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CELL MIGRATION AND MASS TRANSPORT SIMULATION THROUGH VASCULAR GRAFT (POROUS MEDIA) USING A MULTI-SCALE APPROACH

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ABSTRACT

The cardiovascular diseases are emerging as a main public health problem in the world, according to the World Health Organization. Treatments for these pathologies include vascular grafts, stents, and drugs, among others. For example the vascular grafts are biomedical devices used for the partial replacement of damaged arterial vessels [1].

Properties of the micro-structure of the graft such as porosity, permeability, tortuosity and diffusivity are key properties in the transport of cells and in the healing process [2, 3]. However, erroneous cell migrations and the influence of shear stress are important to understand pathologies such as activation and deposition of platelets, thrombus formation, intimal hyperplasia development, hemolysis, among others [4].

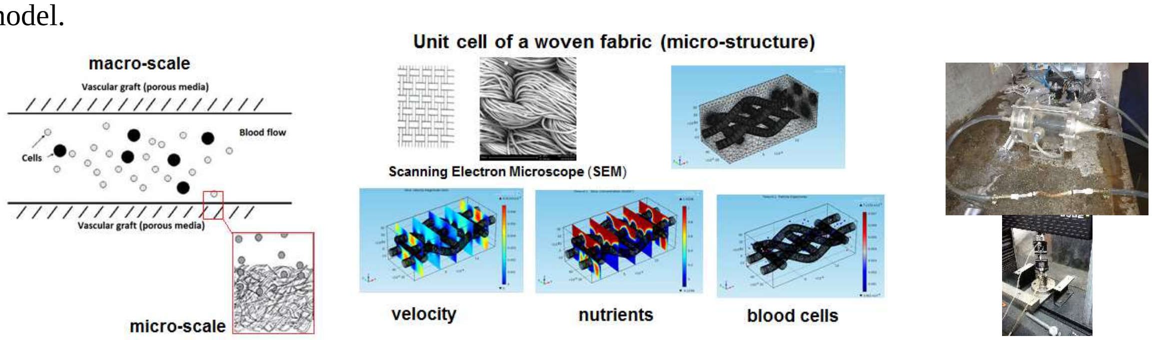
In the same way, mass transport within the human vasculature can be divided into two types: blood flow in the lumen (macro-scale) and transmural flow in the porous wall (micro-scale) of the vascular graft. The hemodynamic nature of blood within the lumen is dominated by convection transport, while mass transport within the porous wall, both the artery and vascular graft, is dominated by diffusion transport [5].

Additionally, blood is not merely a continuum or a mono-phasic fluid. It is composed of a various cellular components. For that reason, the modeling of blood must include interactions of those cellular components and it is necessary to use multi-scale methods for coupling cellular dynamics and continuum mechanics [6].

The aim of this study is focused to simulate and understand the transport phenomena and the mobility of cells at different scales through the textile vascular graft as a porous media in response to changes such as flow rates, concentration of nutrients, properties of the cells, and geometry of the fabric, varying the porosity and permeability of the fabric by factors such as size and distribution of pores, thickness, materials, among others, in order to provide criteria elements that allow the design improvement of the textile vascular grafts with well-controlled internal structures and make decisions on surgical procedures (anastomosis).

RESULTS

For this purpose, it is applied a multi-scale method for coupling the two scales for blood flow: Finite Element Method with a Discrete Particle Method. The domain includes a straight and cylindrical vascular graft (end-to-end anastomoses) for large-scale and the micro-structure of the graft for small-scale. In order to calculate the flow field, Navier-Stokes and Brinkman's equation are used to model the free flow and the flow inside the graft (porous media) for large-scale and, Stokes equation to model the flow for small-scale. A Lagrangian formulation is used to model the motion of cells and convection-diffusion equation is used to model the distribution of nutrients. Simulations implemented with FreeFem++ and Comsol® are presented. Finally, the work also shows an experimental characterization of several properties of implants according to the ISO7198 standard with the objective to use experimental data for numerical model.



(a) (b) (c)

Figure 1. a) Domain, b) Unit cell of a woven fabric , c) Permeability and Compliance tests

CONCLUSION

Due to the complex microstructure of the graft and the lack of adequate technological means to gain knowledge experimentally to measure different variables at micro-scale, the numerical methods employing CFD have proven promising to alleviate the problem. On the other hand, the use of controlled porous media not only permits a better control of nutrients and cells, but is also to explore the underlying physics and improve the design of the vascular graft. Finally, with this preliminary model and simulations, it proposes to contribute the understanding of the cell migration and mass transport from the viewpoints of both multiphysics and multiscale.

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