Refining Aortic Valve Stenosis Classification: A Computational Fluid Dynamics Project

CFD Insights services

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Objective

The current project focuses on enhancing the classification of aortic valve stenosis in patients through the development of a computational fluid dynamics (CFD) model. This methodology entails constructing a CFD model using patient-specific computed tomography (CT) data to replicate flow dynamics across the aortic valve during systole. Additionally, an automated process for constructing aortic valves is introduced to assess how stenosis and leaflet characteristics impact flow patterns.

Through this model, various scenarios are examined to assess their effects on critical parameters like maximum velocity and pressure drop, crucial for subject classification. Aortic valve stenosis is a significant contributor to cardiovascular diseases, highlighting the importance of accurate classification methods.

Methodology

The study began by acquiring echocardiography and computed tomography data from a patient. From the computed tomography data, five time points were examined, focusing on the moments of maximum diastole and systole. After careful selection, the three-dimensional geometry of the left ventricle, aortic arch, and ascending aorta was constructed based on these time points.

Subsequently, the geometry mesh underwent processing to ensure smoothness and avoid convergence issues during simulations. Special attention was given to the aortic valve geometry, with the closed configuration observed during maximum diastole being used as the basis. Additional adjustments were made to accurately represent the open configuration during systole.
Transient simulations of blood flow were conducted to analyze flow dynamics during systole. Blood properties were defined based on assumptions of incompressibility and Newtonian fluid behavior. The results were interpreted, emphasizing the transient nature of the phenomenon and the minimal effect of non-Newtonian behavior on pressure drop in the aorta.The simulated results were validated against scientific literature and experimental data. Figure 1 showcases the procedure followed.

Results

The construction of a three-dimensional model enabled the accurate simulation of the flow dynamics across the aortic valve. This capability was confirmed through validation against echocardiogram data of a specific subject and subsequent comparison with findings from various subjects documented in publications ([12], [23]). As a result, the methodology employed for developing the three-dimensional model demonstrated efficacy in estimating key parameters such as maximum velocity and pressure drop during systole.

Interestingly, all three cusps of the aortic valve were observed to exert an equal influence on maximum velocity and pressure drop during systole, highlighting their collective significance in determining these critical parameters.

Moreover, the investigation revealed that the maximum velocity and pressure drop during systole were primarily dictated by the size of the aortic valve area (AVA), rather than the geometric characteristics of the aortic valve itself. Nonetheless, variations in valve geometry were found to impact the flow pattern, leading to changes in the impingement point of the flow jet on the ascending aorta. This alteration in impingement point holds importance as it dictates the magnitude and location of maximum shear stresses on the ascending aorta, thereby influencing the occurrence of ascending aortic aneurysms.

Conclusion

In conclusion, this project successfully developed a computational fluid dynamics model to investigate the flow dynamics across the aortic valve during systole. Through validation against echocardiogram data and comparison with literature findings, the model demonstrated its capability to accurately predict key parameters such as maximum velocity and pressure drop. The study highlighted the equal influence of all three cusps of the aortic valve on these parameters, emphasizing their collective significance. Furthermore, it was found that the size of the aortic valve area (AVA) played a crucial role in determining maximum velocity and pressure drop during systole. Some results related to the AVA effect are shown on Figures 2 and 3.

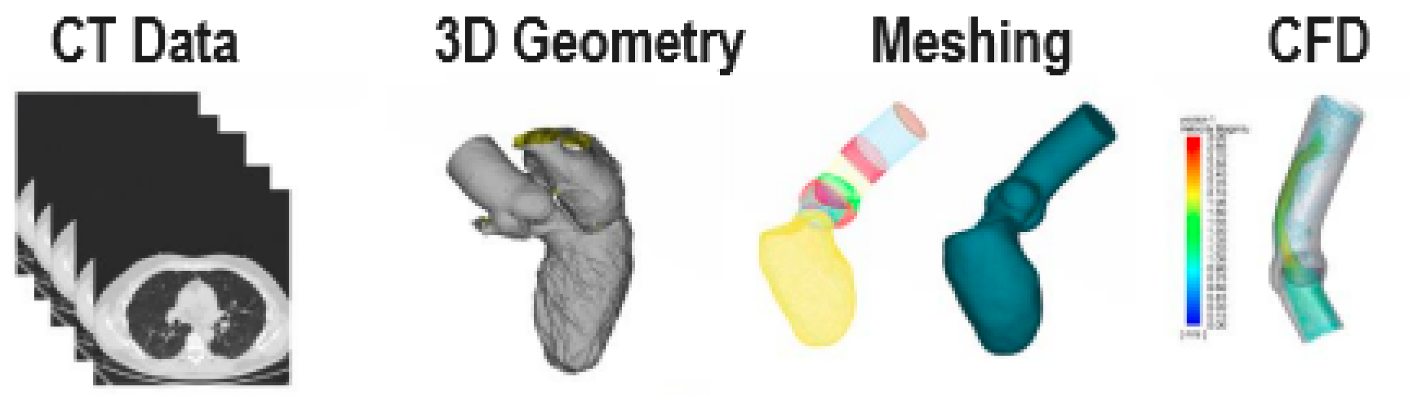

Figure 1:Simplified overview of the procedure followed.

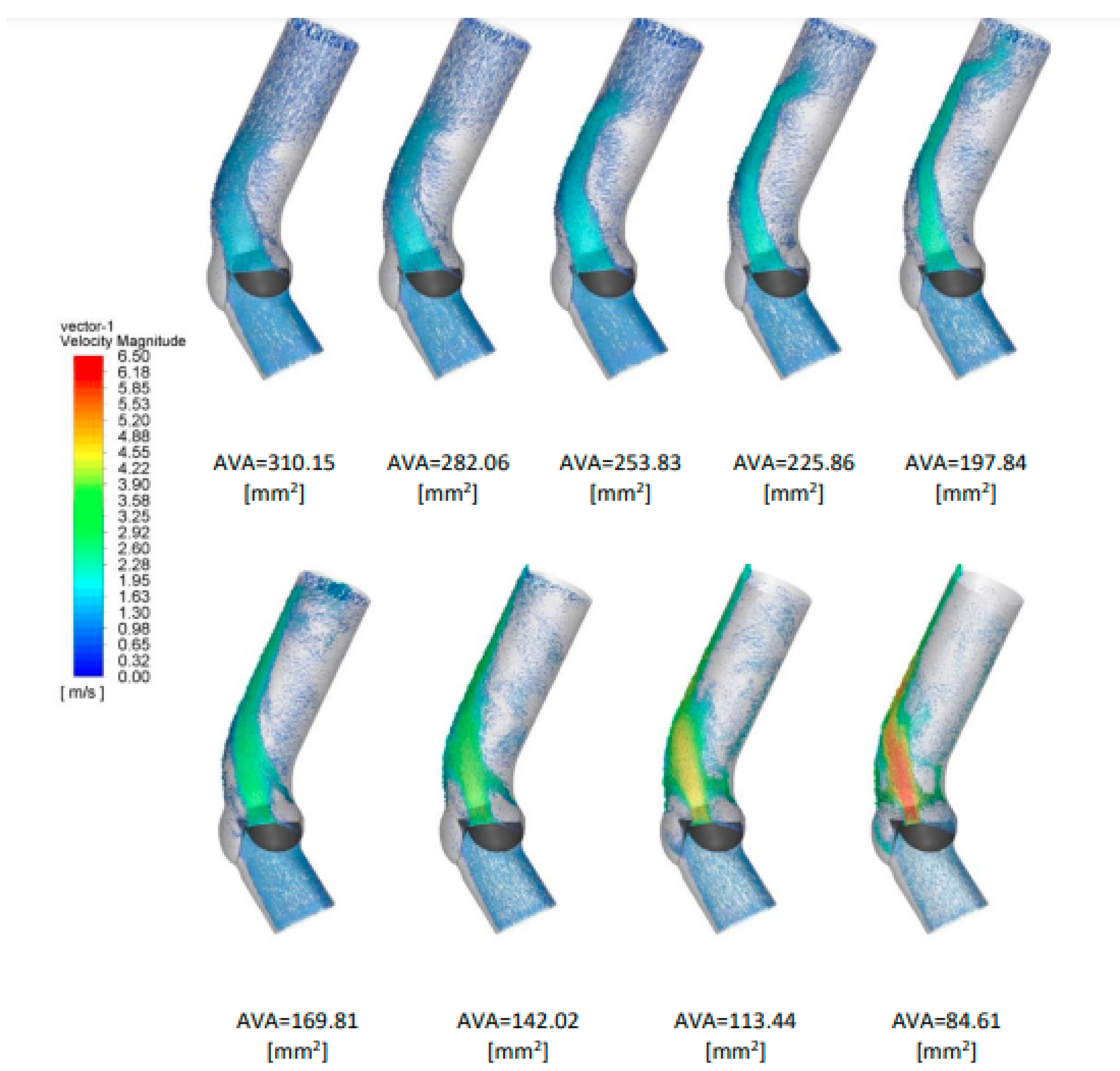

Figure 2:Representation of velocity vectors for different AVA cases.

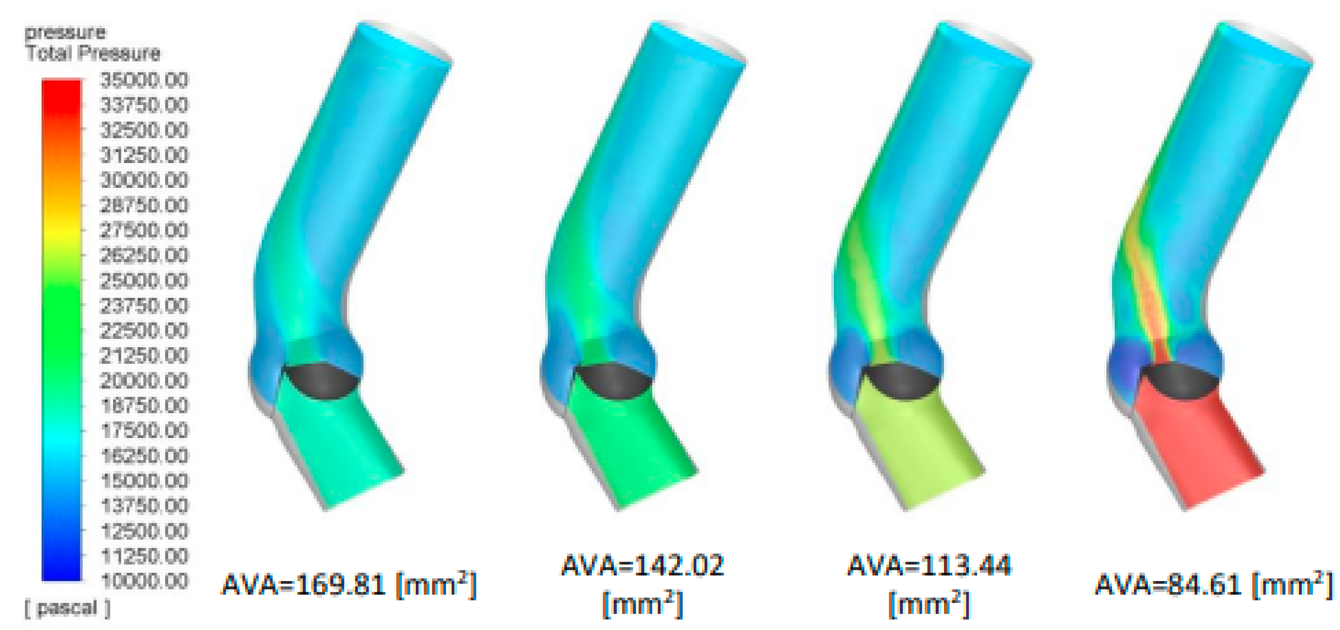

Figure 3:Representation of pressure drop for different AVA cases.