A Non-Newtonian Model for Blood Flow Behind a Flow Diverting Stent

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Abstract

When calculating the blood flow in cerebral arteries and intracranial aneurysms, usually, blood is modeled as a Newtonian fluid since the shear rates are very high and so the shear-thinning behavior of blood can be neglected [1]. Beside the surgical treatment of cerebral aneurysms (clipping) there are two endovascular methods of treatment: coiling [2] and using flow diverting devices [3]. Both methods aim to slow down the blood flow inside the aneurysm sack to start clotting and finally lead to cicatrization of the pathological structures. The flow past such endovascular devices is much slower and more constant leading to much lower shear rates. Thus, the modeling of blood as Newtonian fluid should be reviewed.

We used the CSG capabilities of COMSOL Multiphysics® to model a bend cerebral parent vessel (diameter 2.14mm) with a side wall aneurysm (neck length 4.41mm, height 4.09mm) and a complex flow diverting device (Figure 1). The stent consists of 16 wires (70µm diameter) knitted to a mesh. The permeability of the device lies at round 55%, which corresponds to industrial samples. To model the blood flow we used the CFD Module (steady state solution of a single phase laminar flow problem) and a material sweep with two blood models. The first one is a Newtonian model with constant dynamic viscosity, the second one is a Carreau Yasuda model like used in [4]. The parameters were found using nonlinear least square regression on normalized measurements of human blood (HCT 40%, 37°C) (Figure 2).

Using the Carreau Yasuda model resulted in a range of dynamic viscosity from 3.57mPa*s to 7.1mPa*s (Figure 3). But not only the viscosity differs: the range of shear rates is slightly expanded as well as the range of velocities (Figure 4), the flow rate into the aneurysm sack is raised from 810mm^3/s to 843mm^3/s and the average velocity within the aneurysm sack is increased from 4.7cm/s to 5.0cm/s.

Against the first intuition the Newtonian model overestimates the effect of the flow diverting stent. Even there can't be seen relevant differences in the flow pattern, the error can be seen at the characteristic numbers. In our example this overestimation was about 4% to 6%. Thus, the Newtonian model seems not to be sufficient for flow calculations past endovascular devices. Further investigations with even better blood models and 3D

images of real flow diverting stents in vivo have to be done.

Reference

[1] J. R. Cebral et al., Efficient pipeline for image-based patient-specific analysis of cerebral aneurysm hemodynamics: technique and sensitivity, IEEE Transactions on Medical Imaging, Vol. 24, pp. 457-467 (2005)
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[3] M. Leonardi, Treatment of Intracranial Aneurysms Using Flow-Diverting Silk Stents (BALT): A Single Centre Experience, Interventional Neuroradiology, Vol. 17, pp. 306-15 (2011)
[4] J. Boyd et al., Analysis of the Casson and Carreau-Yasuda non-Newtonian blood models in steady and oscillatory flows using the lattice Boltzmann method, Physics of Fluids, Vol. 19, Issue 9 (2007)

Figures used in the abstract

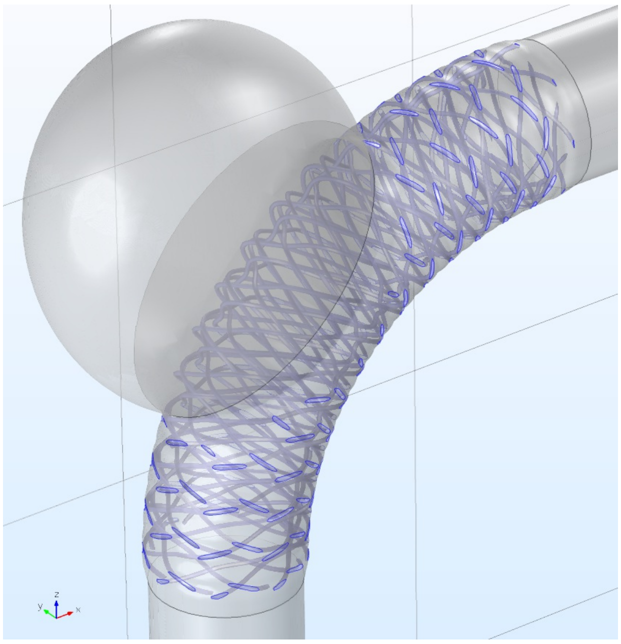

Figure 1: Geometry of cerebral aneurysm and flow diverting stent.

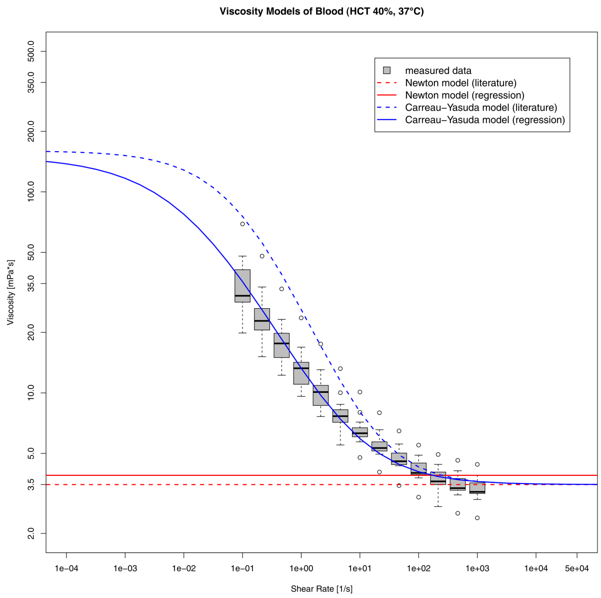

Figure 2: Viscosity models of blood (HCT 40%, 37°C). Parameters were taken from literature (dashed lines) and from regression (full lines).

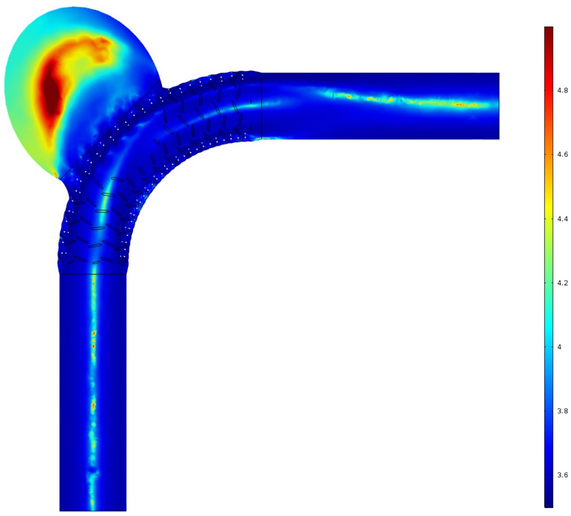

Figure 3: Viscosity profile of the Carreau Yasuda model. Values are given in mPa*s.

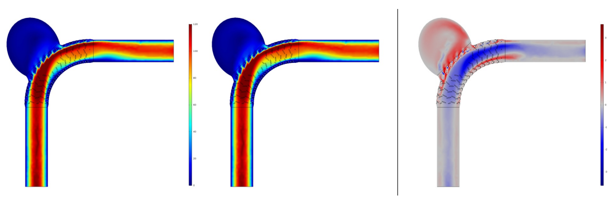

Figure 4: Velocity profiles of the Newtonian model (left), the Carreau Yasuda model (middle) and the difference (Carreau Yasuda - Newton) between them (right). Values are given in cm/s.