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 Life-sciences 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

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

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