Fluid–Structure Simulation of a Transcatheter Aortic Valve Implantation: Potential Application to Patient-Specific Cases

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Abstract Valve diseases are more and more treated with transcatheter aortic valves. This work is based on an experimental setup with the corresponding fluid–structure interaction model to show the feasibility of performing accurate simulations which is able to capture the main behavior of a transcatheter valve both from structural and fluid dynamic points of view. The application of this methodology to patient-specific cases is also illustrated.

Introduction

Transcatheter aortic valve (TAV) (Tchetche et al. 2014; van Gils et al. 2014) implantation is a mini-invasive procedure adopted in the treatment of valve diseases. The behavior of a TAV is influenced by the mechanics of the aortic root, the leaflets, the stent frame, and the fluid passing through the site where the valve is implanted. This work presents a fluid–structure interaction (FSI) model for the evaluation of Nitinol TAVs.

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Materials and Methods

A TAV (Figs. 1, and 2), after it was used in an in vitro mock loop (Fig. 3), was virtually implanted in a reconstruct aortic root simulating in vivo conditions (Fig. 4). The Nitinol TAVs are equipped with polyurethane leaflets and the model was built according to their dimensions. All material properties of the valve were acquired through experimental tests. As boundary conditions, the typical ventricular and aortic pressure curves were applied to the inlet and outlet sections, respectively (Fig. 5). The leaflets and compartment were coupled to the domain during the simulation. The commercial explicit finite element solver LS-DYNA was used to run the FSI simulation.

Results

The comparison between in vitro mock loop valve kinematics and the FSI corresponding results were in good agreement (Fig. 6). The mean strain and strain amplitude of the valve predicted by FSI simulation considering the aortic root (Fig. 7), if compared to a case where the valve is implanted in a silicon cylindrical compartment for accelerated fatigue tests, showed higher strains potentially dangerous for the fatigue behavior.

Fig. 1 Nitinol TAV (*right*) and corresponding finite element model (*left*)

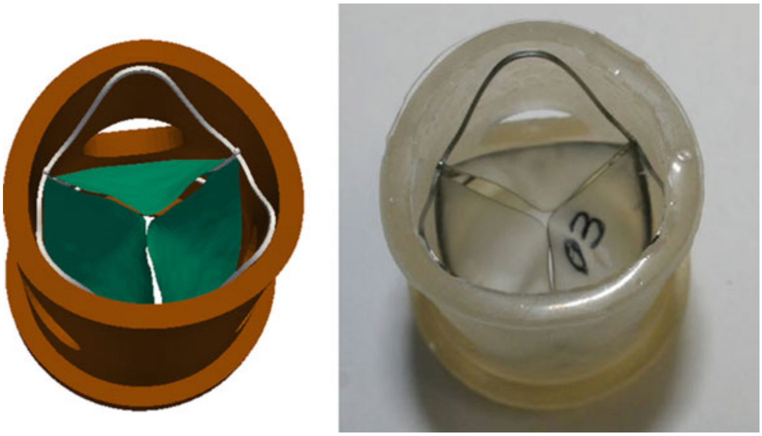

Fig. 2 TAV inserted in a silicon compartment (*right*) and corresponding finite element model (*left*)

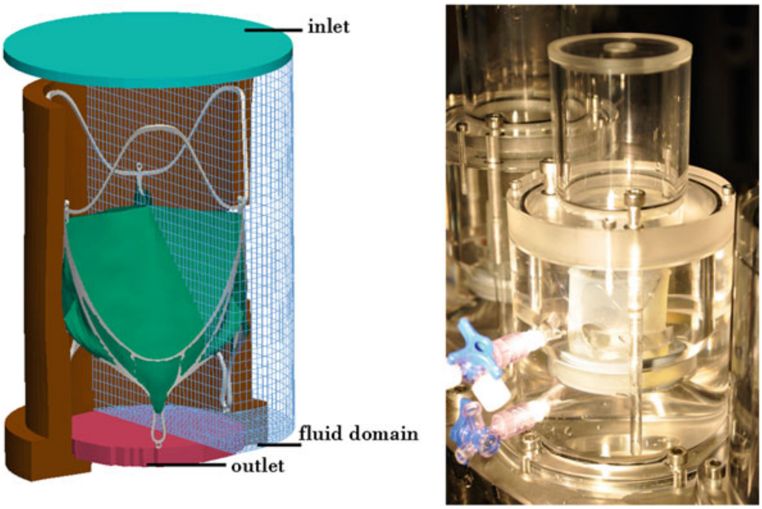

Fig. 3 In vitro mock loop (*right*) and corresponding fluid–structure interaction model (*left*)

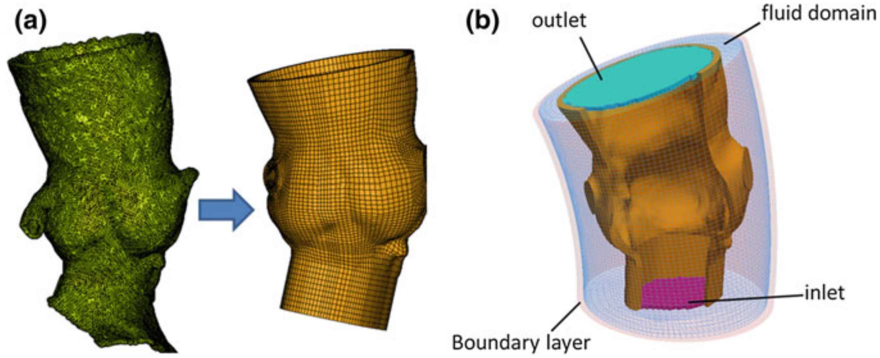

Fig. 4 **a** 3D aortic root anatomy of stereo lithography (STL) format was transformed to hexahedral solid elements. **b** Fluid–structure interaction model for the in vivo case

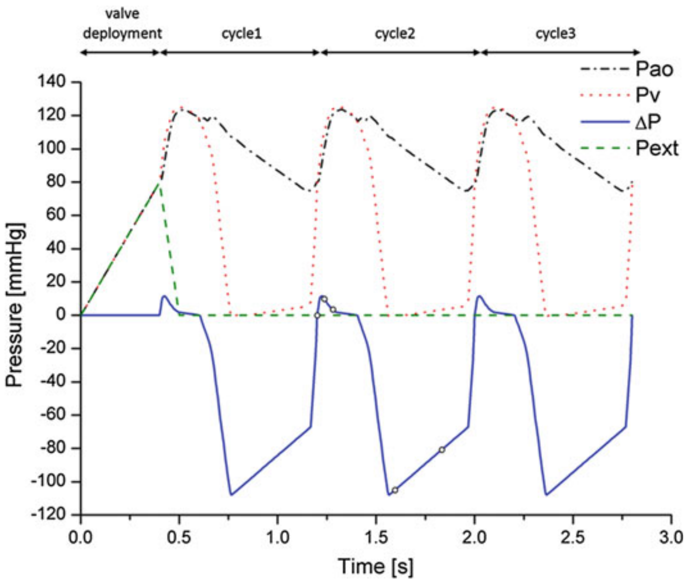

Fig. 5 Aortic (ao), ventricular (v), and extramural (ext) pressure tracings used in the patient-specific FSI simulation. The transvalvular gradient (ΔP) is also reported

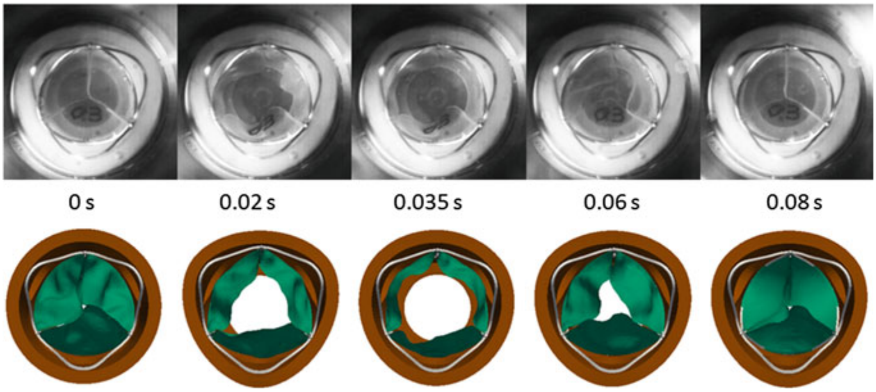

Fig. 6 Top views of the valve kinematics at five time instants for the simulation in vitro test (*top*) and the FSI (*bottom*)

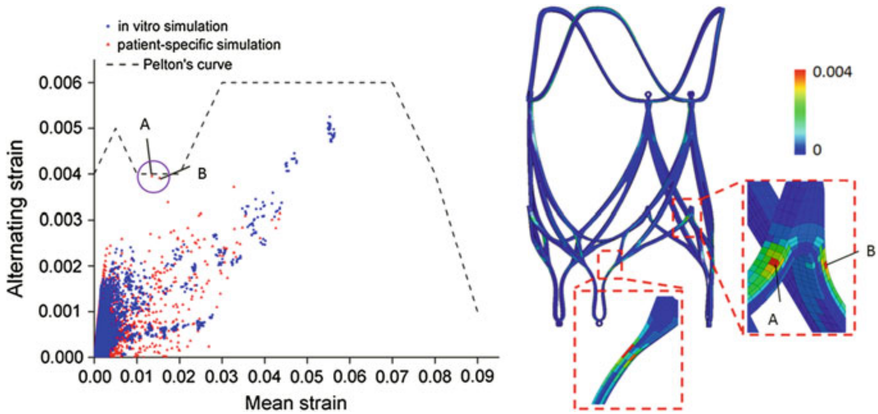

Fig. 7 The *insets* show the locations with the highest alternate strains. The *circle* indicates that there are two elements with alternate strain near the fatigue limit

Discussion

This study shows the feasibility of performing accurate simulations able to capture the main behavior of a TAV both from structural and fluid dynamic points of views. The application of this methodology to patient-specific cases enhances the capability to perform a correct surgical planning.

References

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