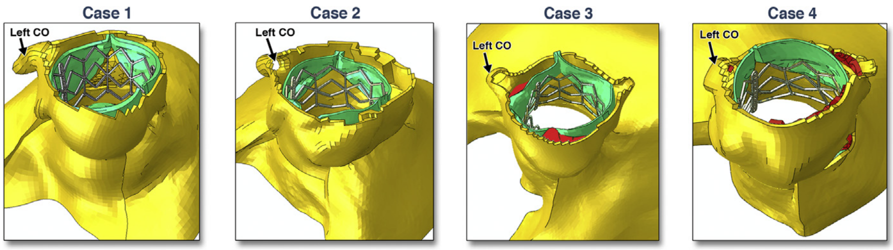

Figure 2. Coronary Occlusion

Side views of the deformed aortic root after the maximal stent deployment were used to evaluate the potential coronary artery occlusion. Case 2 shows successful transcatheter aortic valve replacement (TAVR) in the aortic valve position. Case 4 demonstrates coronary occlusion with TAVR. CO = coronary ostia.

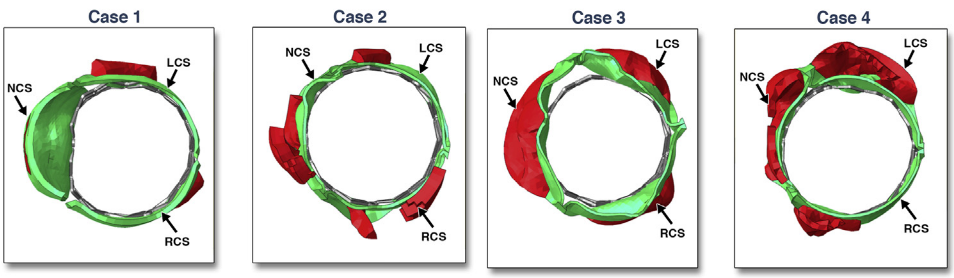

Figure 3. Paravalvular Leak

Short-axis views of the transcatheter aortic valve (TAV) stent inside deformed native leaflets were utilized to assess the possible paravalvular leak (PVL). Case 3 demonstrates PVL following TAV replacement. The implant site of the first TAV was suboptimal, as the native leaflet insertion point was adjacent to the lower edge of the stent. A large PVL was present after the deployment of the first TAV. Subsequently, a second TAV was deployed inside of the first one to correct the defect due to suboptimal valve positioning. The valve positioning of the first TAV was replicated in the finite element model simulation, demonstrating a large PVL that was noted clinically. LCS = left coronary sinus; NCS = noncoronary sinus; RCS = right coronary sinus.

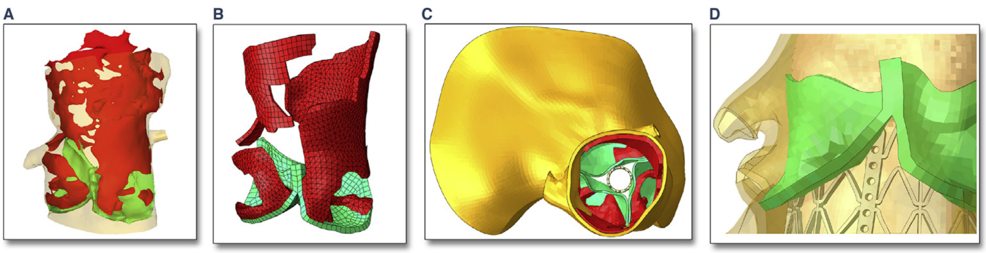

Figure 4. Sequences in the Development of the Aortic Root Model of Case 4

(A) initial image segmentation; **(B)** reconstructed models of aortic leaflets and calcification; **(C)** top view of the whole aortic root model; and **(D)** side view showing left main ostial occlusion (without showing the calcification). Pre-procedure simulation analysis (Online Video 1) suggested the possibility of left main ostial occlusion and the potential for aortic annulus rupture. Repeat echocardiographic and angiographic evaluation was performed, also suggesting a potential risk for coronary artery occlusion and annulus rupture. The transcatheter aortic valve replacement procedure was canceled in this patient.

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APPENDIX

For a supplemental video and legend, please see the online version of this article.