Effects of applied pressure and clot viscosity on aspiration catheter performance

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Introduction

The coronary vessels are prone to suffer from blockage which mainly occurs when a clot blocks and thus interrupts the movement of blood. This clot might form in some other locations but travels to the coronary vessel. The ratio of thrombin to fibrinogen [1] and the time elapsed after clot initiation may lead to variation of rheological parameters and clot viscosity [2]. Catheterization is one of the therapeutic approaches used to tackle the problem. Simple aspiration catheters are used by interventionists as an easy and reliable method. By percutaneous intervention the catheter is advanced to the blocked coronary vessel and application of an aspiration pressure removes the clot. The present work aims to investigate the performance of an aspiration catheter (Xtract, Lumen Biomedical, Inc) via computational fluid dynamics (CFD). To the purpose, the effect of aspiration pressure applied for the clot absorption is studied for different viscosity of clot. Clot viscosity variation is assumed to capture its mechanical properties, reflecting how mature the clot is due to the time passed after clot coagulation. The results from this study indicate that both clot viscosity and applied pressure affect catheter aspiration performance. By increasing the clot viscosity the catheter aspiration performance decreases depending on the applied pressure. An increase in applied pressure (if high enough) may mildly increase the performance of the catheter. This study is preliminary to future tuning of clot properties based on patient-specific rheological data from blood samples, which might improve the efficacy of the procedure.

Materials and Methods

The very first part of the aspiration procedure is modelled at different conditions based on the viscosity of clot and the applied aspiration pressure, with the aim of establishing a procedure to predict initial catheter performances. Clot viscosity varied from 50 to 300 Pa·s, representing different degree of clot freshness. A Carreau non-Newtonian model of viscosity was used for blood [3]. To predict the behaviour of clot and blood movement, the Navier-Stokes equations were solved numerically by means of Fluent (ANSYS Inc). The interface locations between the two fluids - blood and clot - were tracked through the Volume of Fluid (VOF) approach [4].

To include the behaviour of the fluid inside the catheter, a simplified lumped-parameter model was considered:

$$L\frac{dQ}{dt} + RQ = P_{proximal} - P_{distal} \tag{1}$$

where L is the fluid inertia (blood), R is the hydraulic resistance of the catheter, Q is the volume flow rate and $P_{proximal}$ and P_{distal} are the applied pressure at proximal and distal tips of the catheter, respectively.

The time history for the applied aspiration pressure was taken from the literature [5] and is presented in Fig.1. However, based on Eq.1, the applied pressure reduces at distal tip, due to the resistance and inertia of the catheter lumen. For the current study the pressure at distal tip is considered from very low amount to a high amount.

Results and Discussion

Figure 2 depicts the typical shape of the volume occupied blood clot (in red) a few moments after start.

Figures 3 and 4 show the effect of clot viscosity on catheter aspiration performance, defined as the volume percentage of aspired clot, when the applied pressure is 10 and 50 kPa at the distal tip of the catheter, 1 s after aspiration starts. As expected, when the viscosity of clot increases, the aspiration performance decreases. When the applied pressure is low (10 kPa, Fig.3) the increase in clot viscosity does not affects the aspiration performance at viscosities higher than 150 Pa·s. When the applied pressure is higher (50 kPa, Fig.4), the aspiration performance steadily decreases.

For clots with the same viscosity, aspiration performance is higher for the case with 50 kPa pressure than the case with 10 kPa pressure. For instance, with a viscosity of 50 Pa·s, after 1 s from aspiration start, the volume of aspirated clot is 15% in the former case and 25% in the later case. They become 7.4% and 11% when pressure is 10 kPa and 50 kPa, respectively. The effect of aspiration pressure for the clot viscosity of 100 Pa·s is shown in Fig.5. At low pressure, the volume of aspirated clot does not change significantly, while the aspiration performance increases smoothly at increasing aspiration pressure.

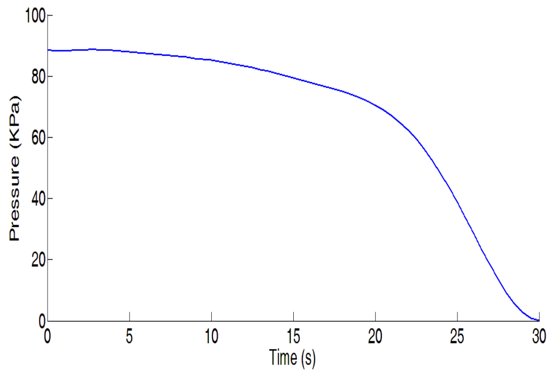

Figure 1. Time-varying aspiration pressure from in vitro test for the Invatec Diver CE device at proximal end [4].

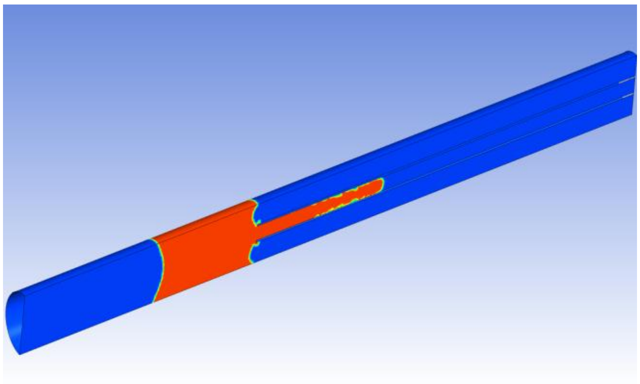

Figure 2. Schematic view of partially aspirated clot inside the catheter, symmetric domain.

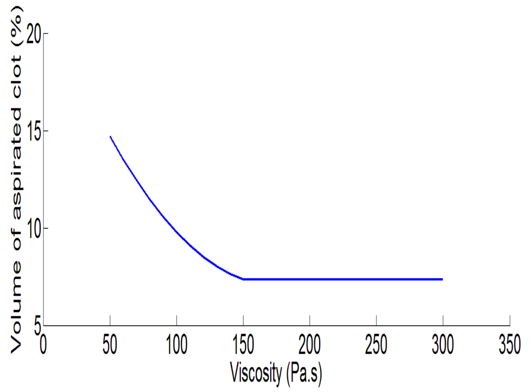

Figure 3. Volume of aspirated clot as a function of clot viscosity at an applied pressure of 10 kPa, 1 s after aspiration starts.

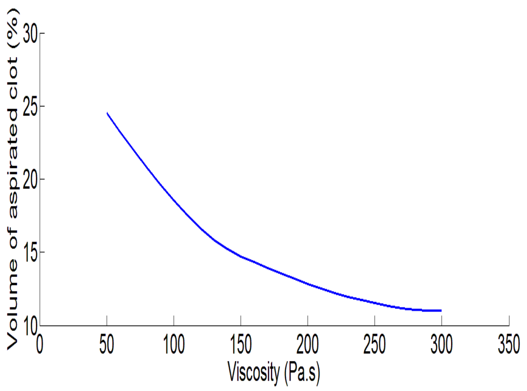

Figure 4. Volume of aspirated clot as a function of clot viscosity at an applied pressure of 50 kPa, 1 s after aspiration starts.

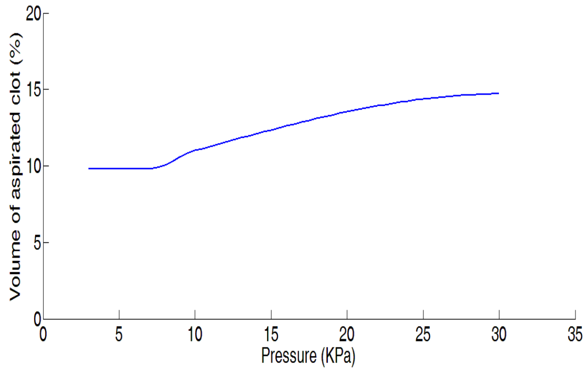

Figure 5. Volume of aspirated clot as a function of aspiration pressure for a clot viscosity of 100 Pa·s, 1 s after aspiration starts.

Conclusion

The aspiration performance of the Xtract catheter – measured as the percentage volume of aspired clot – was investigated at different clot viscosity and applied aspiration pressure. This study shows that both viscosity and applied pressure affect the volume of clot aspiration. In general the trends of the volume of the aspirated clot versus clot viscosity are descending at increasing viscosity and reach a plateau for the viscosity higher than150 Pa·s and applied pressure of 10 kPa. When the applied pressure is high enough, it causes higher aspiration with moderate slope while in a wide range of applied pressure the variation of pressure does not change significantly catheter aspiration performance.

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References

1. Collet, J.P., Woodhead, J.L., Soria, J., Soria, C., Mirshahi, M., Caen, J.P., & Weisel, J.W. 1996, Fibrinogen Dusart: electron microscopy of molecules, fibers and clots, and viscoelastic properties of clots. *Biophysical Journal* 70, 500-510. (doi: 0006-3495/96/01/500/11)

2. Anand, M., Rajagopal, K. & Rajagopal, K.R. 2006, A viscoelastic fluid model for describing the mechanics of a coarse ligated plasma clot *Theor. Comput. Fluid Dyn.* 20, 239–250. (doi: 10.1007/s00162-006-0019-9)

3. Turkeri, H., Piskin, S. & Serdar Celebi, M. 2010, Non-Newtonian blood flow simulation in a realistic artery domain, ECCOMAS CFD 2010 – V European Conference on Computational Fluid Dynamics, Lisbon, Portugal, 14–17 June 2010, 1-12.

4. Favero, J.L, Cardozo, N.S.M., Secchi, A.R. & Jasak, H. 2010, Simulation of free surface viscoelastic fluid flow using the viscoelasticInterFoam Solver, 20th European Symposium on Computer Aided Process Engineering – ESCAPE20, S. Pierucci and G. Buzzi Ferraris (Eds.), Ischia, Naples, Italy, 6-9 June 2010, 1-6.

5. Pennati, G., Balossino, R., Dubini, G. & Migliavacca, F. 2010, Numerical simulation of thrombus aspiration in two realistic models of catheter tips. *Artificial Organs* 34, 301–310. (doi: 10.1111/j.1525-1594.2009.00770.x)