MODELLING TRANSCATHETER MITRAL VALVE REPLACEMENT USING THE LIVING HEART PROJECT

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Introduction

Transcatheter mitral valve replacement (TMVR) is an emerging alternative treatment for those patients not qualified for surgery. However, TMVR can determine an obstruction of the left ventricular outflow tract (namely, neo-LVOT) induced by the transcatheter heart valve (THV) displacing the native mitral valve leaflet towards the myocardial wall. This condition can lead to hemodynamic impairment and ultimately patient death.

Methods

The simulation study of TMVR in the failed annuloplasty band ring consisted of the following steps: 1.adapting the original living heart human model (LHHM) to account for a failed mitral valve by inhibiting the active contraction of the myocardial wall near the posterior papillary muscle; 2.modeling the suturing of the annuloplasty band ring into the mitral annulus using wire connections and contact conditions; 3.Simulating the deployment of the S3 Ultra device by virtually inflating the balloon and then modeling the heartbeat of repaired mitral valve apparatus; 4.computational flow analysis of the left heart hemodynamics to quantify the sub-aortic flow and pressure gradient near the LVOT obstruction.

The LHHM developed by SIMULIA is an advanced cardiac tool in which the geometry is a realistic and accurate representation of an adult male anatomy [1]. The LHHM includes all ventricular and atrial chambers, heart valves and major vessels (i.e., the aorta, pulmonary artery and vena cava) and the biomechanical response is governed by an electrical potential activating the contraction of myocardial wall. The coupling with a 1-D lumped parameter model allows one to consider the interaction between the circulating blood and the deforming myocardium and thus obtain the pressure-volume loop. Anatomical parts are meshed with tetrahedral elements and linear truss elements (only for chordae tendineae) for a total of 443,564 mechanical degrees of freedom.

RESULTS AND DISCUSSION

A realistic and high-fidelity computational tool of cardiac biomechanics was used to virtually simulate the transcatheter mitral valve-in-ring replacement and then investigate the hemodynamic and structural mechanics of LVOT obstruction (Fig.1). The most striking finding is the assessment of the dynamic behavior of the neo-LVOT area over the cardiac cycle, suggesting that the risk stratification of patients undergoing TMVR should not only be based on pre-TMVR imaging criteria at end-systole. This finding improves our understanding of the impact that LVOT obstruction has on THV performance and offers a computational approach to better assess the anatomic suitability of patients undergoing TMVR. Ultimately, this knowledge has the potential to enhance procedural planning to yield better clinical outcomes and to inform the way we design the next-generation of transcatheter heart valves.

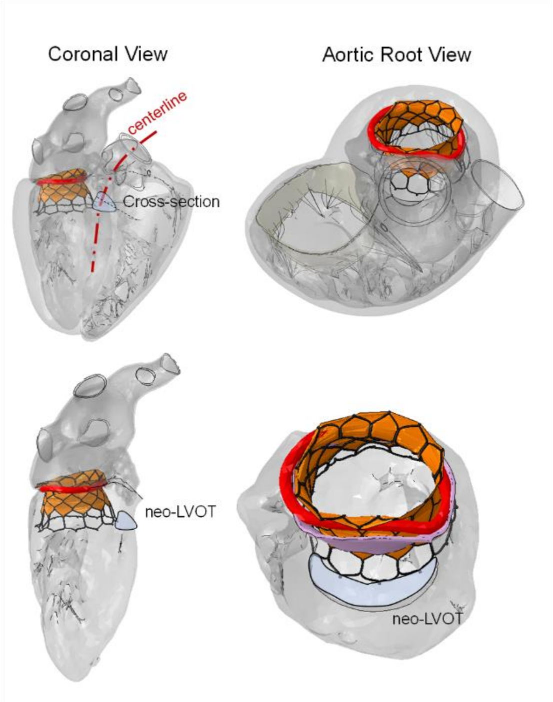

Figure 1: LVOT obstruction and estimation of neo-LVOT area using the LLHM.

References

1. Gao, H., et al., Parameter estimation in a Holzapfel–Ogden law for healthy myocardium. Journal of engineering mathematics, 2015. 95(1): p. 231-248.

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