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Computational analysis of the endothelial cell morphology due to distinct flow patterns / Saez, P.; Gallo, D.; Morbiducci, U.; Steinman, D.A.. - (2016). ((Intervento presentato al convegno 12th World Congress on Computational Mechanics tenutosi a Seoul (Korea) nel July 24-29, 2016.

Availability:

This version is available at: 11583/2676234 since: 2017-07-10T19:00:43Z

Publisher:

International Association for Computational Mechanics

Published

DOI:

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Computational analysis of the endothelial cell morphology due to distinct flow patterns

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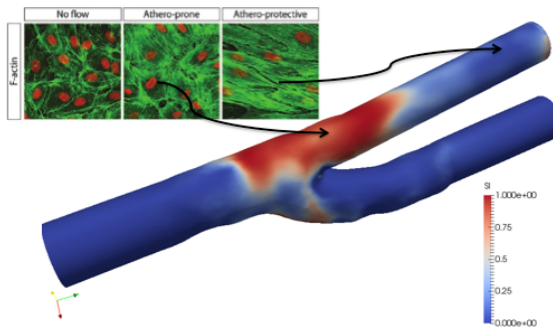
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Endothelial cells (ECs) play a significant role in modulating arterial functions [1,2]. ECs are the interface between vessel wall and blood flow, and perform tasks such as the regulation of permeability and the sensing of fluid forces acting on the vessels' walls. ECs have shown contrasting effects between laminar shear flow with a definite direction the "disturbed" shear seen at arterial branch points. Evidences suggest that wall shear stress (WSS) is capable of (1) changing the morphology and orientation of ECs via a cytoskeleton filaments remodeling and (2) stimulating the ECs to produce several chemical factors. ECs subjected to a laminar flow and high WSS tend to elongate and align in the direction of flow and expression of genes that may protect ECs from inflammation and the development of atherosclerotic plaques. In areas of low and oscillatory WSS, ECs lack organization of the cytoskeleton, intercellular junctional proteins and a unique pattern of ECs gene expression predisposing these arterial regions to atherosclerotic lesion. Despite increasing efforts in the experimental characterization of the ECs remodeling, the computational approach has not gained such an attention. In this work we study the morphological change of ECs within a realistic hemodynamic environment. For such an aim, we adopted a remodeling model for the ECs based on the reorientation of individual cytoskeleton filaments to describe the EC cell shape due to different flow features. A wide amount of flow features is obtained from CFD simulations of 46 patient specific geometries of carotid bifurcation (Fig. 1) [5], allowing the study of the relationship between near-wall fluid features and ECs morphology consistently with experimental observations found in literature [3]. The impact of different variables such as the oscillatory shear index (OSI), the time average wall shear stresses (TAWSS) and fluctuations of the mean wall shear stress orientation on ECs shape is explored.

Fig 1. Results of the EC morphology model from computational CFD. Numerical results agreed with experimental observations [3] in athero-prone and athero-protective patterns. Zones of recirculating flow (athero-prone) showed random circular patterns corresponding with high SI, while laminar flow (athero-protective) showed highly aligned structures with low SI.



We advance our previous computational approach [4], by incorporating the remodeling rate of the cell structures due to the magnitude, direction and fluctuations of the flow stimulus. We are able to reproduce experimental results in literature describing ECs shape as a function of WSS. In figure 1, the shape index (SI) distribution is presented (1 when the shape is round and 0 when it is elongated). In general, low SI values are found for regions where both OSI is high (>0.3) and TAWSS is lower than 0.4 Pa. With this approach, the relation between hemodynamics and wall pathology via the EC morphological response can be investigated from a new perspective. Our model can be extended to simulate collagen and smooth muscle cell growth, where remodeling and the associated release of chemical substance are involved. The approach proposed here can be used to better localize the onset of vascular dysfunction.

References

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