Experimental Validation of Numerical Models for Atherosclerosis Risk Prediction Using Preclinical Devices Fabricated With Laser

Alberto Otero-Cacho[1], María Aymerich[1], M. Teresa Flores-Arias[1], Ezequiel Álvarez[2], Alberto Pérez-Muñuzuri[1] y Vicente Pérez-Muñuzuri[1]

[1]*Faculty of Physics, Universidade de Santiago de Compostela, Santiago de Compostela, E15782 España*
[2]*Instituto de Investigación Sanitaria de Santiago(IDIS); Fundación Ramón Domínguez, SERGAS; 15706 Santiago de Compostela, España y CIBERCV, Madrid, España*
**alberto.perez.muñuzuri@usc.es*

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Abstract

Hemodynamic characteristics of the blood play a key role in the incidence and development of cancer disease (metastases) and cardiovascular disease (arterial stenosis and atherosclerosis) among others. In this work, a theoretical and experimental comparison between flux behavior in coronary vessels is performed. By laser techniques, we manufacture preclinical devices that imitate blood vessels and we employ them to simulate flux conditions in different geometries. We focus on the blood flow characteristics in vessel bifurcations with different angles to identify recirculation and backward areas known to favor the formation of atherosclerotic plaque. Numerical analysis via CFD of such configurations was carried out. We assume rigid walls and a Newtonian non-turbulent incompressible flow. To that end, the size of the recirculation zones has been measured theoretically and experimentally.

Keywords: laser writing, biomedical applications, flux implementation, backward areas, atherosclerosis risk

Numerical Model

Fig. 1. Considered vessel geometry in the computational model 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 [25º, 180º] interval making 8 different geometries using CAD tools. All vessels have the same diameter (2 mm).

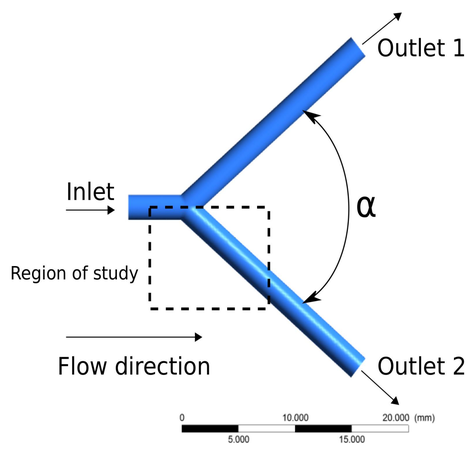
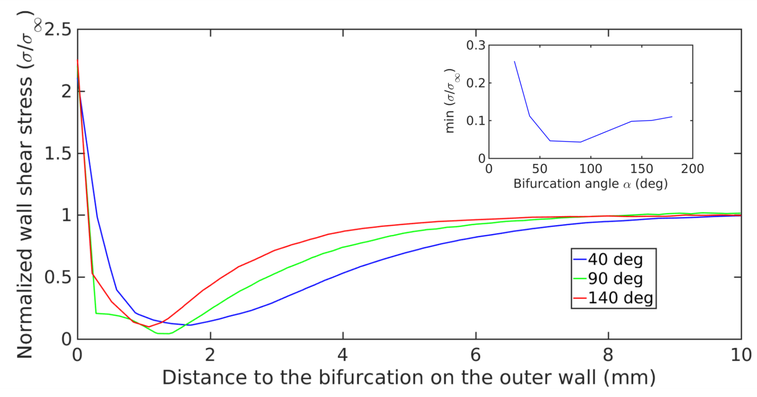


Fig. 2. Wall shear stress is a widely used parameter to determine which zones are more prone to form plaque. Blood vessel walls with low shear stress are more prone to plaque formation and thus to the development of atherosclerosis. Angle dependence evolution of shear stress in outer bifurcation wall is represented.



Laser fabrication of the channels and experimental validation of the backward areas

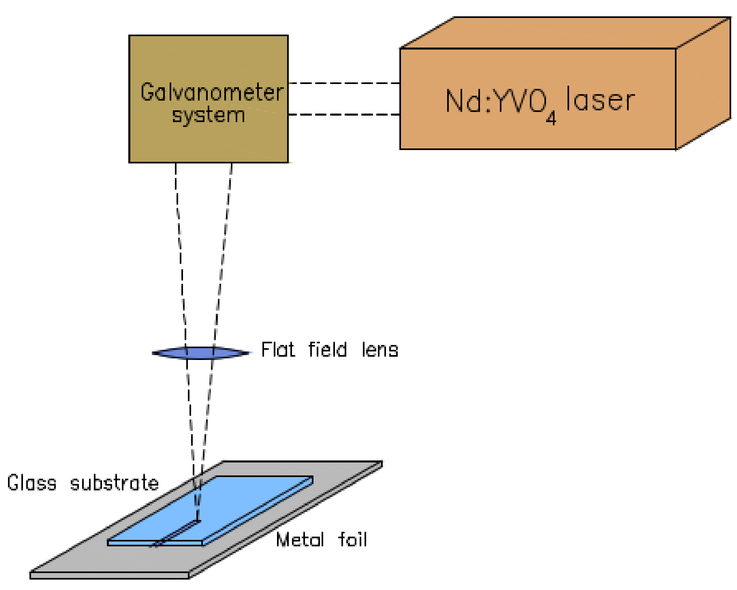


Fig 3. Experimental setup for the laser backwriting technique. The laser was combined with a galvanometer system formed by mirrors that addresses the laser beam, so no need of sample movement was needed. A flat field lens with 100 mm focal length was employed in order to focus the laser over the substrate and provided a working area of 80x80 mm^2.

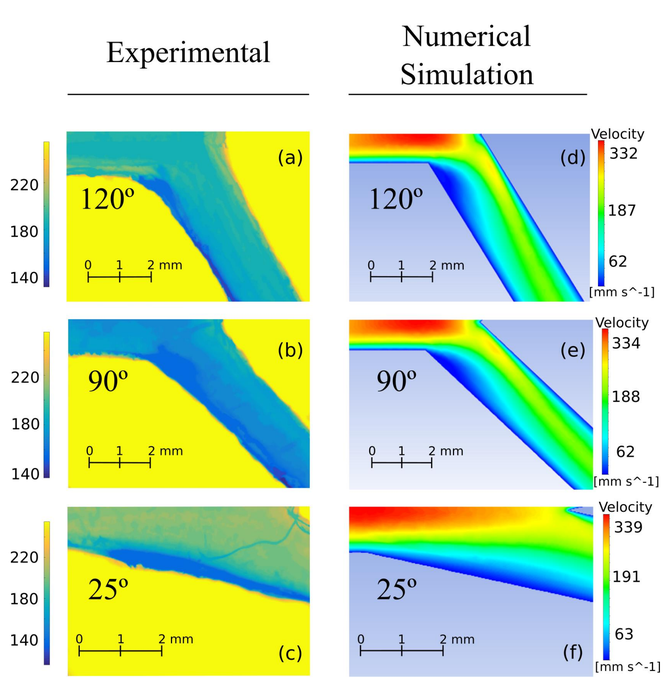


Fig 4. Comparison between experimental and numerical simulation data in half geometry of three different values of α (25º, 90º and 120º). a), b), c) represent different gray values obtained in the experimental part after injecting 27ml/min of solution of sucrose (35%) and 2.5ml/min of ferroin. d), e), f) show the contours of the velocity magnitude considering an input velocity of 0.2m/s.

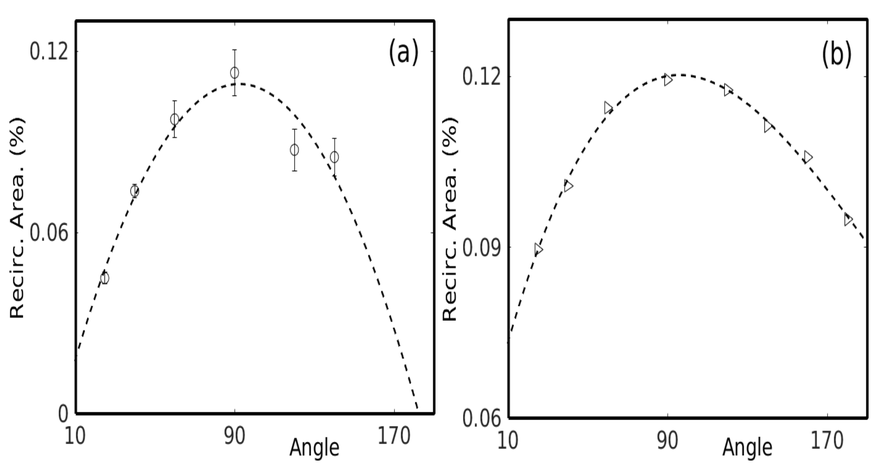


Fig 5. Evolution of recirculation area is represented. In (a) recirculation area is represented considering experimental data (gray values). In (b) recirculation area is represented considering numerical simulation data (contours of velocity).

Conclusions

In this work it was performed numerical and experimental analysis of blood flow in coronary artery bifurcations in order to identify recirculation and backwater areas that could favor the formation of atherosclerosis plaque and development of cancer disease (metastases). For the experimental validation, preclinical devices that mimic blood vessels were fabricated by using laser backwriting technique [1]. The results obtained demonstrate that recirculation zones and low values of shear stress are located in the outer walls of bifurcation. Furthermore, it was found that there is a critical bifurcation angle that could be prone to stenosis than the others. In some studies, the incidence of bifurcation angle in plaque formation has been studied through in vitro experimental models reaching very similar conclusions as in our work [2]

References

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Acknowledgements

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