Comparative Hemodynamic Analysis of Medtronic Avalus Heart Valves Using Computational Fluid Dynamics

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INTRODUCTION

Aortic valve replacement is a well-established procedure for treating stenosis or insufficiency. A common challenge is **prosthesis-patient mismatch (PPM)**, where the implanted valve is too small for the patient's body size. PPM can lead to **high pressure gradients, complications, and reduced survival rates** [1].
To avoid PPM, surgeons often implant a **larger valve**, which may require either **annulus enlargement** or **tilted implantation**. Both can alter hemodynamics. This study investigates whether the **hemodynamic benefits of larger valves** outweigh the potential disadvantages of tilted implantation.

Fig. 1: Aortic geometry with inlet (left) and outlet (right) extensions.

METHODS

3D Aorta Model: Annulus diameter of 23 mm (Fig. 1).
Simulated Scenarios (Fig. 2):

- 23 mm valve at 0° (centered)
- 25 mm valve at 12° angle
- 27 mm valve at 25° angle

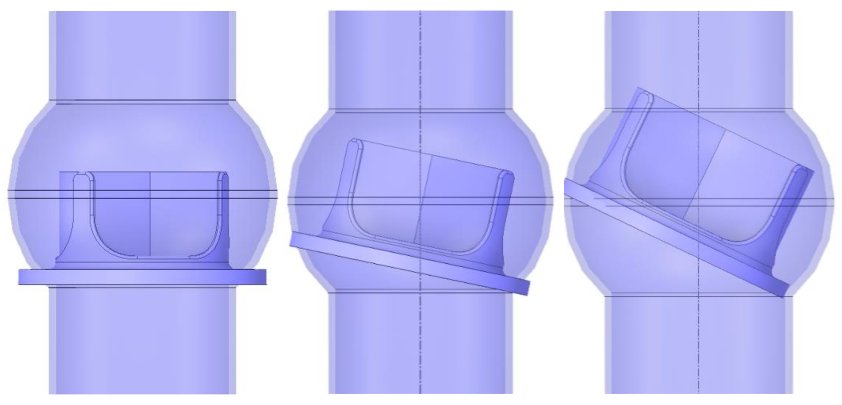


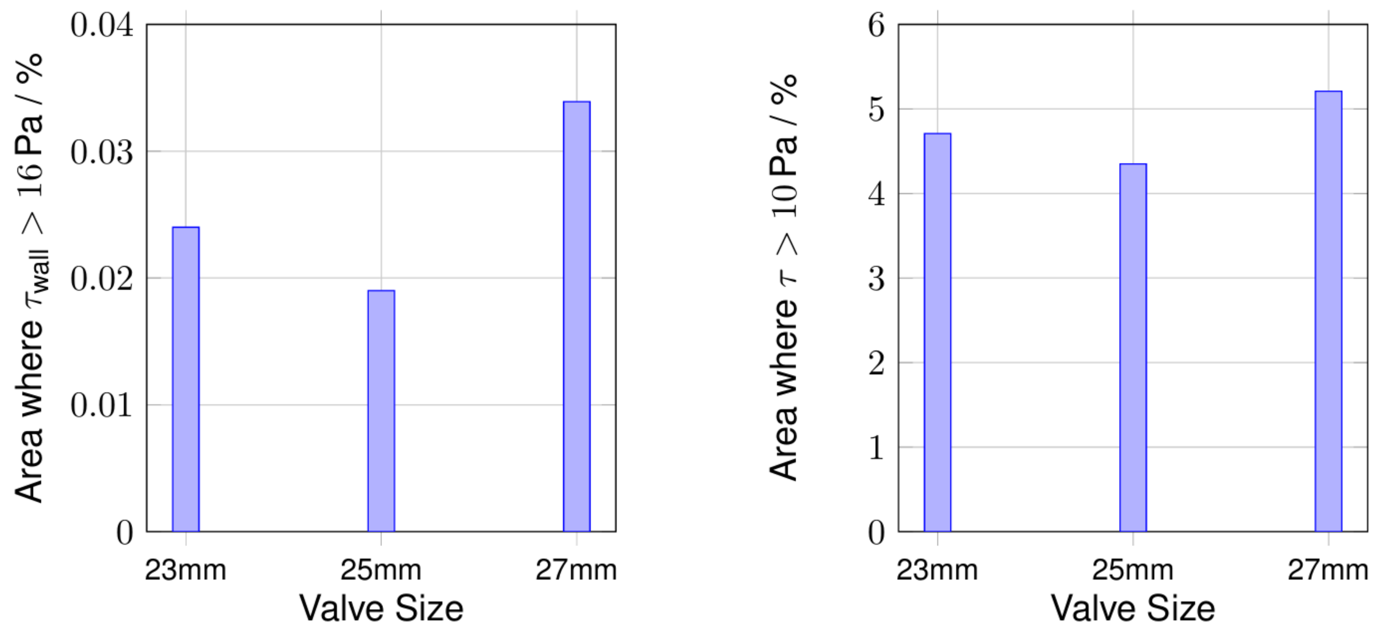
Fig. 2: 3D models of the heart valves in the aorta - from left to right: 23 mm, 25 mm and 27 mm.

The simulations were performed in Ansys Fluent with:

- Steady blood flow at 0.3 m/s
- Turbulence model: k-ω SST
- Boundary conditions from literature

Evaluation Criteria:

- **Shear Stress > 10 Pa**: Indicates potential platelet activation [2]
- **Wall Shear Stress (WSS) > 16 Pa**: Suggests thrombosis risk [2]
- **Flow behavior**: Turbulence, recirculation zones, and asymmetry



(a) Percentage of surface area with $\tau_{wall} > 16$ Pa (b) Percentage of surface area with $\tau > 10$ Pa

Fig. 3: Comparison of the percentage of surface area exceeding WSS > 16 Pa and shear stress > 10 Pa for different valve sizes.

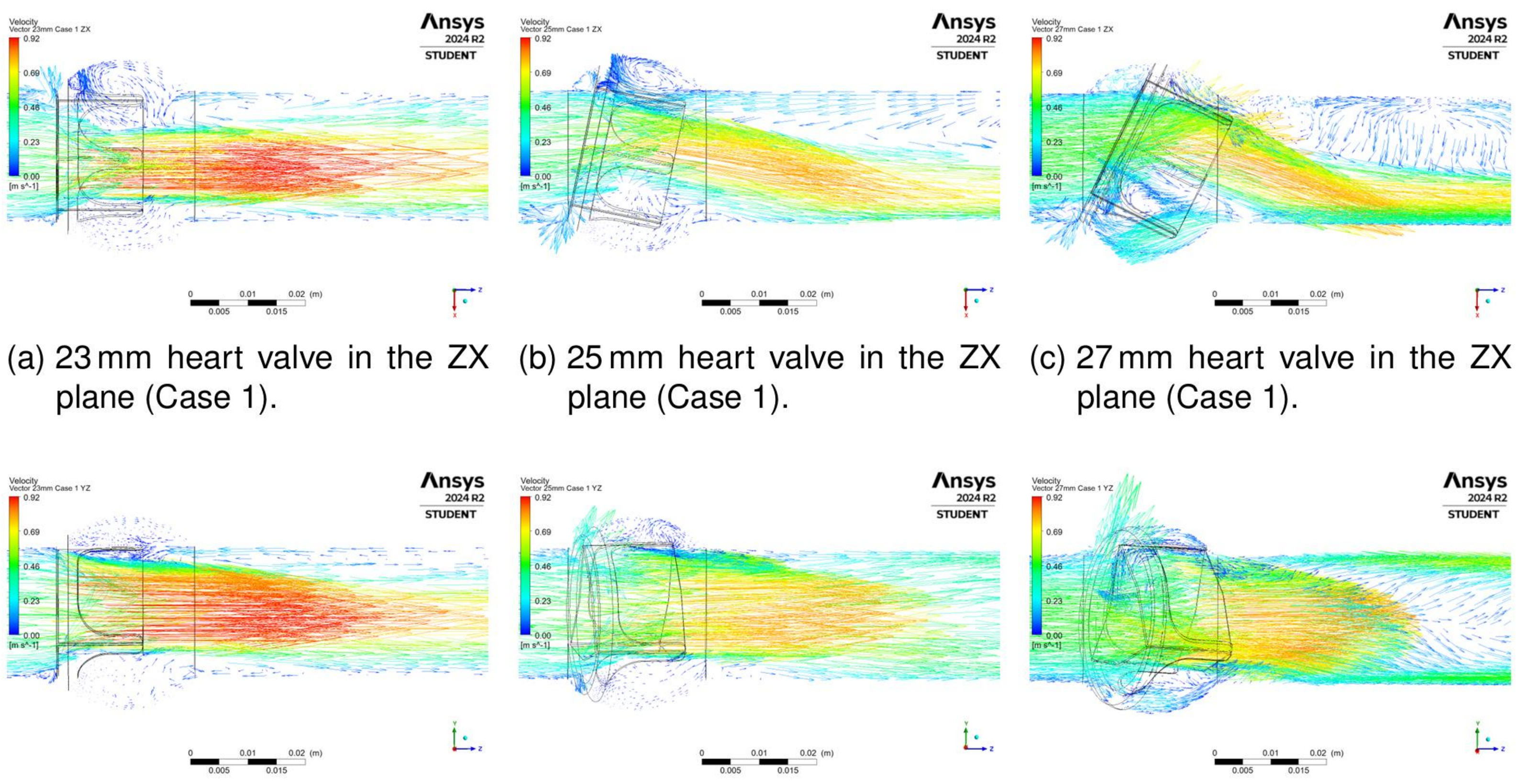
RESULTS

The measurement results are presented as bar graphs in Fig. 2.
23 mm valve (0° tilt) used as reference values for comparison:
25 mm valve (12° tilt):

- **WSS: ↓ -20.83 %**
- **Shear stress: ↓ -7.64 %**

27 mm valve (25° tilt):

- **WSS: ↑ +41.25 %**
- **Shear stress: ↑ +11.26 %**



(a) 23 mm heart valve in the ZX plane (Case 1). (b) 25 mm heart valve in the ZX plane (Case 1). (c) 27 mm heart valve in the ZX plane (Case 1).
(d) 23 mm heart valve in the YZ plane (Case 1). (e) 25 mm heart valve in the YZ plane (Case 1). (f) 27 mm heart valve in the YZ plane (Case 1).

Fig 4: Velocity vector fields in ZX and YZ planes. Highest velocity: 0.92 m/s. The inlet is on the left. Black line shows valve contour.

Flow Behavior

- **23 mm valve (aligned):** Highest speed (0.92 m/s), symmetrical flow, small vortex behind the valve.
- **25 mm valve (12° tilt):** Lower speed, slight lateral deviation, stable flow, moderately larger vortex.
- **27 mm valve (25° tilt):** Strong lateral deviation, higher speed along the aortic wall, pronounced vortices, and significant backflow.

CONCLUSION

1. Upsizing to **25 mm reduced** WSS, shear stress, and peak velocities compared to the 23 mm valve while maintaining stable flow. No adverse effects were observed, even with the required tilt.
2. Upsizing to **27 mm introduced higher** WSS, shear stress, turbulence, and recirculation due to excessive tilt and restricted flow area.

Moderate upsizing with controlled tilting improves haemodynamic performance and supports clinical decision-making for valve sizing and implantation.

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