Indonesian Journal of Electrical Engineering and Computer Science
Vol. 42, No. 3, June 2026, pp. 884~891
ISSN: 2502-4752, DOI: 10.11591/ijeecs.v42.i3.pp884-891

Velocity hemodynamic patterns in aortic valve stenosis: a study of inlet velocity during systole phase

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Article Info

Article history:

Received Dec 26, 2024
Revised Mar 17, 2026
Accepted May 26, 2026

Keywords:

Aortic valve stenosis
Blood velocity
Cardiac cycle
Computational fluid dynamic
Inlet velocity
Systole phase
Valve orifice

ABSTRACT

This work highlighted a close-up version of the aortic valve that provide detail parameter and clearer graphics compared to the 3D version. Therefore, four simplified models are designed and simulated by using computational fluid dynamics (CFD) which are one healthy valve model (100%) and three stenotic models with varying valve opening (70%, 50%, and 30%). The model dimensions and setup parameters are determined by comparing the healthy aortic valve with the previous data. The analysis focused on two different views, which are the view on a targeting line velocity along the x-axis, and the view at the y-axis around the aortic valve. Results on the evaluation graph at the x-axis and y-axis show significant differences in flow patterns between healthy and aortic valve stenosis. The healthy model of 100% valve opening depicted a lower velocity (m/s) at 1.5m/s compared to the stenotic model of 70%, 50%, and 30% valve opening that showed higher velocities of 3.24 m/s, 6.09 m/s, and 14.57 m/s, respectively, due to the narrowing of the valve opening. Thus, the smallest orifice of the valve produced a higher velocity. This finding highlights the importance of hemodynamic assessment in aortic valve stenosis by providing valuable insight for clinicians in pre-surgical evaluation.

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1. INTRODUCTION

Coronary artery disease (CAD) is a subset of cardiovascular disease (CVD) that accounts for 32% of these deaths with heart attacks, where strokes being the primary causes [1], [2]. In Malaysia, CAD is the leading cause of death that was placed on 64th world rank in 2018 in the population of coronary heart disease [3]. Unhealthy lifestyles are one of the causes that contribute to the growing sudden cardiac arrest in CAD which can raise the death rate among Malaysians [4], [5]. According to the CAD disease, it is caused by the narrowing and blockage of coronary arteries due to plaque build-up which can lead to cardiac arrest [6]-[8].

In cardiovascular system, there are four valves known as pulmonary valve, tricuspid valve, mitral valve and aortic valve at the right and left ventricles [9], [10]. Aortic valve is made up of three leaflet that open during the systolic phase (contraction) of the left ventricle which allowing the blood to be pumped into the aorta [11], [12]. The primary role of aortic valve is to prevent backflow during the resting phase in left ventricle [13]. Furthermore, there is a severe condition of heart valve disease known as aortic valve stenosis that reported as one the most important cardiovascular defect [14], [15]. The stenosis occurred when the aortic valve narrows, and blood cannot flow normally [16], [17]. Overtime, this may cause left ventricle to pump harder to allow blood through the narrowed aortic valve. Evenmore, a formation of the plaque at aortic valve may lead to the sudden rupture at the valve and may progressively weaken aortic wall [18], [19]. Recently, sternotomy procedure that is an open surgical of aortic valve repair is one of the standard treatments. To reduce the uncomfortable to the patients, transcatheter aortic valve (TAV) implantation that is one of the invasive methods has been carried [18]. There is a non-invasive method that physician can applied to overcome and observed the stenotic disease by using computational method known as computational fluid dynamic (CFD). By combining the echocardiogram image and CFD simulation, the visualisation of the blood flow could be observed clearly and physician would able to predict the condition prior to the surgery. Thus, this study focuses on the simulation of simplified model of a healthy aortic valve and three models for the intensity of stenotic aortic valve. The four models will be varied for difference orifice sizes, inlet velocity and valve cups thickness.

2. METHOD

There are two conditions of the valve considered in this study that are normal aortic valve and stenotic aortic valve. The simplified models were designed in Solidwork. Since the aim of this study is to evaluate the simulation of aortic valve stenosis using different size of valve orifice, valve cusps thickness and inlet velocity, the observation on blood flow mechanism along the aortic root at different valve orifice is made by comparing the velocity of the blood ejected right after the valve region.

2.1. Pre-Computational Setup Parameter

The analysis of developed simplified models was comprehensively conducted to examine the blood flow velocities behavior at several stages of normal and stenotic aortic valve. The process begins with the discretization technique that utilized Navier-Stokes equation describing the motion of viscous fluid substances and the conservation of mass in the fluid flow, as follows [20].

$$\rho\frac{\delta u}{\delta t} + \rho(u.\nabla)u) = -\nabla p + \mu\nabla^2 u \quad (1)$$

$$\nabla. u = 0 \quad (2)$$

Here, u represents velocity, p is pressure, ρ denotes density and μ stands for viscosity, each variable plays a crucial role in capturing the dynamics of blood flow through the aortic valve [20], [21]. These equations collectively enable the detailed exploration of blood flow patterns and the assessment of hemodynamic parameter within the normal and stenotic aortic valve.

Later, the inlet velocity profile for the aortic valve models was established over six cardiac points during systole phase, as shown in Figure 1. The points are middle acceleration (MA), three-quarters acceleration (3QA), peak flow (PF), quarter-deceleration (QD), mid-deceleration (MD), and end systole (ES) [22]. Based on PlotDigitizer system, the specific time intervals and inlet velocities were selected randomly depending on the PF point, to monitor the behaviour of the blood flow along aortic root, thus, to observe the velocities profile right after the blood passes through the valve in different stages of normal and stenotic aortic valve. Table 1 shows the indicator of the setup velocity profile at difference time according to Figure 1.

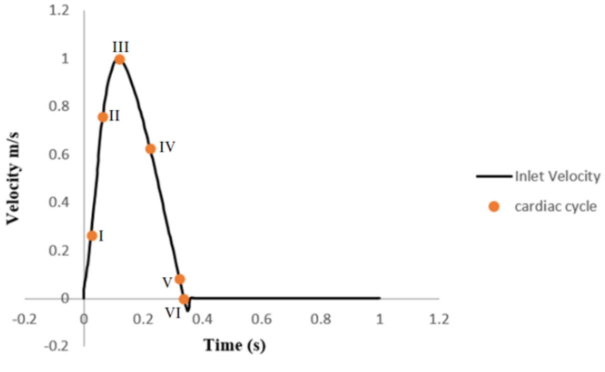


Figure 1. Six targeting points of inlet velocity profile used in this study

Table 1. Indicator of the velocity profile used in simulation

	Cycles of the heart	Time (s)	Velocity (m/s)
I	MA	0.02	0.26
II	3QA	0.06	0.76
III	PF	0.12	1.00
IV	QD	0.22	0.62
V	Mid-deceleration (MD)	0.32	0.08
VI	End systole (ES)	0.34	0

2.2. Design simulation of aortic valve model

The simulation starts with the design of simplified aortic valve model using Solidwork where the dimension for each of these simplified models were derived from echocardiogram image obtained in the previous study Amindari *et al*. [23] as the way to ensure the geometrical representation closely aligns with physiological conditions. Figure 2 depicted the boundary conditions applied to a simplified model of normal and stenotic aortic valve. Three boundaries of inlet, wall and outlet were involved in the model. Inlet is located at the beginning of the aortic root vessel where the initial velocity or pressure of the blood enters the blood vessel during systole. This is the condition where blood is forcefully pumped from the left ventricle into aorta. Meanwhile, the wall boundary is the coordination of contact between the surface and the blood. Here, the wall was set as a rigid wall and not deform under the pressure of the blood flow. The outlet boundary condition was positioned at the end of the simulated blood vessel (aorta). It represents the blood exits after passing through the valve. This boundary typically specifies the pressure or blood flow rate leaving the aortic root model. Additionally, the density of the blood is constant with 1,060 kg/m3 and the viscosity of the blood was setup at 0.0035Pa. Moreover, this model was also setup in the realizable k-epsilon (2eqn) and the solution method was used second order discretization.

To observe the blood characteristics, two views condition were considered as shown Table 2. Those views involved at a healthy aortic valve and three stages of stenotic aortic valves. View A was measured from inlet to the outlet at the center of aortic root. Meanwhile, view B was measured cross-sectionally from wall to wall around the valve region. By observing the line from inlet to outlet and also from wall to wall around the valve region, the velocity of the blood flow could be visualized clearly along the aortic root in difference stages of valve orifice opening degree of 100%, 70%, 50%, and 30% as show in Table 3.

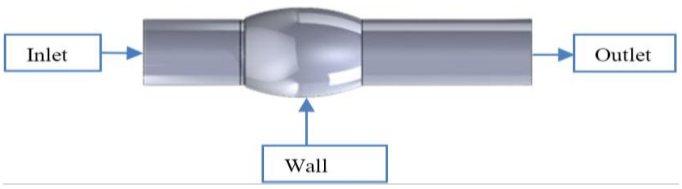


Figure 2. Boundary condition of aortic root

Table 2. Two setup views to analyse blood characteristics along aortic root

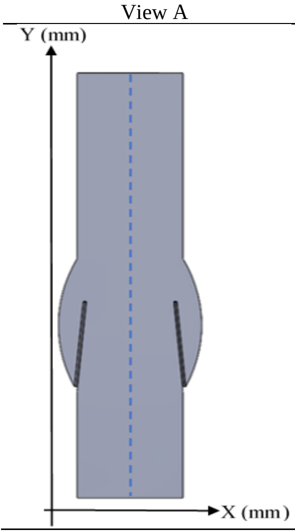
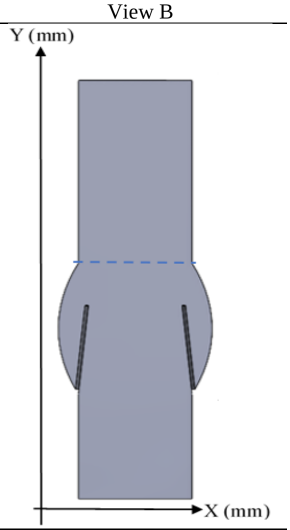
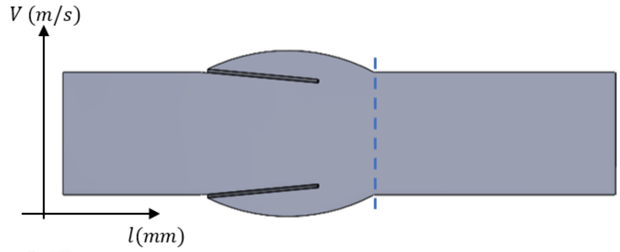
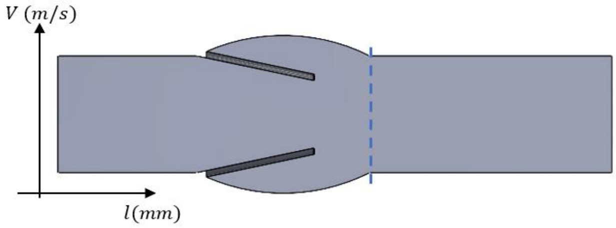
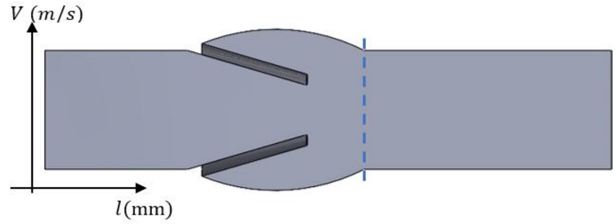
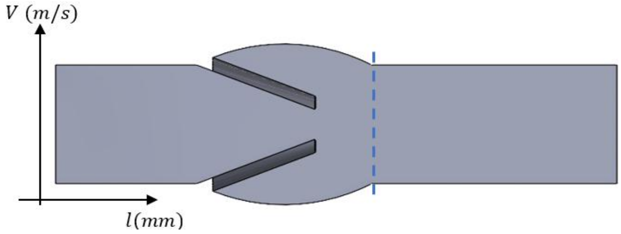
View A	View B
	

Table 3. View conditions B indicating target line around valve region at different valve orifice

Model	Model of aortic valve
100% valve orifice	
70% valve orifice	
50% valve orifice	
30% valve orifice	

3. RESULTS AND DISCUSSION

This study considered two views A and B to observe the blood flow velocity changes. Those results showed the evaluation of the velocity in different opening degree of aortic valve models.

3.1. View A

Figure 3 shows the velocity profile for view A that represents a relationship between velocity of the blood flow (m/s) and length along the aortic root (m) during six points of the systole phase. The stenotic 30% valve orifice model (blue curve) indicated the highest peak velocity compared to other models. It reached to 1.85 m/s during the PF cycle where it depicts the most stenotic aortic valve model. Due to the narrowest of valve orifice, a higher jet velocity in the central region of aortic root is produced and the velocity of the blood is affected when it reached the outlet region. Furthermore, in the stenotic 50% valve orifice model (green curve), there was a slightly less velocity compared to the stenotic 30% valve orifice model with a peak velocity at 0.61 m/s. Meanwhile, the stenotic 70% valve orifice model (pink curve) shows a milder stenosis and having greater valve orifice compared to the stenotic model of 30% and 50% valve orifice. The peak velocity occurred in this model is 0.30 m/s. The healthy 100% valve orifice model indicating the fully open valve condition where the velocity remains low across the length of aortic root with a peak flow during PF at 0.16 m/s. The flow presented smooth line with no significant jet formation or higher speed flow in the center interpreting the healthy and normal hemodynamic condition without having a stenosis. In fact, the results summarized that when the degree of stenosis meet increment pattern (moving from 100% to 30% valve orifice models), the velocity proportionally increased especially around valve region. Theoretically, the high velocity capable to cause turbulent flow and produce higher shear stress that potentially leads a damage of aortic root as shown in previous study [24], [25]. In addition, when the blood passes through the smaller valve orifice, it accelerates the blood flow to the highest velocities due to restricted opening at the valve.

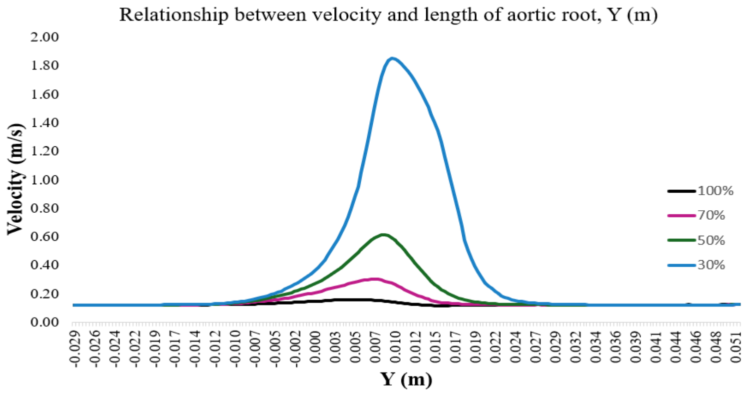


Figure 3. Relationship between velocity and length of aortic root during the six cardiac cycles

3.2. View B

Table 4 tabulates a velocity profile at various stages of six points during systole phase for the healthy and three stenotic aortic valves. The results of the velocity profile were obtained through the targeting line from wall to wall of aortic valve models where the line has been configured in the region immediately downstream of the valve. This line is to observe the velocity that passed through the valve at different stages of healthy and stenotic models. In fact, the line at x-axis is the length (m) of the wall vessel, meanwhile 0 m is the central of the length.

During MA, the inlet velocity obtained at 0.02s is 0.26 m/s. The healthy 100% valve orifice model showed the blood flow is evenly distributed with moderate velocities along the central part of the wall vessel. Meanwhile, the stenotic 70% valve orifice model visualized slightly high velocity profile in the center and indicated higher peak compared to that of the healthy 100% valve orifice model. The velocity occurred at this stage is 0.30 m/s. Furthermore, the stenotic 50% valve orifice model depicted that at the central peak, a sharper shape is produced indicating the increment of velocity due to the narrowing of the valve. Quantitatively, the blood velocity that passed through the stenotic 50% valve orifice model reached the peak at 0.83 m/s, higher than that of the healthy 100% and stenotic 70% valve orifice models. For the stenotic 30% valve orificie model, the velocity increased significantly showing a jet-like flow of stenosis. The highest peak value of the velocity was 3.02 m/s.

During 3QA, the inlet velocity was setup with 0.76 m/s at 0.06s. The healthy 100% valve orifice model shows a similar pattern with MA that has a slightly high velocity at 0.93 m/s. This is due to the condition that 3QA is the duration point of acceleration of the blood flow increment prior to the PF. Meanwhile, for stenotic valve orifice model of 70%, 50% and 30%, the trend continues significantly at 2.26 m/s, 4.38 m/s and 10.54 m/s, respectively, indicating the increment of flow acceleration.

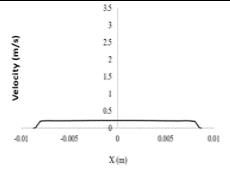
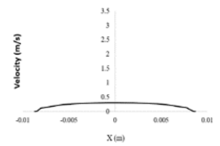
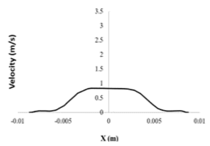
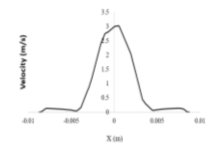
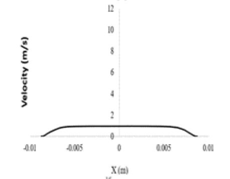
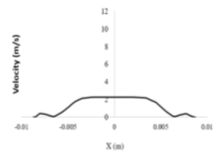
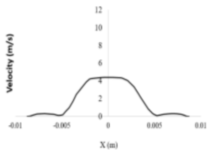
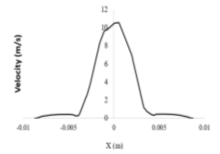
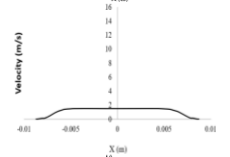
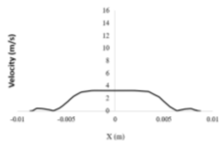
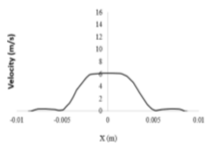
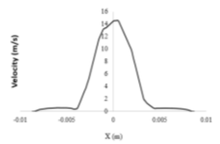
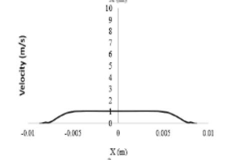
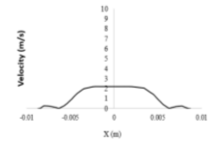
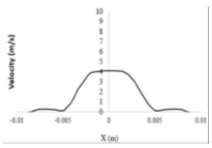
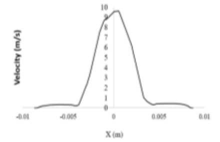
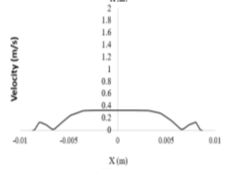
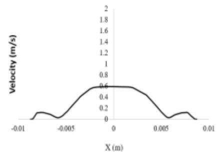
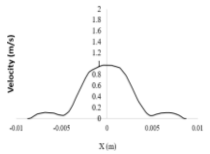
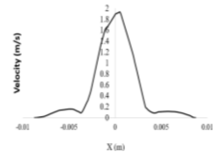
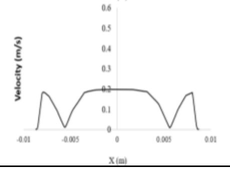
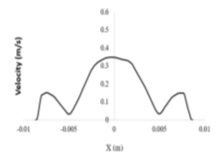
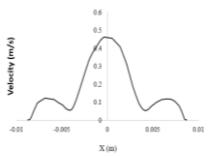
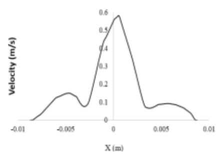
PF marked the highest inlet velocity that was setup of 1.00 m/s at 0.12s. Similar to the MA and 3QA, the healthy 100% valve orifice model depicted the slowest velocity at 1.5 m/s when compared to the other models. This is due to the fully opening valve without any obstacle during the flowing of blood. Thus, the velocity shows a smooth distribution at the center of the vessel. In contrast to the stenotic models of 70%, 50%, and 30%, the narrowing of the valve is the factor that leads to a significant increment in velocity, where the peak velocity of those models is 3.24 m/s, 6.09 m/s, and 14.57 m/s, respectively. Meanwhile, the 30% stenotic aortic valve model shows the most peak and sharp due to the smallest valve orifice.

QD had lower inlet velocity of 0.62 m/s than the PF, in 0.22s. The healthy 100% valve orifice model presents a flatten velocity profile as the blood is slowly flow but it still depicted a smooth distribution in the graph. The velocity produced at the region after the blood passes through the valve is 1.06 m/s. Meanwhile, for the stenotic valve orifice of 70%, 50% and 30% models, the velocity profile similarly shows a significant of velocity peaks with the overall flow decelerating at 2.18 m/s, 4.09 m/s, and 9.58 m/s, respectively. Here, the highest peak value of blood velocity is for the case of the stenotic 30% valve orifice model.

During the MD, the inlet velocity that was setup at 0.32s. is 0.08 m/s. MD is the second point of degradation during systole phase before going to the ES point. Here, healthy 100% valve orifice model produced the velocity of 0.33 m/s lower compared to the others three stenotic models. The maximum velocity reached at stenotic valve orifice model of 70%, 50%, and 30% is 0.59 m/s, 0.97 m/s, and 1.93 m/s, respectively, where the 30% model indicated the highest velocity. The last point was observed during ES phase with the inlet velocity of 0 m/s at 0.34s. The healthy 100% valve orifice model depicted the velocity value of 0.2 m/s, meanwhile the stenotic 70%, 50%, and 30% valve orifice models show the velocity of 0.35 m/s, 0.46 m/s, and 0.58 m/s, respectively.

In summary, the velocity profile along the targeting line shows the blood velocity behavior that focused on the downstream region of the valve. Through this observation, the acceleration of the velocity with varies orifice could predict the severe level and damage in vessel that affected from the high blood flow. Furthermore, the results highlighted the strong relationship between valve orifice reduction and flow velocity increment, that may contribute to the development of abnormal hemodynamic forces such as elevated at wall shear stress [24], [26]. The finding of this study emphasizes the importance of accurately assessing valve narrowing in clinical setting as the severe stenosis level would lead to substantial disruption in normal blood flow, thus has potentially to disrupt a cardiovascular condition.

Table 4. Velocity profile at various stages of six points of systole phase

Cardiac cycle	100%	70%	50%	30%
MA				
3QA				
PF				
QD				
MD				
ES				

4. CONCLUSION

Four models aortic valve have been evaluated based on the velocity profile that occurred along aortic root from inlet to the outlet, and from wall-to-wall diameter length of the vessel. Those two limitation views were determined to visualize and analyze the velocity of the blood flow when it reached the targeting lines. By using an echocardiogram image and CFD Ansys simulation, the velocity at ascending aorta can be observed at difference stages of stenosis. Even though the simulated view is a non-real structure of aorta, both simulated view A and view B started with different time of the velocity inlet and varied valve orifice as presenting the stenosis stages. The results summarized that the smaller valve orifice significantly impact the blood velocity before and after the valve region. During the PF phase, the stenotic models show the higher blood velocity compared to the healthy 100% valve orifice model. The stenotic 30% valve orifice model that is the smallest valve orifice yielded the highest velocity at view A and view B compared to the stenotic 50% and 70% valve orifice model.

The future recommendation of this study is building a particle image velocimetry (PIV) which is known as an experiment using a particle seed as a blood and building a model aortic valve with different sizing of valve orifice and thickness. This method will provide details information about the fluid flow by tracking the movement of the particles suspended in the fluid. By using PIV, it can help researchers understand more about the complex flow patterns in aortic valve stenosis. Furthermore, by visualizing it, the researcher also can help physicians to predict a condition of the blood flow when patients have various stenotic stages.

ACKNOWLEDGEMENTS

This research was supported by Universiti Tun Hussein Onn Malaysia through TIER 1 (Vot Q542).

REFERENCES

[1] R. C. Woodruff *et al.*, "Trends in cardiovascular disease mortality rates and excess deaths, 2010–2022," *American Journal of Preventive Medicine*, vol. 66, no. 4, pp. 582–589, Apr. 2024, doi: 10.1016/j.amepre.2023.11.009.

[2] World Health Organization, "Cardiovascular diseases (CVDs)." Accessed: Apr. 05, 2022. [Online]. Available: https://www.who.int/news-room/fact-sheets/detail/cardiovascular-diseases-(cvds)

[3] Health profile Malaysia, "World life expectancy." Accessed: Apr. 05, 2023. [Online]. Available: https://www.worldlifeexpectancy.com/country-health-profile/malaysia

[4] M. Azzani, G. A. P. Muagan, W. M. Atroosh, and I. Z. Ng, "Risk of cardiovascular diseases among young adults: a cross-sectional study in Malaysia," *BMJ Open*, vol. 14, no. 4, p. e084454, Apr. 2024, doi: 10.1136/bmjopen-2024-084454.

[5] C. W. Ang, R. Ismail, Z. Kassim, A. N. Mohd Ghazali, D. Reidpath, and T. T. Su, "Frequent eating out and 10-year cardiovascular disease risk: evidence from a community observatory in Malaysia," *BioMed Research International*, vol. 2022, no. 1, Jan. 2022, doi: 10.1155/2022/2748382.

[6] J. Beki, "Coronary artery disease," *EJCMPR*, vol. 2, no. 5, pp. 203–211, 2023, doi: 10.5281/zenodo.8263024.

[7] R. Prajapati, P. Patel, U. Upadhyay, and A. Professor, "A review on coronary artery disease," *World Journal of Pharmaceutical Research*, vol. 10, pp. 775–790, 2021, doi: 10.20959/wjpr202113-22133.

[8] M. A. Mir, M. A. Dar, and A. Qadir, "Exploring the landscape of coronary artery disease: a comprehensive review," *American Journal of Biodiversity*, vol. 1, pp. 9–22, 2024.

[9] N. Hafizah Mokhtar and A. Abas, "Simulation of blood flow in artificial heart valve design through left heart," *IOP Conference Series: Materials Science and Engineering*, vol. 370, no. 1, 2018, doi: 10.1088/1757-899X/370/1/012066.

[10] S. Whiteman, Y. Alimi, M. Carrasco, J. Gielecki, A. Zurada, and M. Loukas, "Anatomy of the cardiac chambers: a review of the left ventricle," *Translational Research in Anatomy*, vol. 23, p. 100095, Jun. 2021, doi: 10.1016/j.tria.2020.100095.

[11] T. S. Ha, "Numerical Simulation for fluid-structure interaction of a blood flow with the aortic valve using the fem monolithic formulation," *Journal of Science and Technique*, vol. 16, no. 3, Sep. 2021, doi: 10.56651/lqdtu.jst.v16.n03.277.

[12] F. Viola, V. Meschini, and R. Verzicco, "Effects of stenotic aortic valve on the left heart hemodynamics: a fluid-structure-electrophysiology approach," *arXiv*, 2021, [Online]. Available: http://arxiv.org/abs/2103.14680

[13] N. Cesarovic *et al.*, "Septaly oriented mild aortic regurgitant jets negatively influence left ventricular blood flow—insights from 4D flow MRI animal study," *Frontiers in Cardiovascular Medicine*, vol. 8, Aug. 2021, doi: 10.3389/fcvm.2021.711099.

[14] T. S. Ha, "A numerical investigation of blood flow through the aortic valve," *Journal of Science and Technique*, vol. 17, no. 5, pp. 16–27, 2022, doi: 10.56651/lqdtu.jst.v17.n05.527.

[15] J. S. Aluru, A. Barsouk, K. Saginala, P. Rawla, and A. Barsouk, "Valvular heart disease epidemiology," *Medical sciences*, vol. 10, no. 2, p. 32, Jun. 2022, doi: 10.3390/medsci10020032.

[16] O. Pappalardo *et al.*, "Quantification of anatomical aortic valve area by multi-detector computed tomography: a pilot 3D-morphological modeling of the stenotic aortic valve," *International Journal of Cardiology*, vol. 413, p. 132322, Oct. 2024, doi: 10.1016/j.ijcard.2024.132322.

[17] F. Viola, V. Meschini, and R. Verzicco, "An FSEI approach for the assessment of stenotic aortic valve effects on the left heart hemodynamics," *Computers and Fluids*, vol. 265, 2023, doi: 10.1016/j.compfluid.2023.106017.

[18] L. Xu, L. Yin, Y. Liu, and F. Liang, "A computational study on the influence of aortic valve disease on hemodynamics in dilated aorta," *Mathematical Biosciences and Engineering*, vol. 17, no. 1, pp. 606–626, 2020, doi: 10.3934/mbe.2020031.

[19] P. Golforoush, D. M. Yellon, and S. M. Davidson, "Mouse models of atherosclerosis and their suitability for the study of myocardial infarction," *Basic Research in Cardiology*, vol. 115, no. 6, p. 73, Dec. 2020, doi: 10.1007/s00395-020-00829-5.

[20] A. A. Basri, M. Zubair, A. F. A. Aziz, R. M. Ali, M. Tamagawa, and K. A. Ahmad, "Computational fluid dynamics study of the aortic valve opening on hemodynamics characteristics," in *2014 IEEE Conference on Biomedical Engineering and Sciences (IECBES)*, IEEE, Dec. 2014, pp. 99–102. doi: 10.1109/IECBES.2014.7047660.

[21] J. Yin, Y. Xiang, and Q. Dou, "Three-dimensional reconstruction and numerical simulation of blood flow in human thoracic aortic," in *2010 4th International Conference on Bioinformatics and Biomedical Engineering*, IEEE, Jun. 2010, pp. 1–4, doi: 10.1109/ICBBE.2010.5516425.

[22] H. Zolfaghari, M. Andiapen, A. Baumbach, A. Mathur, and R. R. Kerswell, "Wall shear stress and pressure patterns in aortic stenosis patients with and without aortic dilation captured by high-performance image-based computational fluid dynamics," *PLoS Computational Biology*, vol. 19, no. 10 October, p. e1011479, Oct. 2023, doi: 10.1371/journal.pcbi.1011479.

[23] A. Amindari, L. Saltik, K. Kirkkopru, M. Yacoub, and H. C. Yalcin, "Assessment of calcified aortic valve leaflet deformations and blood flow dynamics using fluid-structure interaction modeling," *Informatics in Medicine Unlocked*, vol. 9, pp. 191–199, 2017, doi: 10.1016/j.imu.2017.09.001.

[24] N. Yousri, N. Ibrahim, N. A. H. Roseman, I. Taib, and S. Shanta, "CFD based on the visualisation of aortic valve mechanism in aortic valve stenosis for risk prediction at the peak velocity," *Journal of Advanced Research in Micro and Nano Engineering*, vol. 17, no. 1, pp. 56–68, Apr. 2024, doi: 10.37934/armne.17.1.5668.

[25] O. Mutlu, H. E. Salman, H. Al-Thani, A. El-Menyar, U. A. Qidwai, and H. C. Yalcin, "How does hemodynamics affect rupture tissue mechanics in abdominal aortic aneurysm: Focus on wall shear stress derived parameters, time-averaged wall shear stress, oscillatory shear index, endothelial cell activation potential, and relative residence time," *Computers in Biology and Medicine*, vol. 154, p. 106609, Mar. 2023, doi: 10.1016/j.compbiomed.2023.106609.
[26] Q. Tariq, S. A. Jaber, and A. Ammar, "An in-depth examination modalities of hemodynamic characteristics in mechanical aortic valve: a comprehensive review article," *Al-Nahrain Journal for Engineering Sciences*, vol. 26, no. 4, pp. 326–336, May 2024, doi: 10.29194/NJES.26040326.

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