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ENHANCING MEDICAL INSIGHTS THROUGH COMPUTATIONAL FLUID DYNAMICS: VALIDATING SIMULATION MODEL FOR BLOOD FLOW IN VASCULAR SYSTEM

Ples M.[*], Wolański W.[**], Sobkowiak M.[***]

Abstract: *Understanding blood flow dynamics within the intricate network of blood vessels is crucial for advancing medical diagnostics and interventions. Computational methods, particularly Computational Fluid Dynamics (CFD), have emerged as powerful tools for studying blood flow behavior, offering invaluable insights into hemodynamic parameters and various physiological conditions. However, the utility of computational simulations in clinical decision-making relies on their accuracy and reliability, necessitating rigorous validation. In this paper, we describe a method of validating shear stress simulation on blood vessel walls by comparing it with a physical erosive model. The parametric arterial model was created in ANSYS, using morphometric parameters obtained from Murray's law. The model was simulated with non-Newtonian blood properties and a constant velocity. A physical model was created using 3D printing and tested under similar flow conditions. Results show agreement between simulated and physical models, confirming the efficacy of computational simulations in understanding vascular physiology and pathology. This underscores the need for continued validation and refinement to maximize their clinical utility.*

Keywords: Computational Fluid Dynamics (CFD), wall Shear Stress (WSS), validation, artery, blood flow.

1. Introduction

Understanding blood flow dynamics within the intricate network of blood vessels is crucial for advancing medical diagnostics and interventions (Nichols et al., 2012). Over the years, computational methods, particularly Computational Fluid Dynamics (CFD), have emerged as powerful tools for studying blood flow behavior. These methods offer invaluable insights into the hemodynamic parameters governing blood flow, providing a deeper understanding of various physiological and pathological conditions. By virtually replicating the complex fluid dynamics within blood vessels, CFD facilitates the exploration of flow patterns, shear stresses, and pressure distributions, offering predictive capabilities for assessing vascular pathologies such as atherosclerosis, aneurysms, and thrombosis. However, while computational simulations hold immense promise, their utility in clinical decision-making hinges upon their accuracy and reliability. As such, the validation of these simulations becomes paramount. Validating CFD models involves comparing simulated results with empirical data obtained from *in vivo* or *in vitro* experiments, ensuring that the computational predictions align with real-world observations. Furthermore, the development of physiologically accurate models is essential for bolstering the credibility of CFD simulations. Incorporating realistic anatomical geometries, tissue properties, and boundary conditions into these models is imperative to mimic physiological conditions faithfully. Additionally, refining computational algorithms to accurately capture fluid-structure interactions and biological phenomena further enhances the fidelity of simulations.

[*] Marek Ples MSc: Department of Biomechatronics of Silesian University of Technology, PL, marek.ples@polsl.pl

[**] Wolanski Wojciech BEng, PhD., DSc.: Department of Biomechatronics of Silesian University of Technology, PL, wojciech.wolanski@polsl.pl

[***] Marta Sobkowiak PhD., Eng: PL, marta.sobkowiak.pilorz@gmail.com

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In this paper, we will describe a simple method of validating the simulation of shear stress acting on the walls of blood vessels by comparing it with a simple physical erosive model developed by us. Through this discussion, we aim to underscore the key role of computational simulations in deepening our understanding of vascular physiology and pathology, while simultaneously emphasizing the critical need for rigorous validation and refinement of simulation models to maximize their utility in clinical practice.

2. Methods

The analysis was performed on parametric arterial model created in ANSYS environment. Morphometric parameters were obtained using the Murray's law (1), which tells about maintaining the lowest possible energy during flow. This law refers to both the division of angles and the radii of individual inlet r_0 and outlets r_1, r_2.

$$r_0^n = r_1^n + r_2^n \tag{1}$$

The flow is most energy-efficient when given exponent n is 3 (Murray, 1926).

Having the arterial morphometric data, the parametric model was modelled in ANSYS Design Modeler software. Boundary conditions, as well as parameters of the inflationary layer was setted. The inflationary layer consists of six layers (0.0075 mm high). Properties of the artificial blood to be simulated as non-newtonian liquid (Bird-Carreau Model, Bird et al., 1987), with molar mass: 18.02 kg/kmol, density: 1 050 kg/m^3, thermal capacity: 4 181.7 J/kg.K and viscosity: 0.0035 Pa.s. In the simulations the constant blood velocity Vs = 0.45 m/s was used. The model prepared in this way was simulated. The optimal bifurcation angle calculated in the previous simulations was used (Wolański et al., 2018).

The physical model of the vessel was created using the 3D printing technique FDM with the Czech company Prusa's i3 MK3 printer. ABS material was used for the inner mold with standard printing parameters (0.4 mm nozzle, hotend temperature – 225 °C, hotbed temperature – 90 °C). The printed mold was then coated externally with transparent chemically-cured epoxy resin. After the resin cured, the inner mold was dissolved using acetone. The next step involved applying a thin layer (0.1−0.2 mm) of water-soluble poly(vinyl alcohol) plastic on the inner walls of the vessel model with bifurcation. The vessel was then subjected to a circulation loop simulating flow conditions similar to those in the aforementioned simulation in the ANSYS environment.

3. Results

The simulation result of Wall Shear Stress (WSS) values is illustrated in Fig. 1, while the simulation result using the physical method is shown in Fig. 2.

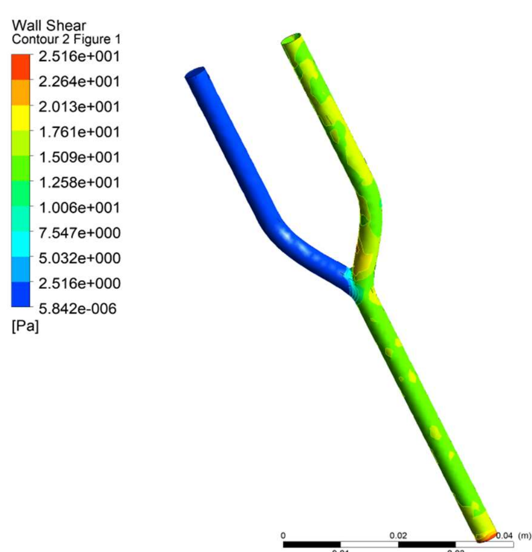

Fig. 1: WSS simulated in silico.

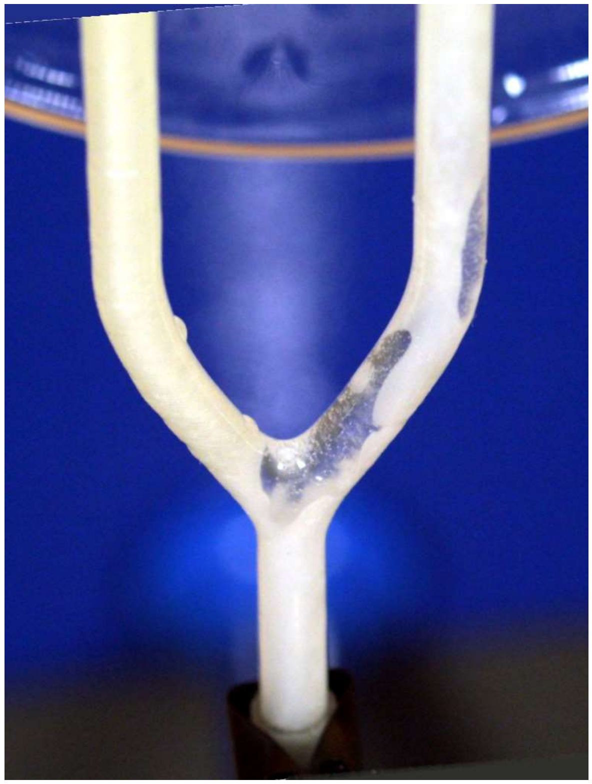

Fig. 2: Effect of physical simulation.

It can be clearly observed that in the areas where the numerical method predicts the highest WSS values, the water-soluble material in the physical model undergoes the fastest dissolution, indirectly confirming the actual highest WSS values at those points (Fig. 3).

The experiment's outcome appears to confirm the convergence of the effects of computer-based simulations (*in silico*) with simulations utilizing real physical effects in the real world.

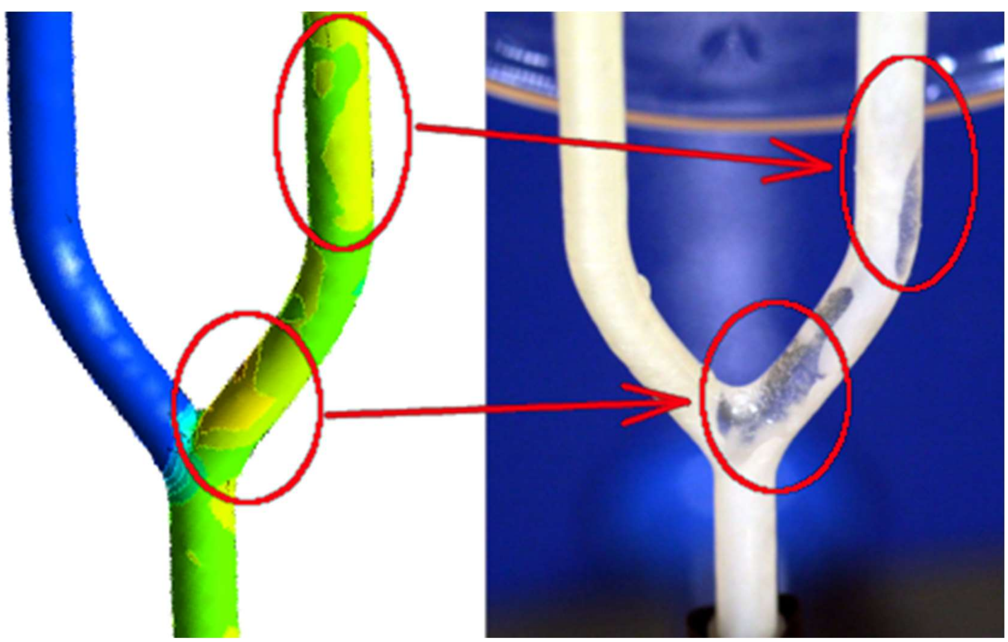

Fig. 3: Comparison effect of in silico and physical simulation results.

4. Conclusions

The presented physical method has demonstrated its efficacy in facilitating rapid validation of computer simulations of blood flow through bifurcated blood vessels. This approach ensures a robust comparison between simulated and observed phenomena, enhancing the accuracy and reliability of computational models in biomedical research and clinical applications. The ability to validate computational simulations with experimental data strengthens confidence in their predictive capabilities and fosters advancements in understanding complex physiological processes, ultimately benefiting medical diagnostics and treatment strategies.

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