ASSESSMENT OF THE COMBINED EFFECTS OF VALVE PHENOTYPE AND ANEURYSM PROGRESSION ON ATAA HEMODYNAMICS

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Introduction

The presence of a bicuspid aortic valve (BAV), with consequent eccentricity of aortic inlet flow, gives rise to altered aortic hemodynamics. This seems to play a role in the highest prevalence of ascending thoracic aortic aneurysm (aTAA) in BAV patients, compared to subjects with tricuspid aortic valve (TAV) [1]. Characteristics of aortic hemodynamics in presence of eccentric inlet flow in both healthy and aneurysmatic aorta have been widely addressed, while perspective studies that investigate the evolution of hemodynamic patterns concurrently with aTAA progression are still limited. Therefore, the main goal of this study is to assess the role of both TAV and eccentric BAV inflow on hemodynamic results at different stages of aTAA.

Methods

Three geometries representing baseline healthy aorta (A_{00}), intermediate aneurysm growth (A_{05}), and fully developed aneurysm (A_{10}), in a virtual patient from [2], are considered (Figure 1a). Transient computational fluid dynamics simulations are performed using Ansys Fluent (Ansys Inc.). The fluid domain is discretized with approximately 7e5 polyhedral elements. Blood is modeled as incompressible and Newtonian, with ρ = 1060 kg/m^3 and μ = 0.00345 Pa·s. The k-ω SST model is employed to account for turbulence. A 3-elements Windkessel model is applied at each outlet to obtain a physiological pressure range of 120-80 mmHg [2,3]. A time-space-varying inlet velocity boundary model is implemented to reproduce TAV / BAV aortic inlet condition, resembling physiological data from [4]. A parametrized elliptic area is identified on the aortic valve plane, representing the valve orifice. A paraboloid velocity profile is imposed inside the ellipse, while everywhere else velocity is set equal to zero. An idealized inlet flow rate waveform is defined over a cardiac cycle and the maximum velocity for the elliptic paraboloid at each time step is assigned to achieve the correspondent instantaneous value of flow rate. Two different cases for the inlet conditions are considered: TAV (Figure 1b) and BAV (Figure 1c). Either TAV or BAV inlet conditions are applied at each stage of aneurysm growth to evaluate hemodynamic evolution.

Results and Discussion

In case of BAV phenotype, the inlet flow is concentrated in a small area of the aortic orifice and the maximum inlet velocity is higher.

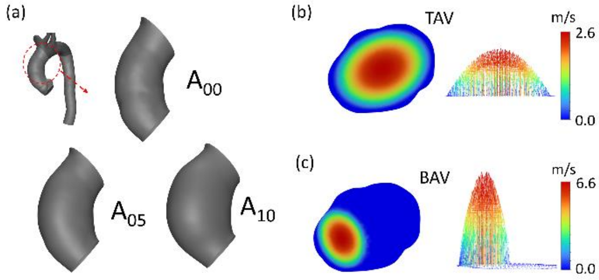

Figure 1: Aorta segmentation with baseline, intermediate, and fully developed ATAA stages (a); TAV (b) and BAV (c) inlet velocity profiles at peak systole.

This causes the presence of a jet flow that impinges on the aortic wall in correspondence with an area of high wall shear stress (WSS), which is not present in TAV cases where the flow is more spread (Figure 2). At all stages of aneurysm growth, the time-averaged WSS in the ascending aorta are 2.5 times higher in presence of eccentric inflow, in agreement with previous findings [1]. The effects of aTAA bulge formation on hemodynamics results are minor, with variations of 5-7% between different stages for both BAV and TAV. These preliminary results highlight the necessity to account for the eccentric inlet flow when modeling aTAA hemodynamics.

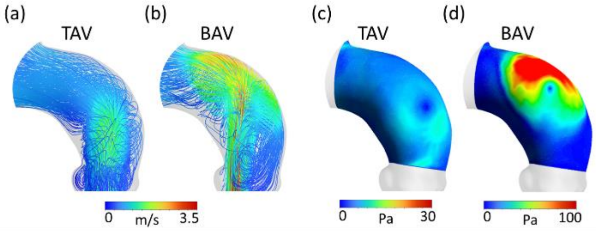

Figure 2: Velocity streamlines (a-b) and WSS (c-d) at peak systole in the ATAA for the TAV (a,c) and BAV (b,d) cases at A_{05} aneurysm growth.

References

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