Influence of the non-linear rheological properties of blood in middle cerebral aneurysms: numerical and experimental *in vitro* analysis

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It is well known that the non-linear rheological properties of blood have a great influence in the development of cardiovascular diseases. Among these pathologies, cerebral aneurysms are one of the most common cerebrovascular accidents and are the cause of one-third of deaths worldwide[1]. This kind of accident starts with a dilatation of an artery usually occurring near arterial bifurcations in the Circle of Willis[2,3]. Despite increasing progress, the initiation, growth and rupture of aneurysms are still not well understood, and further hemodynamic studies are crucial for the diagnostic and treatment of these diseases. However, due to the difficulties associated with working with real blood (due to the economical, safety and ethical issues involved), synthetic models of blood are often used.

Recently, Campo-Deaño et al.[4] developed viscoelastic blood analogues able to mimic the complex rheological behavior of real blood and simultaneously exhibit a refractive index suitable for their use in microchannels made of PDMS (polydimethylsiloxane). In addition, the viscoelastic moduli and the steady shear viscosity data obtained experimentally were fitted using two viscoelastic multi-mode differential constitutive equations-the simplified Phan-Thien-Tanner (sPTT) and Giesekus models:

$$\tau_{ij} = \tau_{ij_s} + \tau_{ij_p} \tag{1}$$

$$\tau_{ij_s} = -2\eta_s D_{ij} \tag{2}$$

$$\tau_{ij_p} = \sum_{k=1}^{n} \tau_{ij_k} \tag{3}$$

with

$$f(\tau_{nn_k})\tau_{ij_k} + \lambda_k \overset{\nabla}{\tau}_{ij_k} - \alpha_k \frac{\lambda_k}{\eta_{pk}}\{\tau_{ij_k}.\tau_{ij_k}\} = -2\eta_{pk} D_{ij_k} \tag{4}$$

and

$$f(\tau_{nn_k}) = 1 + \frac{\lambda_k \epsilon_k \tau_{nn_k}}{\eta_{p_k}} \tag{5}$$

The deformation tensor is given by

$$D_{ij} = \frac{1}{2}\left(\frac{\partial u_j}{\partial x_i} + \frac{\partial u_i}{\partial x_j}\right) \tag{6}$$

The two multi-mode models considered have three coefficients in each mode: the relaxation time (λ_k), the viscosity contribution to the zero shear viscosity (η_{p_k}) and the extensibility coefficient (ϵ_k) or the mobility factor (α_k). α_k should be set to zero for the sPTT model and for the Giesekus model the function should be made equal to 1.

In this work we perform numerical simulations to investigate the hemodynamics in simplified geometries representative of middle cerebral aneurysms using Computational Fluid Dynamics (CFD), which is a technique that has been progressively used for modelling the flow in diseased arteries and it is a tool of great potential for the diagnostic, prediction and treatment of cerebral aneurysms[5]. We consider a Newtonian approximation and the Giesekus and sPTT models based on fitting the rheology of human blood[4]. Three geometries are considered consisting of different bifurcations with an aneurysm located at the end of the parent vessel, between two daughter vessels, in which the neck of the aneurysm and the shape of the daughter branches are varied (Fig. 1). The numerical results were afterwards compared with experimental results of the velocity profiles obtained by means of micro-Particle Image Velocimetry measurements in the different aneurysm configurations using blood analogue solutions.

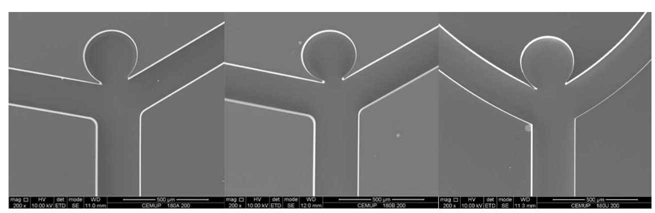

FIG. 1. SEM images of the planar microchannels fabricated in PDMS.

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1 C. Deaton, E.S. Froelicher, L.H. Wu, C. Ho, K. Shishani, and T. Jaarsma, J. Cardiovasc. Nurs. 26, S5 (2011).
2 J.C. Lasheras, Annu. Rev. Fluid Mech. 39, 293 (2007).
3 D.M. Sforza, C.M. Putman, and J.R. Cebral, Annu. Rev. Fluid Mech. 41, 91 (2009).
4 L. Campo-Deaño, R.P.A. Dullens, D.G.A.L. Aarts, F.T. Pinho, and M.S.N. Oliveira, Biomicrofluidics 7, 034102 (2013).
5 L. Campo-Deaño, M.S.N. Oliveira, and F.T. Pinho, Appl. Mech. Rev. (2014) *submitted.*