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MATERIAL BOUNDARY MODELING OF SOFT TISSUE COMPOSITIONS FOR SIMULATION OF TRANSCATHETER AORTIC VALVE IMPLANTATION

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Background. Transcatheter aortic valve implantation (TAVI) is a minimally invasive procedure to replace aortic leaflets in cases of severe aortic stenosis and regurgitation, which can be the result of valve calcification. This state-of-the-art treatment inserts a stent carrying porcine leaflets through a catheter into the vascular system. During the intervention fluoroscopy is used to position the prosthesis along a guidewire. The stent is expanded inside the aortic root to improve cardiac output and valve efficiency.

Motivation. Patient-specific procedure planning currently involves acquisition of CT scan data to determine anatomic measurements within the area of interest to select a correctly sized stent model. Tissue elasticity and projected deformation of leaflets is estimated based on the physician's experience. The dynamic conditions during a heart-cycle and limited information about the local anatomy during stent implantation may require more sophisticated tools during the planning phase, which can preview procedure outcome and potential problems.

Methods. A multi-material finite element (FE) model of the aortic root [1], involving modeling of ventricle, leaflets, calcification and aortic tissue was therefore developed inside a framework, which allows TAVI simulation based on solid mechanics. A remaining challenge in FE analysis of the complex composition of these organic materials is the definition of soft material boundaries, where material properties change continuously between largely fibrous sections (e.g. annulus, leaflets) and connected materials (e.g. ventricle, calcification). We therefore compare three major approaches to connect such material boundaries for volumetric and shell-based FE models:

1. Fixed material boundary (conventional approach using a single material border).
2. Interpolated layers (interpolated material properties in several parallel layers).
3. Element-based assignment (individual material assignment for each finite element).

Experiments. Experiments were conducted on generic phantom models as well as six patient-specific datasets, for which pre- and postoperative CT data was available. Element resolution of approximately 40,000 shell elements or 200,000 volumetric elements was selected based on model convergence analysis, which is in coherence with other aortic models [2, 3]. The experimental setup simulates changes in blood-pressure, balloon-expansion and stent expansion as described in [1].

Results and Conclusion. Our results indicate a reduction in artifacts at material boundaries, which were introduced as a result of hard changes in material properties between elements. Approach (2) specifically allows smooth transitions when using compatible material parameters, while (3) facilitates an interpolation scheme for material models with incompatible parameters. Implementing smooth material transitions can effectively improve the accuracy of FE simulation when modeling soft-tissue material transitions, which is of interest for a variety of medical applications, such as TAVI.

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