Experimental and CFD Numerical Simulations of Atherosclerotic Plaques Occurring in Vessel Branches

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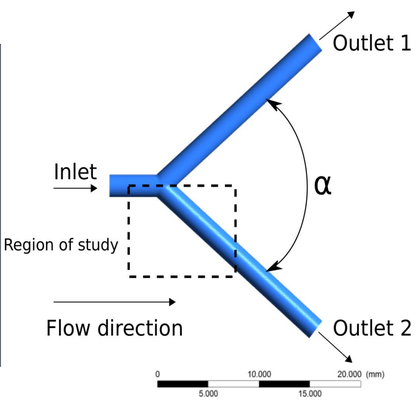
Abstract

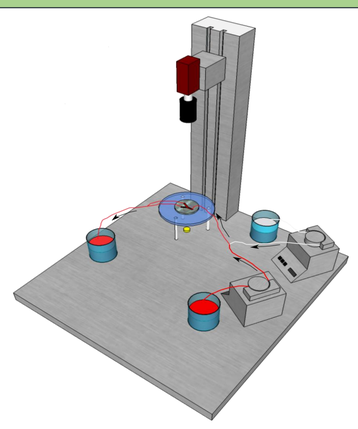
Cardiovascular disease is the leading cause of dead. We performed an exhaustive investigation in a simplified model aiming to characterize those regions in vessel bifurcations that are more likely to develop atherosclerotic plaques. Our investigation is based on numerical simulations (via CFD) and on in-vitro experiments realized in an ad-hoc designed polydimethylsiloxane (PDMS) channel [1]. The results obtained demonstrate that low velocity regions and low shear stress zones are located in the outer walls of bifurcations. In fact, we found that there is a critical range of bifurcation angles that is more likely to vascular disease than the others. Influence of inflow velocity on this critical range of angles is also analyzed [2].
Furthermore, we carried out numerical simulations with the aim of understanding nano-and-microparticles behavior in blood flows through a blood vessel stenosis. Different shapes and sizes were analyzed. [3]

Numerical Model and Experimental Setup

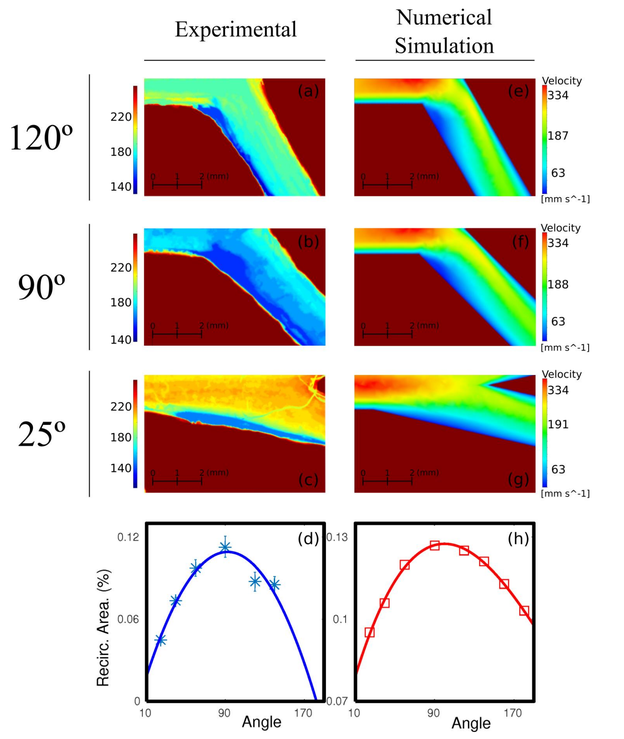
Considered vessel geometry in the computational model; it consists in a mother vessel that is divided into two daughter vessels when the mother vessel reaches the bifurcation point. Different vessel angles were considered in a [25˚, 180˚] interval making 8 different geometries using CAD tools. All vessels have the same diameter (2 mm).



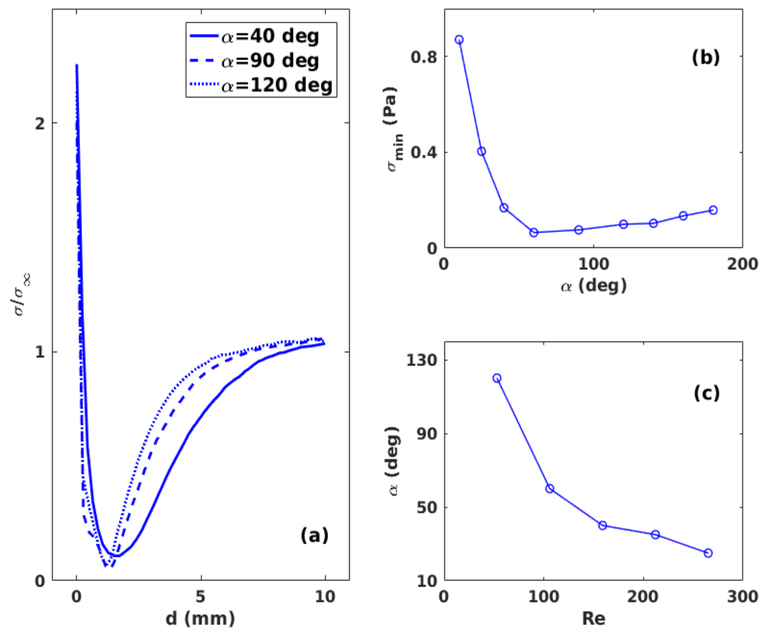
General scheme of the experimental setup. Two peristaltic pumps are used to pump ferroin and sucrose solution from their corresponding reservoirs. The mixture of both fluids occurs in a Y-shaped bifurcation and after that, the mixture enters the PDMS geometry that is illuminated with a led.



Results



Comparison between experimental and numerical simulation data in half geometry of three different values of α (25˚, 90˚ and 120˚). First column (panels a to c) present (color coded) the spatial distribution of the flow velocity in the channel when a sucrose solution is circulated in the device at 27 ml/min. The column on the right shows the flow velocity magnitude considering an input velocity of 0,2 m/s. The sizes of the areas of low circulation are plotted in panels (d) for experiments and (h) for numerical simulations for different bifurcation angles



a) Wall shear stress versus distance to the bifurcation along the outer bifurcation wall for different bifurcation angles. σ∞=1.55 Pa b) Minimum wall shear stress as a function of α. c) Bifurcation angle in which the lower value of wall shear stress appears versus Reynolds number

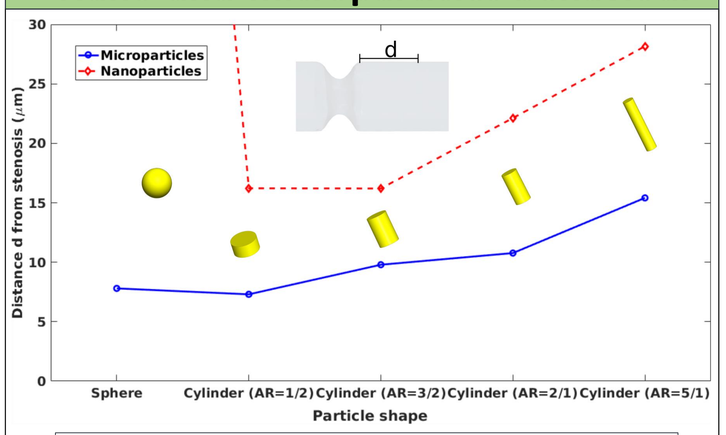
Conclusions

In this work it was performed numerical and experimental analysis of blood flow in coronary artery bifurcations in order to identify low velocity areas that could favor the formation of atherosclerosis plaque. The results obtained demonstrate that low velocity regions and low shear stress zones are located in the outer walls of bifurcations. Furthermore, it was found that there is a critical range of bifurcation angles that could be more prone to stenosis than the others and that the flow velocity influences this range of angles. In addition, numerical simulations carried out in order to better understand nano-and-microparticles behavior flowing through stenosis show that particles with low aspect ratio could be more effective as drug carriers than others with other shapes.

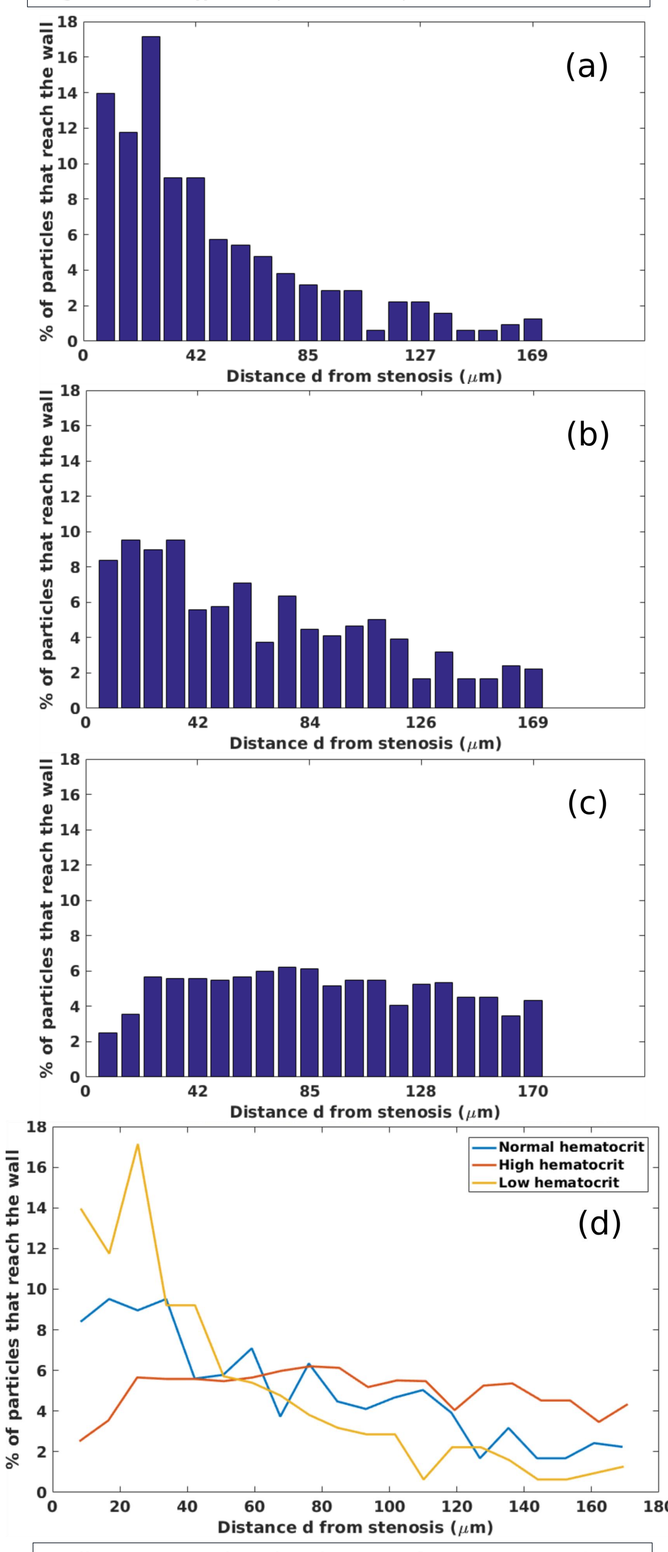
References

[1] Aymerich, M., Álvarez, E., Bao-Varela, C., Moscoso, I., González-Juanatey, J. R., and Flores-Arias, M. T. (2017). Biofabrication **9**(2), 025033.
[2] A. Otero-Cacho, M. Aymerich, M.T. Flores-Arias, M. Abal, E. Alvarez, V. Pérez-Muñuzuri, and A.P. Muñuzuri (2018). Scientific Reports **8**, 2795.
[3] A. Otero-Cacho et al. in preparation

Nano-and-microparticles behaviour



Disc and rod shaped nanoparticles with low aspect ratio reach the wall before other geometries. Nanoparticles with spherical shape do not touch the outer wall showing a low efficiency as drug carrier. In general, microparticles migrate more efficiently than nanoparticles.



Wall microparticles distribution after stenosis. a) Low hematocrit. b) Normal hematocrit. c) High hematocrit. d) Comparison.

Ongoing Work

In vitro experiments. Nanoparticle behaviour considering flows through a blood vessel stenosis.

Acknowledgements

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