Image-based Estimation of Strains after Aortic Valve Stent Implantation

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ABSTRACT

Background Transcatheter Aortic Valve Implantation (TAVI) is a safe and efficient alternative to conventional treatment of high-risk patients with severe aortic stenosis [1]. A stented xenograft valve is implanted inside the native aortic valve, pushing the leaflets and calcifications on the leaflet against the vascular wall. A tight fit between the stent and the surrounding tissues is required to prevent paravalvular aortic insufficiency (AI) after TAVI. Exceeding forces on the aortic annuls can lead to ruptures or impede conduction of activation potentials through the atrioventricular node, resulting in arrhythmia. The mechanical situation of the stent after TAVI (e.g.[2]) as well as the biomechanics of the aortic wall [3] and valvar leaflets [4] are understood in principle. Yet, no clinical data exists about the amount of force which is required to avoid AI or conduction abnormalities. Our work aims at developing a method for evaluating the mechanical situation in patients after TAVI based on medical imaging.

Methods A FEM model of the Medtronic CoreValve Revalving System was created (see Figure 2, lower row) from microCT images which were acquired in an unloaded state. Postoperative cardiac CT images were acquired in clinical routine from 29 TAVI patients after transfemoral CoreValve implantation. Figure 1 illustrates the method for estimating the circumferential strain at the stent-tissue interface from these images: An automatic image preprocessing algorithm extracts the volume of interest that contains the implanted stent from the whole CT volume and suppresses high-intensity voxels which do not belong to the stent, e.g. calcium (steps 1-3). Non-maximum suppression is applied to detect local maxima in the image as candidate voxels for the detection of the 165 grid points of the stent (step 4). A heuristic selection step is employed to distinguish between candidates that represent true grid points of the stent and candidates added by noise or artifacts (step 5). Cubic spline interpolation is applied to construct a FEM model of the deformed stent (step 6). A rigid transformation is applied to register the extracted model with the model representing the unloaded state (step 7) and to extract kinematic boundary conditions (step 8). The standard solver of ABAQUS is used to calculate the strains in the stent in accordance to the deformation (step 9). The simulations
yield local strain measures that remain within the linear elastic regime of the generally superelastic properties of Nitinol. Therefore it is sufficient to implement an isotropic Hookean material.

**Conclusion**  We propose a novel approach to use deformable, implanted structures as a means to evaluate forces (or strains) within the human body. On the example of TAVI, the presented implementation covers the complete process chain, from a clinical routine image to a model of local strains. The proposed method makes forces and strains in the human body measureable in a non-invasive way. This will allow clinical studies on the influence of different biomechanical parameters on TAVI outcomes on a quantitative level.

![Figure 1: Flow chart of the analysis method.](image-url)

**References**