LAMINAR BLOOD FLOW IN STENOTIC MICROCHANNELS

Joana A. C. Calejo, Valdemar Garcia, Carla S. Fernandes

ESTiG/IPB - School of Technology and Management, Polytechnic Institute of Bragança, Bragança, Portugal

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Introduction

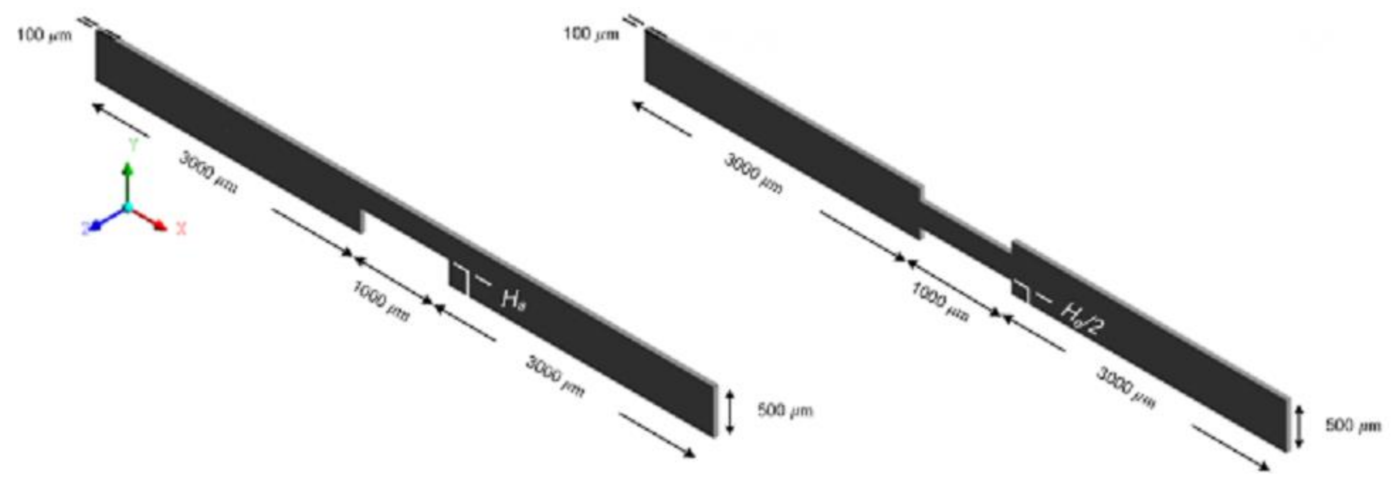
Over the past few decades, the interest in the atherosclerosis's studies has assumed a prominent place in medicine since this cardiovascular pathology has become one of the major causes of death. The dominant pattern is atherosclerosis, characterized by the formation of atheromas. Most of the times, the formation of an atheroma is accomplished by a thrombus formation. It is thought that the location of higher pressures and velocities promote the endothelium lesion and hence the formation of a thrombus, which normally conduce to a thromboembolism due to the high speeds and pressures [1]. Microfluidic devices are becoming one of the most promising new tools for diagnostic applications and treatment of several chronic diseases and the microchannels used in these devices usually have rectangular shape. Hence, it is essential to understand the blood flow behaviour involved in this kind of microchannels.

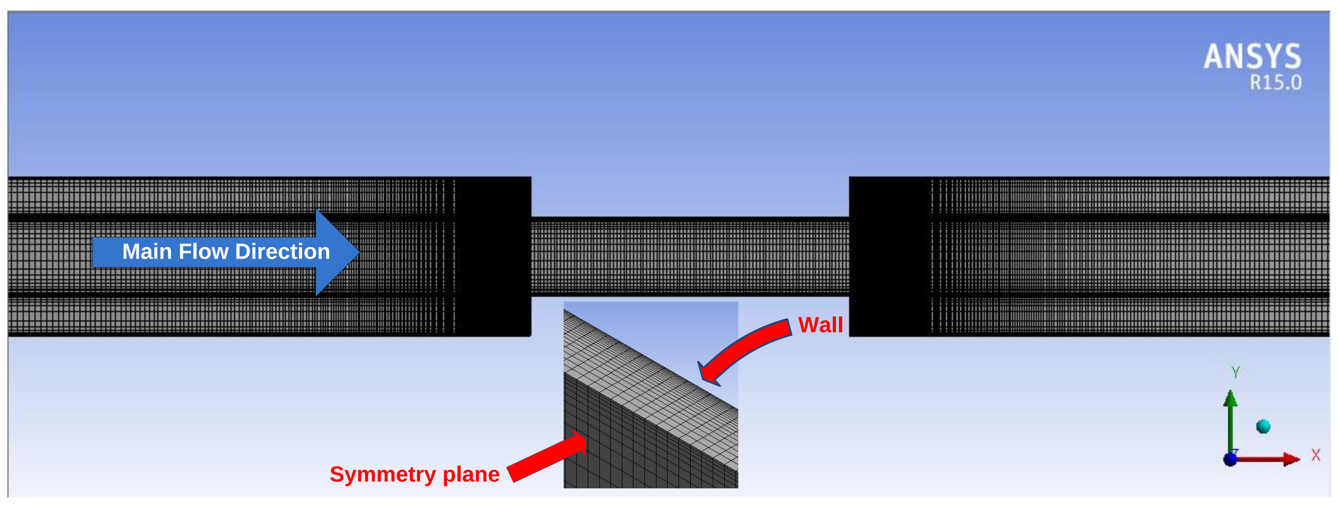
In this work, Newtonian and non-Newtonian laminar blood flow in rectangular microchannels with symmetric and asymmetric atheroma were numerically studied. Simulations were carried out using the commercial finite-volume package FLUENT®. In the calculations, blood was considered both Newtonian and non-Newtonian fluid, its rheology being described, in the second case, by the Carreau model [2].

Simulations were carried out in 3D rectangular geometries. Six channels with distinct stenosis degrees - 15%, 30% and 50% - were studied, 3 of them with symmetric atheroma and the other 3 with asymmetric atheroma. With this study we intend to analyse the impact of the atheroma's symmetry, as well as the influence of non-Newtonian properties of blood on its flow.

Numerical simulations

Geometry and mesh





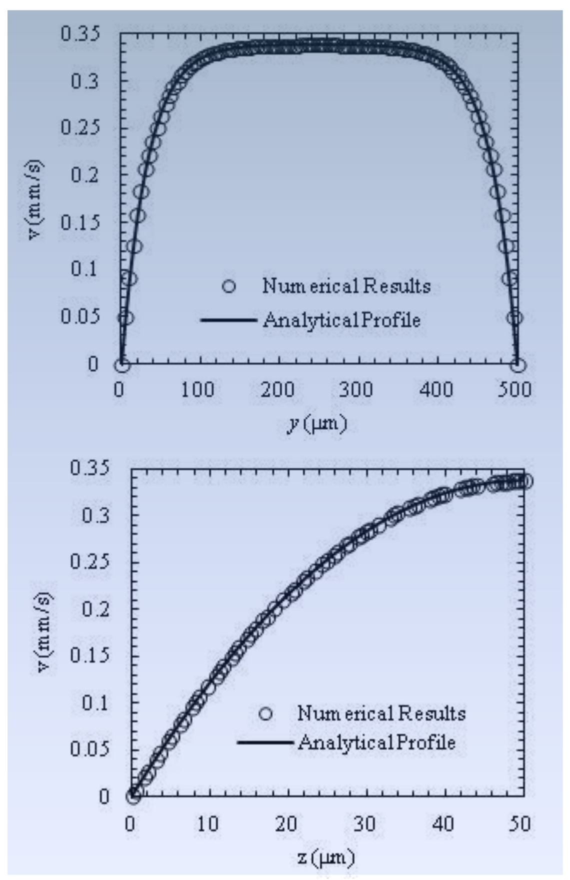
Model validation

Validation of numerical model was performed in two regions: before the atheroma and in the section of the atheroma.

Velocity profiles were compared with analytical solution [3]:

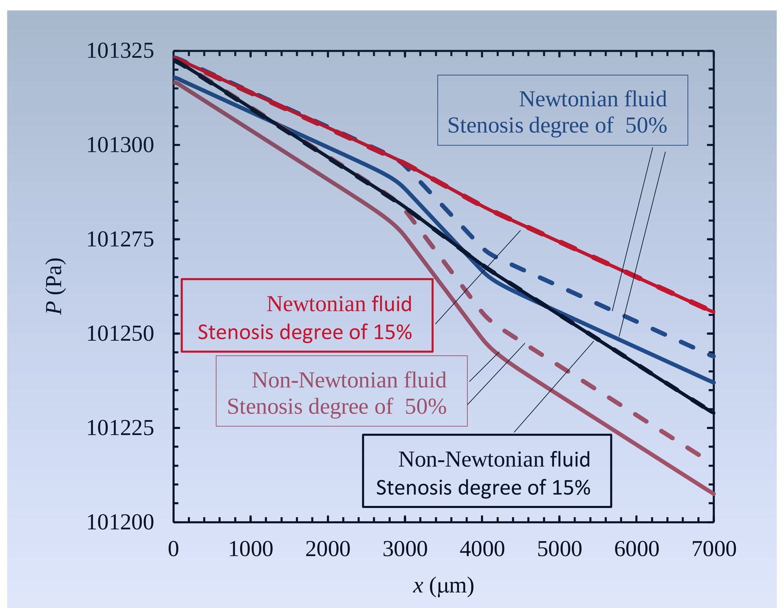
$$v_x(y,z) = \frac{2(w+h)^2 Po}{\pi^3 w^2} u \sum_{n,odd}^{\infty} \frac{1}{n^3}\left[1-\frac{\cosh\left(n\pi \frac{z}{h}\right)}{\cosh\left(n\pi \frac{w}{2h}\right)}\right]\sin\left(n\pi\frac{y}{h}\right)$$

For laminar flows, **pressure drop** can be estimated by the correlation $f = Po\,Re^{-1}$. Poiseuille's number, *Po*, is 19 before the atheroma and varies in the section of the atheroma according to the relation between high and width of the channel [4]. A good agreement was found for both sections : relative errors ranged between 0.01 and 0.1%.



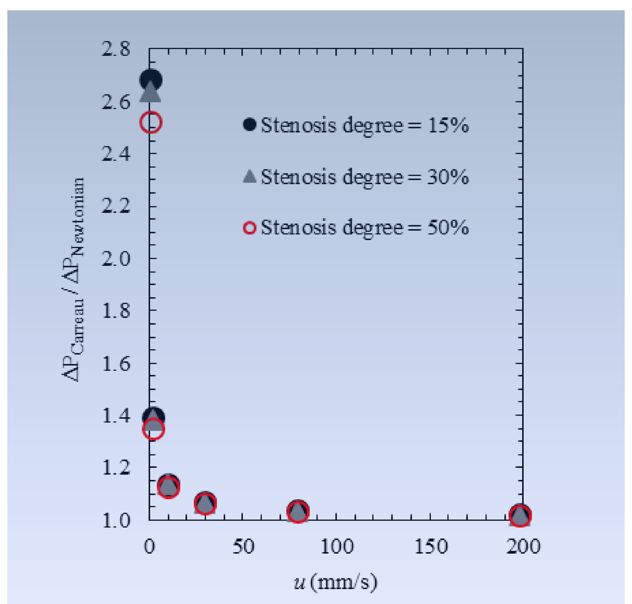
Results and discussion

Pressure drop



Pressure along channels for u = 1.98 mm/s: (---) symmetric atheroma; (–) asymmetric atheroma.

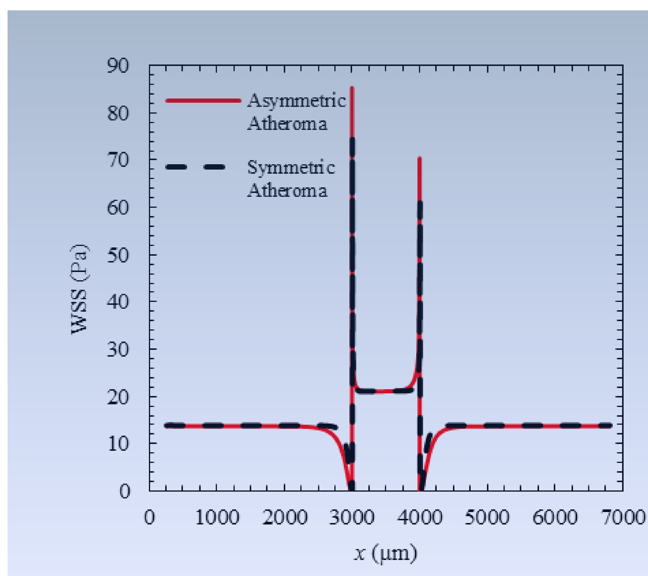
As expected, the influence of the symmetry of the atheroma in the pressure decrease with the decrease of the stenosis degree and pressure for Newtonian flow is higher than the one obtained for the non-Newtonian flow.



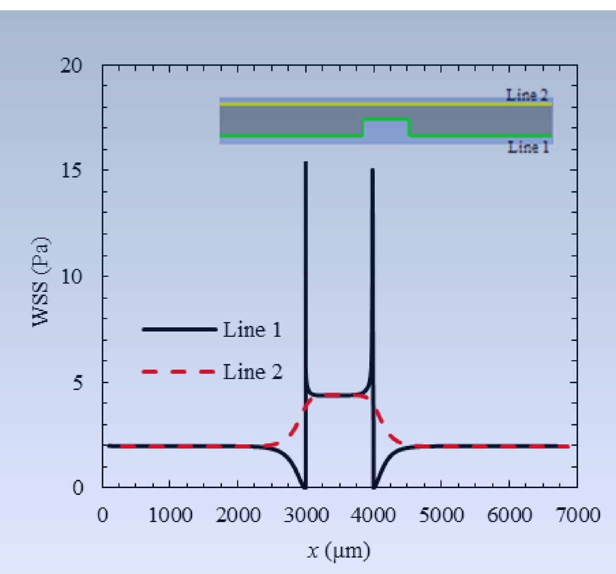
Ratio between pressure drop of non-Newtonian and Newtonian fluids.

Pressure drops are higher for the non-Newtonian flows and the impact of non-Newtonian properties on this flow property decrease with the increase of mean velocity, u.

Wall shear stress



WSS along Line 1 for 30% of stenosis degree, Newtonian fluid for u = 79.2mm/s.



WSS in top and bottom of the channel with 50% of stenosis degree for the Carreau fluid for u = 9.9 mm/s

The wall shear stress (WSS) along the channels for both Newtonian and non-Newtonian flows have been analyzed and it was verified that the maximum value was reached at the symmetry plane in the corner of the atheroma.

The asymmetry of the WSS profile is more pronounced for the asymmetric atheroma, being this asymmetry less pronounced for lower velocities. In the opposite side of the atheroma, Line 2, the presence of this obstruction is also felt.

The impact of non-Newtonian blood properties in the WSS was studied and it was concluded that WSS for Carreau fluid are higher than the ones developed for the Newtonian fluid and this impact increases with the decrease of mean velocity.

Conclusions

With this study, the influence of blood's non-Newtonian properties, stenosis degree and symmetry of atheroma in laminar flow's properties in stenotic rectangular microchannels were analysed. It was possible to conclude that in the range of studied mean velocities, local velocity is not affected by the used rheological model or symmetry of the atheroma. The non-Newtonian properties of blood leads to higher pressure drops and wall shear stress being this effect more pronounced for lower velocities.

Acknowledgment

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