COMPUTATIONAL MODELING OF THE INTERACTION OF LYMPHATIC AND VASCULAR MICROCIRCULATION IN UREMIA

L. Possenti[1], G. Casagrande[1], S. Di Gregorio[1,2], P. Zunino[2], M.L. Costantino[1]
1-Department of Chemistry, Materials and Chemical Engineering "Giulio Natta", Politecnico di Milano, Italy
2-MOX, Modelling and Scientific Computing, Department of Mathematics, Politecnico di Milano, Italy

SIXTH NATIONAL CONGRESS OF BIOENGINEERING

INTRODUCTION

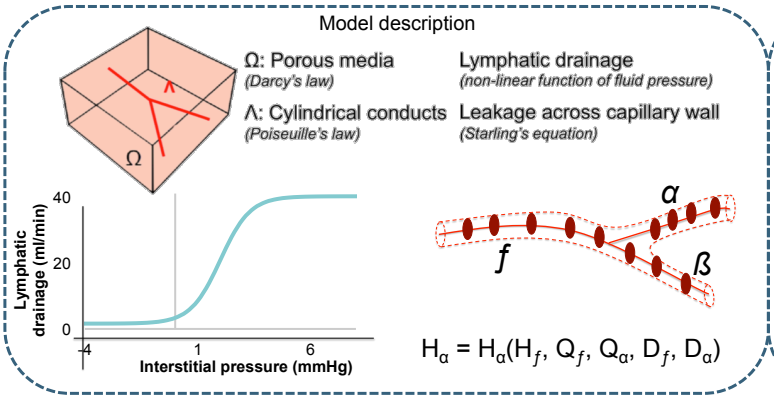
Microcirculation have a key role in the homeostasis maintenance in physiological and uremia conditions, and proper models were needed to describe these complex phenomena. Due to this complexity, a comprehensive approach is required accounting for: (i) capillaries-to-tissue interactions taking into consideration capillary wall permeability; (ii) hydraulic and oncotic pressures; (iii) microvasculature morphology and capillary density; (iv) blood properties along with hematocrit heterogeneity within the vessels network [1]; (v) extravascular properties; (vi) the presence of lymphatic system. Recently, microcirculation alterations have been pointed out in uremic patients in terms of worsening of peripheral perfusion and reduced capillary density [2]. Aim of this study is to develop a computational model able to describe the interaction of a vascular network with the surrounding tissue, accounting also for the contribution of lymphatic system. With this model, differences in local equilibriums peculiar of healthy and uremic subjects can be analyzed and studied at the micro-scale.

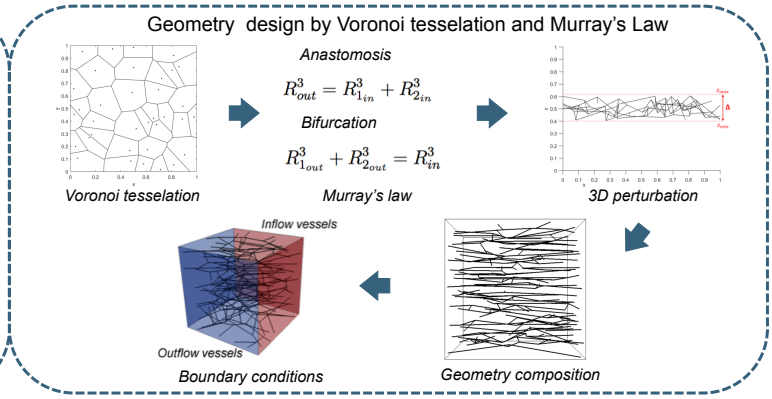
MATERIALS AND METHODS

A finite element model of microcirculation interactions with the surrounding interstitium has been implemented using GetFEM++. Starting from a previous work [3], the model has been improved combining different features as follow: (i) coupled capillary and interstitial flow; (ii) realistic vasculature; (iii) hematocrit dependent flow properties (Fåhræus-Lindqvist effect); (iv) prediction of Red Blood Cells (RBCs) distribution along the vasculature (simulating plasma skimming effect); (v) non-linear description of the lymphatic drainage. Then, the model has been tested and used to analyze fluid balance and hydraulic pressure at microcirculatory level in healthy and uremic subject.

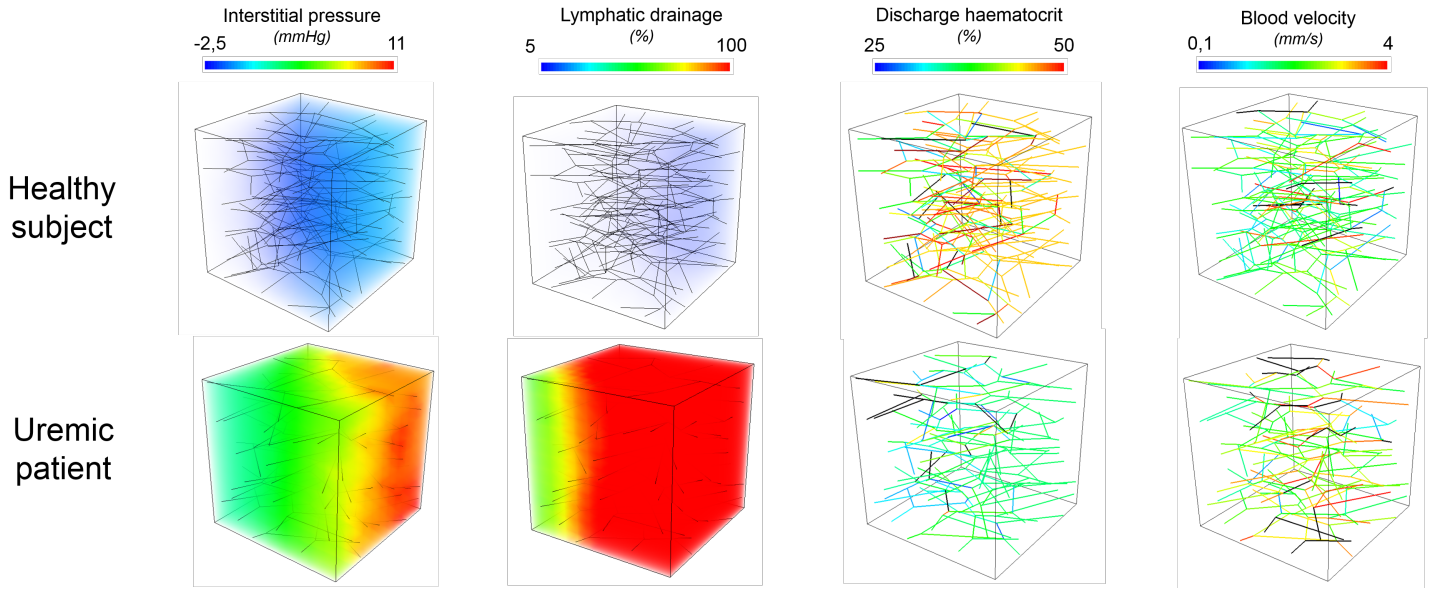
Parameters changed for healthy and uremic patients

	Healthy	Uremic
Ht (%)	45	35
Lp $(m^2\, s\, kg^{-1})$	10^{-12}	8.80×10^{-12}
$\Delta\pi$ (mmHg)	25	19
σ (-)	0,95	0,75
S/V (m^{-1})	7000	4900

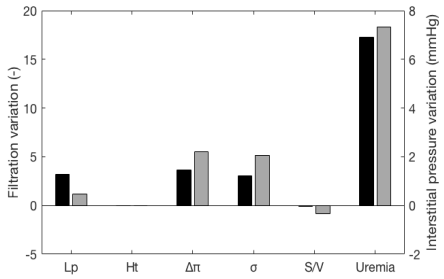




RESULTS



Healthy The pressure trend along the capillaries is coherent with the physiology. Looking to the interaction of the microvasculature with the interstitium, we observe that the pressure gradient in the vasculature induces a secondary, weaker gradient in the interstitium, generating modest flows in the interstitial volume.
The hematocrit is characterized by a high spatial variability.
Uremic A higher interstitial pressure is reported along with a greater lymphatic drainage, as shown in figure. The non-linear relationship implemented for lymphatic drainage produces a strong non-linear effect reaching the saturation flow rate. A gradient in interstitial pressure is present also in this condition, and it is more pronounced than in physiological conditions.
Single parameter weight The effect of each parameter variation is shown in the graph (changed one at the time with respect to physiological conditions; last column depicting uremic conditions). The maximum variation of both the mean interstitial pressure and the net filtration is reported due to variation of oncotic pressure difference or capillary wall properties. Moreover, the overall effect, namely the uremic conditions, is not equal to the sum of each parameter variation, suggesting interactions in between parameter alterations.



Effect of parameters alteration (black: filtration – grey: mean interstital pressure).

CONCLUSIONS

The proposed model of fluid homeostasis in microcirculation allows us to simulate fluid balance by means of tri-dimensional finite element model for physiological and in particular for pathological conditions. Non-linearity included in the model is found to be necessary to accurately describe the phenomena. However, their inclusions rise the required computational time, which is still acceptable. This work shows the appropriateness of the 3D/1D micro-scale finite element approach to describe microcirculation fluid balance: with respect to current modeling approach of fluid homeostasis it allows a local description and make possible the analyses of the effects related to capillary density variations and different network morphologies (e.g.: tortuosity). Future applications of this model would allow the study of specific peripheral districts in order to better understand microcirculation worsening related to uremia. In addition, we believe that such a model, being a flexible investigation tool, could be successfully employed in different medical research areas, such as oncology, neurology and nephrology.

Contact address:
luca.possenti@polimi.it

References: [1] S Di Gregorio; Master thesis, Politecnico di Milano, AY 2016/2017; [2] Y. C. Yeh, A. Chao, C.-Y. Lee, C.-T. Lee, C.-C. Yeh, C.-M. Liu, M.-K. Tsai, An observational study of microcirculation in dialysis patients and kidney transplant recipients, European Journal of Clinical Investigation (2017); [3] L. Cattaneo, P. Zunino, Computational models for fluid exchange between microcirculation and tissue interstitium, Networks and Heterogeneous Media 9 (1) (2014) 135–159. doi:10.3934/nhm.2014.9.135