

Healthy and BAV-affected aortic root dynamics: Fluid-Structure Interaction simulations from MRI-based 3D models

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Introduction

Background. Bicuspid aortic valve (BAV) is the most common congenital cardiac abnormality (1-2% of EU population), and originates from the fusion of two of the three aortic valve (AV) leaflets. Even when normally functioning at echocardiography, BAV alters aortic root hemodynamics and stresses. In advanced pathological scenarios, BAV is often associated with aortic dilatation, rupture, and dissection.

Aim of the study. FSI models were developed to detect and quantify the biomechanical alterations induced by normally functioning BAV, i.e. valvular dynamics alterations and abnormal stresses and strains, to elucidate the processes underlying the advancement of the pathological condition.

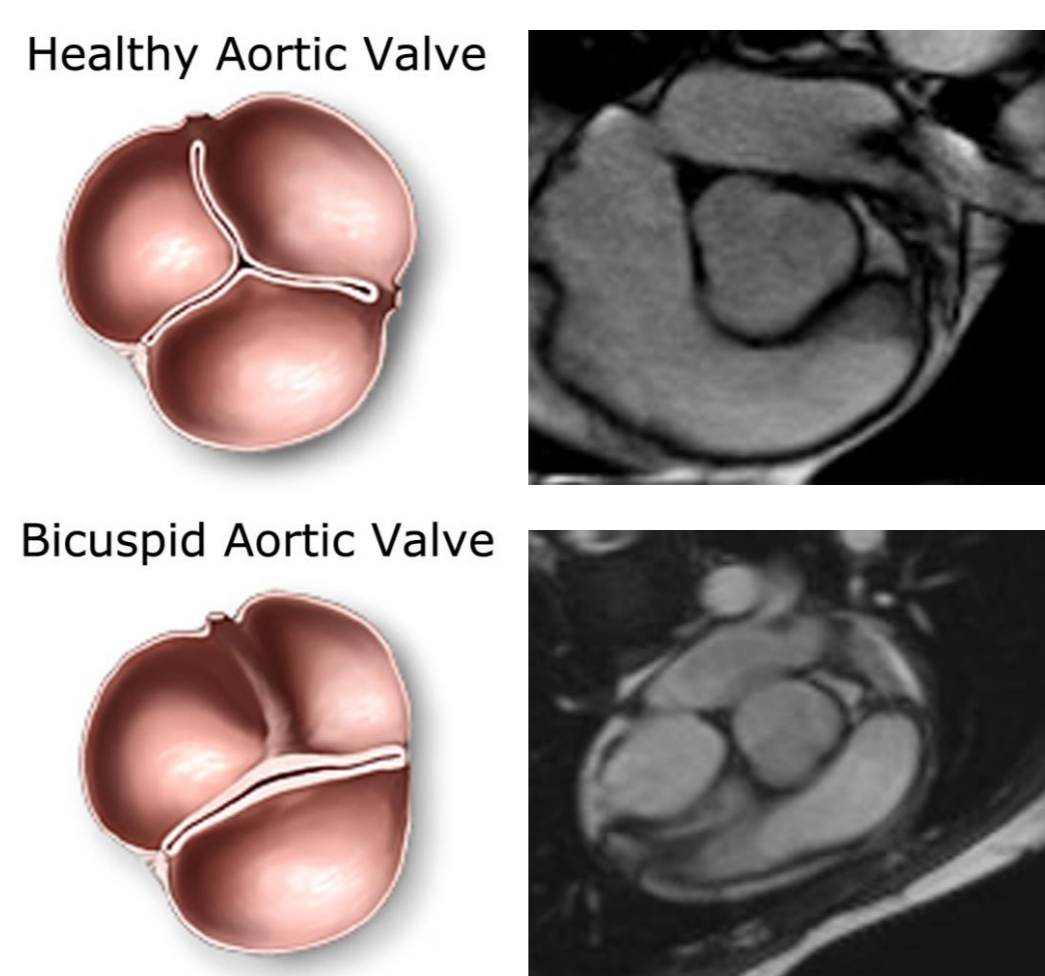


Figure 1. Sketches and MRI of a healthy AV and a BAV.

Materials and Methods

Healthy and BAV-affected aortic root biomechanics was simulated throughout the cardiac cycle using LS-DYNA[®] 971 (LSTC, Livermore, USA). Magnetic resonance imaging (MRI) was performed on 10 healthy subjects and 8 patients with normally-functioning BAV (Fig. 1). Multiple long-axis and short-axis cut-planes were acquired for the aortic root; geometrical parameters describing their shape and dimensions (Fig. 2a) were measured by an expert radiologist.

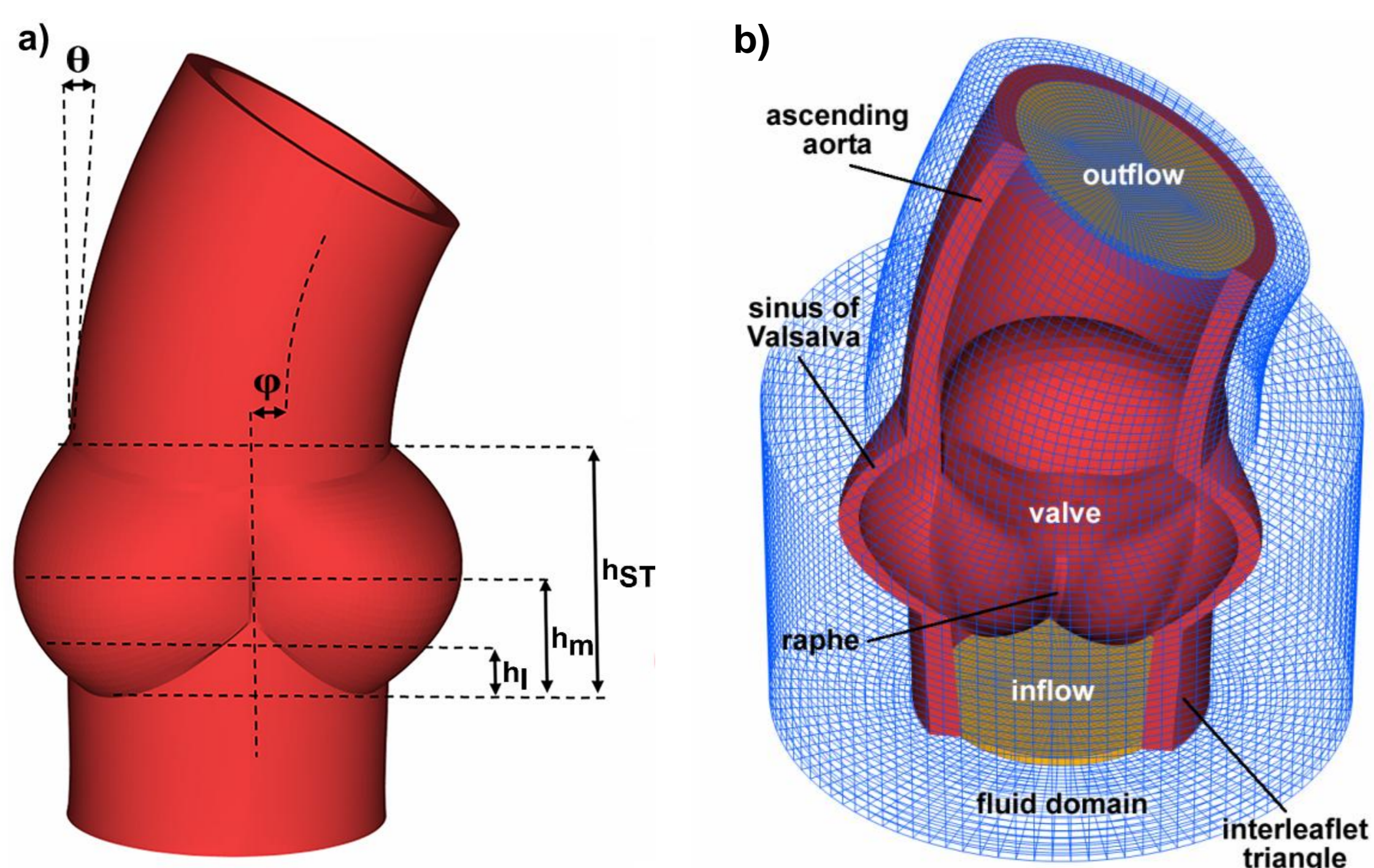


Figure 2. a) MRI-derived geometrical parameters of the aortic root models. b) Schematic representation of the FSI BAV model.

Average values from healthy and BAV-affected subjects were used to define the corresponding 3-D geometrical models (Fig. 2b). The same mechanical properties and boundary conditions were assumed for both models. AV leaflet mechanical response was modelled via a non-linear, transversely isotropic and incompressible hyperelastic model (Billiar and Sacks, 2000). Aortic wall response was modeled as linear, elastic and isotropic, and blood was assumed as a Newtonian and nearly incompressible fluid. Time-dependent blood pressures were applied at the inlet and at the outlet of the fluid domain.

Results and Discussion

Results BAV induced several mechanical abnormalities. In diastole, the valve was competent, but a minor prolapse of the fused leaflet was observed; AV peak stresses increased by 10% in the non-fused leaflet, but in the fused one they were 5 times higher (Fig. 3). In systole, the valvular orifice was elliptic, 50% smaller, and tilted. As a result, blood velocity was 28% higher and blood flow was skewed towards the outer wall of the aorta (Fig. 4), consistently with clinical findings (Hope et al., 2011).

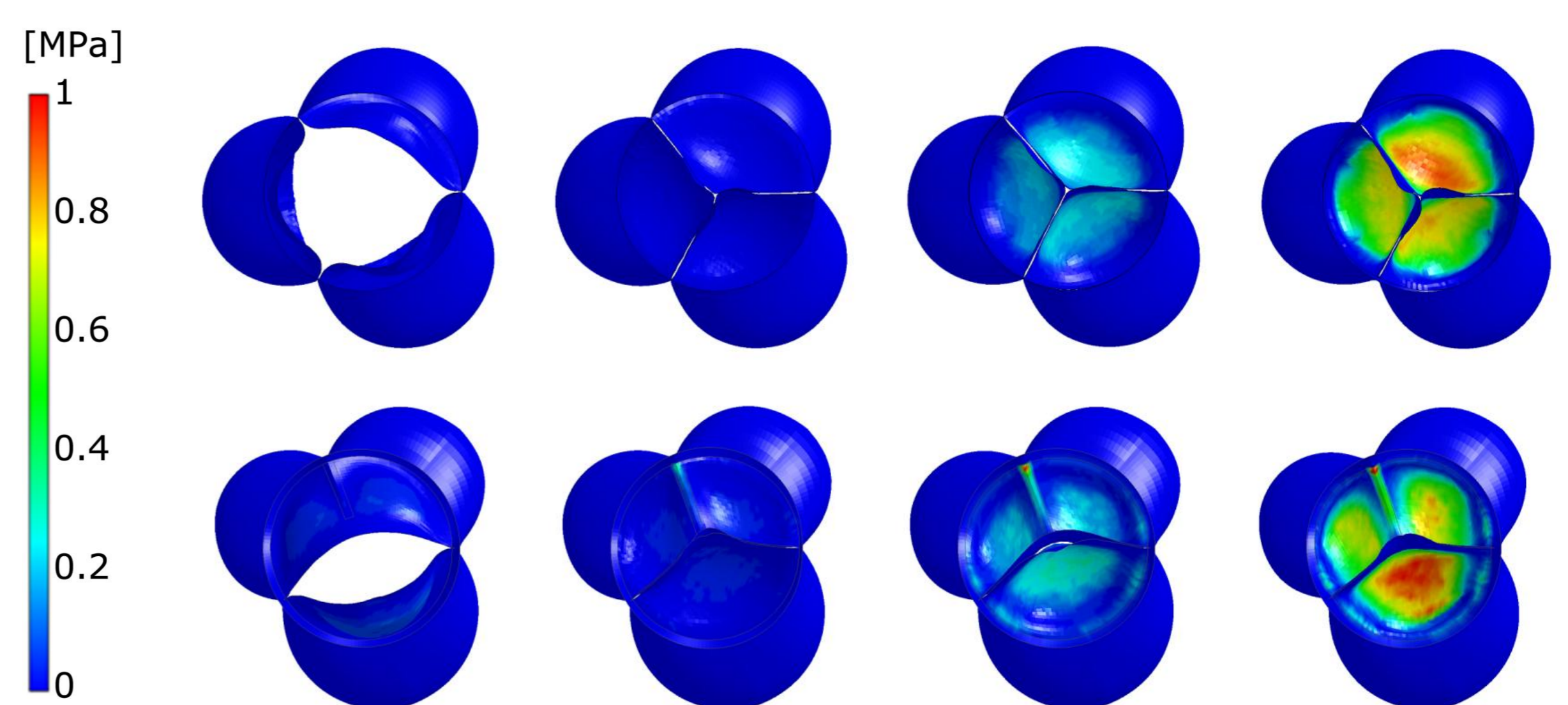


Figure 3. Healthy (top) and BAV (bottom) valvular configuration and maximum principal stress distribution from systole (left) to peak diastolic pressure (right).

Discussion This study allowed to assess how aortic root geometric changes due to BAV may lead to increased stresses on the leaflets. Such increased stresses may contribute to tissue remodelling and promote the premature leaflet degeneration.

Moreover, BAV fluid dynamics was altered by the presence of an eccentric fluid jet which insists on the portion of aortic wall (Fig. 5) where cellular degeneration and aneurysm formation were most frequently observed (Della Corte et al., 2010).

Future studies will focus on patient-specific MRI-based models to quantify the influence of different patterns of BAV-related geometrical alterations on

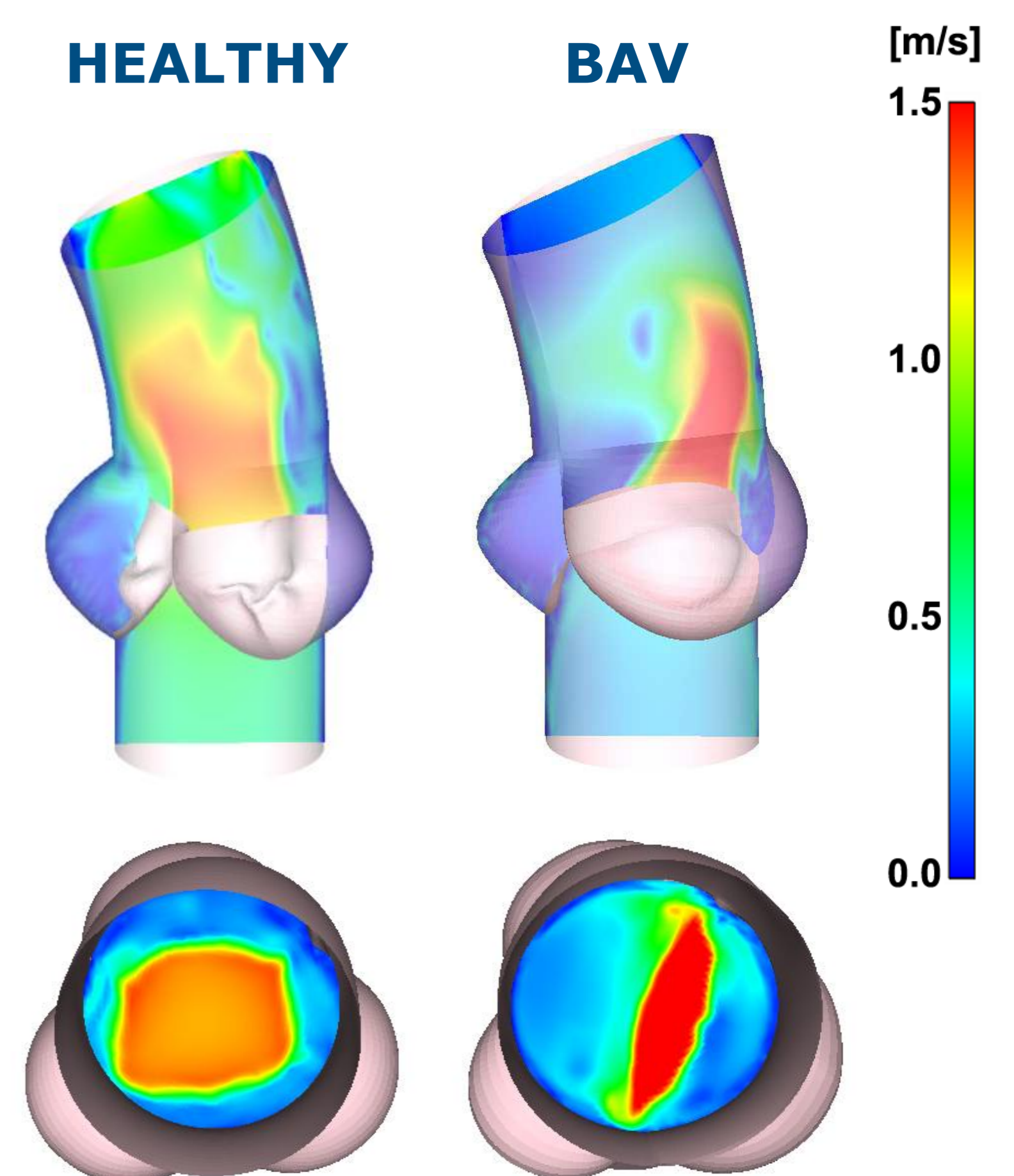


Figure 4. Blood velocity magnitude along the aorta and at the valve orifice in healthy (left) and BAV-affected (right) aortic models.

Acknowledgements

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