Numerical Modeling of the Coronary Artery using ANSYS Fluent

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Abstract

Cardiovascular disease (CVD) (Doost et al., 2016) are abnormalities that distort the effective flow of blood to and away from the heart. To be able to fully understand how these things happen, CFD tool (ANSYS Fluent) is used to model how blood flows into and away from the coronary artery. Blood, air and aluminum was used as main materials in the simulation. The present study aimed to establish a relationship between actual hemodynamic conditions and the parameters that define with ANSYS Fluent. And, to obtain numerical solution to research the best physical model to determine viscosity and pulsatile velocity in a healthy human.

Keywords

Cardiovascular disease, coronary artery, blood flow, Navier Stokes equation, ANSYS Fluent

1. Introduction

Cardiovascular disease (CVD) [1] are abnormalities that distort the effective flow of blood to and away from the heart. To be able to fully understand how these things happen, CFD tool (ANSYS Fluent) is used to model how blood flows [2] into and away from the coronary artery.

Governing Equation

Continuity

$$\frac{\delta\rho}{\delta t}+\nabla.(\rho v) = 0$$

Navier Stokes equation

$$\rho(\frac{dv}{dt}+\mathrm{v}.\nabla\mathrm{v}) = -\nabla \mathrm{p}+\mu\nabla^2\mathrm{v}+\mathrm{f}$$

Blood viscosity is modeled using the Carreau fluids model [3]

$$\mu_{eff}(\dot{\gamma}) = \mu_{inf} + (\mu_o - \mu_{inf})(1 + (\lambda\dot{\gamma})^2)^{\frac{n-1}{2}}$$

With

$$\mu_o = 0.056\left(\frac{kg}{ms}\right), \mu_{inf} = 0.0035\left(\frac{kg}{ms}\right), \lambda = 3.313s \text{ and } n = 0.3568$$

The Carreau model [4] for the velocity profile is given as

$$\mathrm{v}_{inlet}(t) = \begin{cases} 0.5\sin[4\Pi(t+0.0160236)] & : 0.5n < t \le 0.5n + 0.218 \\ 0.10 & : 0.5n + 0.218 < n \le 0.5(n+1) \end{cases}$$

The power model [5]

$$V_{inlet} = 2 * 0.988[1 + 0.624 * sin(7.854.t)]m/s \text{ for the power law.}$$

Proceedings of the 7th International Conference on Digital Technologies in Education, Science and Industry (DTESI 2022), October 20–21, 2022, Almaty, Kazakhstan
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Another velocity model proposed by [6] is used in simulation. This model considers the duration of a cycle to be 0.8s.

$$V_{inlet}(t) = \begin{cases} 0.8\sin[2.857\Pi t] & : 0 < t \leq 0.35 \\ 0.6\sin\left(2.22\Pi(t-0.35)\right) & : 0.35 \leq t \leq 0.8 \end{cases}$$

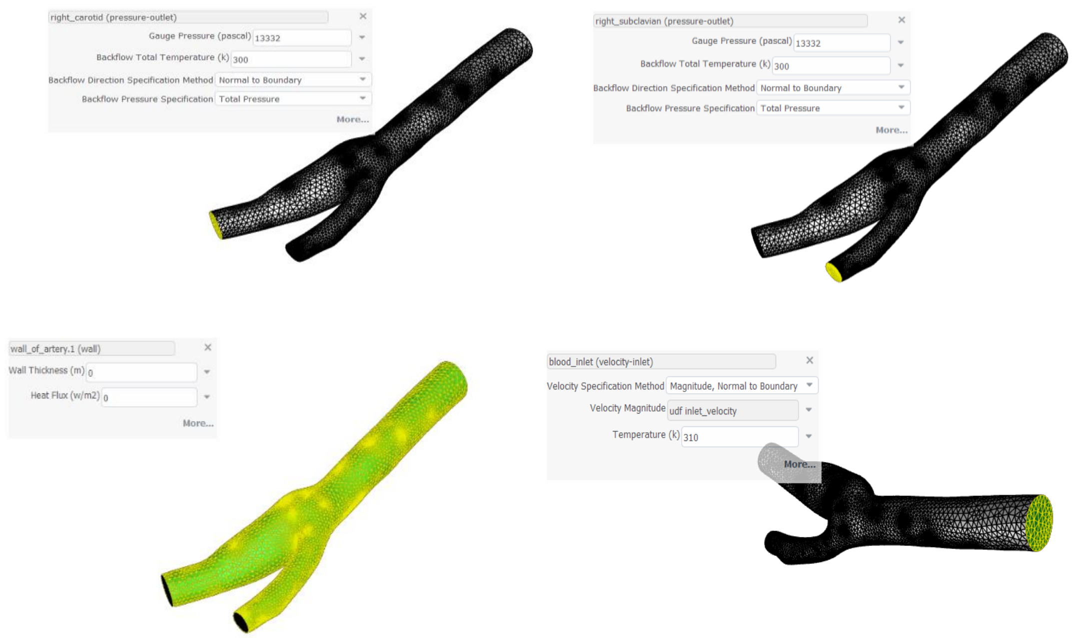

Figure 1: Coronary artery physical model with boundary conditions

2. Physical model

The first step in building physical models (figure 1) is the first step in running a CFD simulation [7]. The Ansys Design modeler is used in drawing the coronary artery [8, 9].

2.1. Meshing and Grid independence study

In the mesh workspace in Ansys, various surfaces corresponding to boundary conditions are named to create these boundaries for simulation. The generated geometry is then meshed to obtain simpler elements. Default settings are used. Grid independence analysis is conducted by running simulations with grid cells numbers obtained as a result of varying element sizes.

2.2. Numerical Setup in ANSYS Fluent

Under general, pressure-based solver is selected and problem is solved in transient state. Energy equation is selected and laminar is chosen for viscous model. K-epsilon model is chosen, and standard wall functions is selected for Near Wall Treatment.

Table 1
Setting Parameters

Setting Parameters	Type	Setting/Options
Solver type		Pressure-based
Viscous model		Laminar
Pressure-velocity coupling scheme [10]		Phase Coupled Simple

Spatial discretization	Gradient	Least squares cell based
	Pressure	Second order
	Momentum	Second Order upwind
Residuals	Continuity	1e-04
	U,v,w- velocity	1e-04

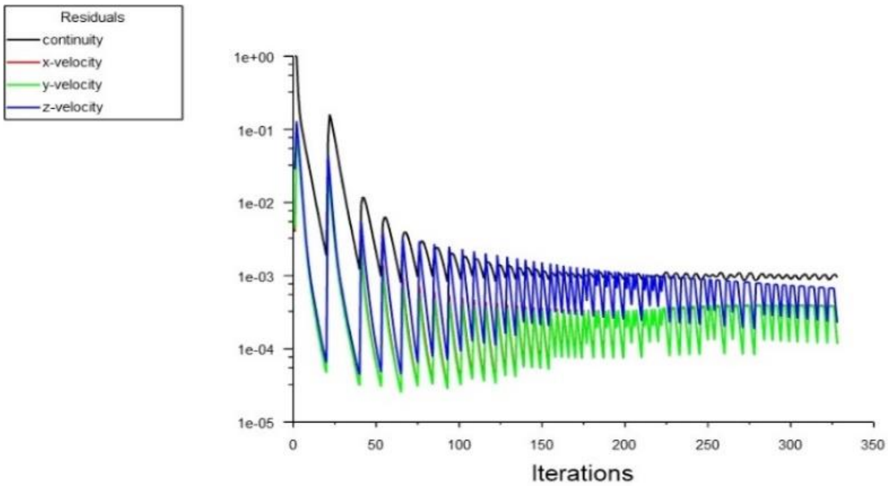

Figure 2: Residue graph showing convergence of continuity equation and velocity in the x, y and z direction

2.3. Material Properties

The materials used for this simulation are blood and air (fluids) and aluminum (solid). Blood is treated as an incompressible fluid in simulation and material properties are considered as constants. Density of blood is assumed to be 1050kg/m3, cp=3513j/kg-K, thermal conductivity(K)=0.44W/mK, viscosity(μ)=0.0035kg/ms. When blood is treated as compressible, a user defined function (udf) is written and inserted into ANSYS Fluent to account for differences in properties. Properties of air are written in ANSYS Fluent. Aluminum is material selected for aorta with properties already written in ANSYS Fluent.

2.4. Boundary Conditions

All boundaries are considered to be in the mixture phase.

Inlet_blood-is considered as a velocity inlet, with magnitude, normal to boundary chosen as velocity specification method and an initial value of 0.3m/s. The initial temperature is 37℃ (310K).

Mathematical description [4] for the velocity profile is given as

$$\mathrm{v}_{inlet}(t) = \begin{cases} 0.5\sin[4\Pi(t+0.0160236)] & : 0.5n < x \leq 0.5n + 0.218 \\ 0.10 & : 0.5n + 0.218 < n \leq 0.5(n+1) \end{cases}$$

Interior_solid is the internal boundary and the interior wall boundary condition is applied.

Outlet_blood is the outlet boundary, and the pressure outlet boundary condition is applied with a gauge pressure of 13332Pa. Under momentum, Pressure profile multiplier of 1 is applied with a normal to boundary backflow direction specification method.

Outlet_small is the outlet boundary and the pressure outlet boundary condition is also applied here.

Wall_artery- wall boundary conditions are applied.

2.5. Solver Settings

Hybrid initialization. Explicit method is used for discretization.

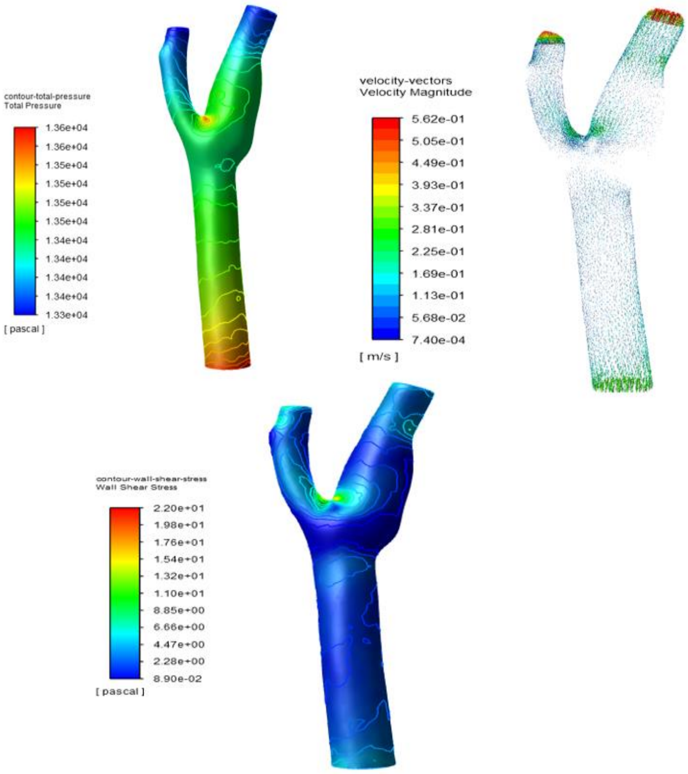

Figure 3: Pressure, velocity and wall shear stress distribution

According to literature [11], the mean velocity of blood inside the artery ranges from 0.11-0.13m/s. From the results above (figure 3), case A was closer with a value of 0.1399163m/s.

The lowest pressure recorded was 13444.24Pa also in case A. The average shear stress that acts on the artery wall is between 2.48-4.27Pa [12] depending on sex and age and it is observed that case A and C had values in this range.

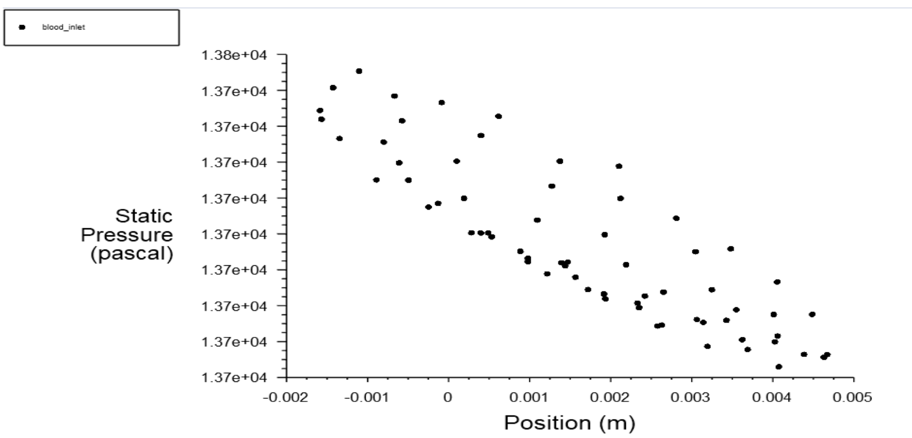

Figure 4: Plot of static pressure against diameter of blood inlet

3. Conclusion

In this numerical investigation, ANSYS Fluent was used to investigate the best model to determine viscosity and pulsatile velocity in a healthy human. The coronary artery was the main organ for study.

The numerical results showed that varying the viscosity of blood had a direct impact on viscosity and wall shear stress.

Models provided in ANSYS Fluent used for the simulation provided ranges that were above normal for average pressure and velocity with values between 13564.89Pa and 13618.12Pa for case Carreau and power law respectively. The highest shear stress was recorded for the Carreau model with a value of 6.03 which was way above normal values. Generally, ANSYS Fluent works better when values of viscosity and velocity are kept constant.

4. Acknowledgements

The project was accomplished with the financial support of the Science Committee of the Ministry of Science and Higher Education of the Republic of Kazakhstan according to the Program of grant funding of scientific and (or) scientific-technical projects in 2022-2024 (Grant No.AP14871641).

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