A TWO-PHASE HAEMODYNAMIC MODEL FOR ARTERIAL MICROVASCULAR BIFURCATIONS

Tanchanok Wisitponchai (1, 2), Junxi Wu (1), Asimina Kazakidi (1)

1. Department of Biomedical Engineering, University of Strathclyde, Glasgow, UK;
2. Department of Biomedical Engineering, School of Engineering, King Mongkut's Institute of Technology Ladkrabang, Bangkok, Thailand

Abstract

The mechanistic links between haemorheology and clinical diseases, such as ischemia and stroke, are poorly understood due to the small size of microvessels and their intrinsic variability [1]. Several studies of the microcirculation have suggested that formation of a cell-free layer (CFL) due to the core movement of red blood cells (RBCs) influences wall shear stress (WSS) and velocity profiles. A better understanding of the blood flow in microvascular arterial networks and of metrics not easily measured in vivo can be achieved with the use of computational fluid dynamics methods. This study investigated the three-dimensional (3D) hemodynamics in a bifurcation where both the CFL and RBCs phases were taken into account. Moreover, the effect of CFL width on wall shear stress and velocity distribution was examined.

Methods

The geometry of a symmetric 20-µm-vessel-diameter Y-junction was constructed and meshed with polyhedral elements in Star-ccm+. Using the volume of fluid (VOF) multiphase approach, blood was simulated as a two-phase flow model consisting of a Newtonian CFL phase and a Newtonian or non-Newtonian (Carreau-Yasuda model) RBCs phase. Rheological properties relating to the selected parent vessel diameter, a ~40% hematocrit in rats [2] and an in-vivo viscosity model were assigned. A wall distance of 1.7 and 2.6 µm was assumed as CFL width. For the bifurcations with different CFL width, a plasma viscosity of 1.3 mPa-s was assigned to the CFL phase, whereas RBC viscosity in the RBC phase was varied, such that a whole-blood viscosity of 3.68 mPa-s was achieved.

Results & Discussion

The two-phase haemodynamic model was able to capture blood movement and velocity profiles observed experimentally in animal arterioles [3, 4]. The maximum RBC velocity profile was at the center of the parent vessel (Fig. 1A&C), however in the daughter vessels, the RBC phase moved towards the inner wall of the bifurcation, even though the maximum velocity was detected near the outer wall (Fig. 1A&D). Moreover, the model demonstrated that CFL widths influenced the variation of wall shear stress (Fig. 1B) and velocity profiles (Fig. 1C&D). In comparison to Newtonian, assuming the non-Newtonian fluid at the RBC phase reduced wall shear stress at the Y-junction (Fig. 1B). This work brings us a step closer to the understanding of blood rheology in microvessels.

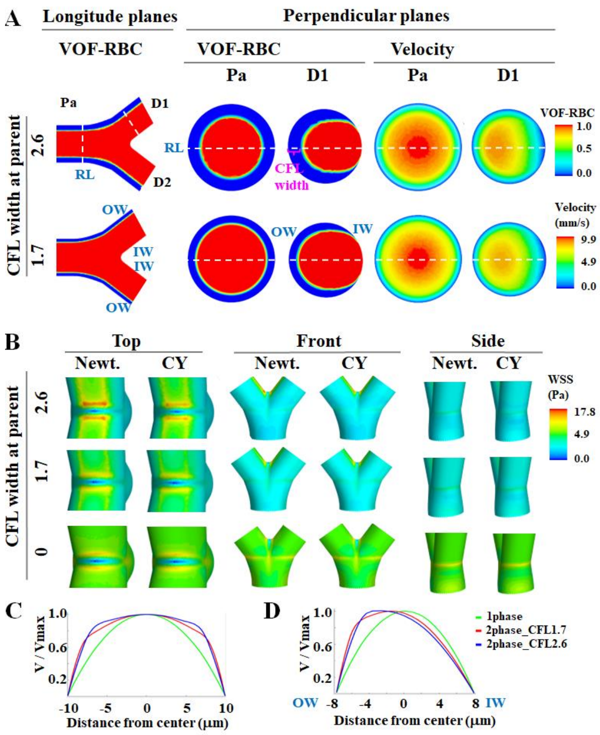

Figure 1: Two-phase haemodynamic model of a symmetric Y-junction with different CFL widths. A) CFL and RBC phases (blue and red, respectively) and velocity distribution. B) WSS at the Y-junction, compared to single phase (zero CFL width). C & D) Velocity profiles perpendicular to the axis of the parent (C) and the daughter vessel (D). Noted that, Pa, D1, RL, Newt., CY, OW, and IW stand for parent, daughter, referent line, Newtonian fluid, Carreau-Yasuda model, outer wall, and inner wall, respectively.

References

1. Alexy et al, Front Physiol, 13:906768, 2022.
2. Kim et al, Am J Physiol Heart Circ Physiol, 293(3):H1526-35, 2007.
3. Namgung et al, Front Physiol, 8:693, 2017.
4. Santisakultarm et al, Am J Physiol Heart Circ Physiol, 302(7):H1367-77, 2012.

Acknowledgements

Results were obtained using the ARCHIE-WeSt High Performance Computer (www.archie-west.ac.uk) based at the University of Strathclyde.