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Comparison of Aortic Flow Patterns in Patients with and without Aortic Valve Disease: Hemodynamic Simulation Based on PC-MRI and CTA Data

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Abstract: Recent studies have revealed that aortic valve diseases are associated with the increased incidence of the aortopathy development. However, the influence of aortic valve diseases on aortic hemodynamics remains unclear. The purpose of this study was therefore to investigate the hemodynamic differences in patients with and without aortic valve disease through patient-specific simulations performed on two aorta models (BAV with severe stenosis *vs.* normal tricuspid aortic valve (TAV)). Realistic geometries and boundary conditions were obtained from computed tomography angiography (CTA) and phase-contrast magnetic resonance imaging (PC-MRI) measurements, respectively. In addition, 4D-MRI were performed to validate the numerical methods used to simulate transient flow characteristics. Obtained results shown that the 3D streamlines in the patient with normal TAV were relatively symmetric and evenly distributed. For the patient with BAV, concentrated and high-speed inflow jets were found to impinge on the ascending aorta accompanied by strong vortices. These results indicate that the aortic valve phenotype plays a crucial role in featuring the disturbed flows primarily in ascending aorta, which may relate to the development of aortic diseases.

Keywords: Ascending aorta, computed tomography angiography, phase contrast magnetic resonance imaging, four-dimensional magnetic resonance imaging, computational fluid dynamics.

1 Introduction

Bicuspid aortic valve (BAV) is the most common congenital cardiac malformation affecting 1-2% of population and highly associated with congenital abnormalities of the aorta and the proximal coronary vasculature [Fedak, Verma, David et al. (2002)]. Compared with a normal tricuspid aortic valve (TAV) with three semilunar leaflets, BAVs are composed of two uneven leaflets, normally with fused commissure in the large leaflet. In this study, hemodynamic simulations were performed on two aorta models to

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quantitatively evaluate to what extent the aortic valve diseases (herein BAV with severe stenosis *vs.* normal TAV) would affect the aortic hemodynamics. Patient-specific geometries and boundary conditions were obtained from computed tomography angiography (CTA) and magnetic resonance imaging (PC-MRI), respectively.

2 Methods

CTA and MRI images were acquired from one patient with BAV and another one with normal TAV upon ethical approval. Blood flow was assumed to be an incompressible Newtonian fluid governed by the unsteady three-dimensional Navier-Stokes equations. The density and dynamic viscosity of blood were set to 1025 kg/m^3 and 0.0035 Pa·s, respectively. In addition, aortic walls were assumed to be rigid where the non-slip boundary conditions were imposed. All simulations were herein conducted with commercial software ANSYS CFX 16 (ANSYS, Inc.).

3 Results and discussion

Model-simulated flow patterns for all two models agree qualitatively with those derived from 4D-MRI data. The patient with normal TAV showed laminar flow patterns with no eccentric blood flow. For the patient with BAV, a large scale helical flow structure forms in the ascending aorta and moves through the arch. The rotation is clockwise when viewed in the direction of forward movement, similar to in vivo measurements.

4 Conclusion

Our results demonstrate that CFD models, given patient-specific prescription of boundary conditions based on PC-MRI data, can reasonably reproduce the major flow characteristics in the aorta as measured *in vivo* by 4D-MRI. Moreover, pronounced differences in ascending aorta hemodynamics were observed between bicuspid aortic valve and normal tricuspid aortic valve patients.

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References

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