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Porous medium theory in patient pre-treatment planning

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Physicians often face multiple possible strategies treating a specific disease and it is crucial to have a predictive numerical methodology that can help with selection of the best option. Brain aneurysms are a result of a weakened blood vessel wall that, if not treated well, can have a lethal rupture. To prevent the rupture, multiple devices are available, including coils and flow diverters. These devices impede the flow of blood for better coagulation; thus, significantly reducing the chances of rupture [1]. However, the choice is patient specific and a numerical investigation of these devices on hemodynamics is necessary. Computational fluid dynamics (CFD) is often used to asses the performance of these devices and their effect on hemodynamics. Unfortunately, due to the complexities associated with a conventional CFD study including the extremely time-consuming meshing procedure and high computational cost, this technique has not received the attention it deserves. To bypass the complexities mentioned above, researchers have suggested the use of a porous medium approach [2]. In this approach, the explicit geometry of the device is replaced by a homogeneous porous region. This avoids the need for a body fitted mesh and therefore extremely simplifies the meshing procedure and reduces the CFD run time. However, the main challenge is the non-uniform geometry of these devices that invalidates the homogeneity assumption and needs a rather intricate approach. To address this challenge, we propose a novel way that considers the heterogeneity of the devices while not sacrificing the accuracy. The device is replaced by a non-uniform map of permeabilities and porosities and the Navier-Stokes equations are solved by incorporating Darcy's law.
An area that yet must be addressed is the blood coagulation during treatments, as it leads to a dynamic change in porosity and permeability of the domain. Thus, the heterogeneous map has to be dynamically updated which requires a more comprehensive approach to consider for this complex phenomenon. Additionally, the force on the porous region imposed by the flow of blood can lead to deformations in the region which then can alter the hemodynamics. This approach and its challenges pertains to the study of air flow in the lungs. To understand the flow behavior in airways to improve the drug delivery, airways are often considered to be porous as it would be rather challenging to mesh the pathways via a conventional CFD mesher. However, as there are multiple length scales available in the lungs, more research needs to be done to introduce a multi-scale porous medium approach for this purpose. Moreover, the fact that the movement of walls can have significant effect on the flow of air or blood, a model which considers the movement of the porous region is necessary. In summary, we believe that the work presented in this study has addressed a significant challenge in the application of porous medium theory in biomedical related studies. Nonetheless, the aforementioned challenges open doors for research areas that lead to a more comprehensive modeling pipeline using the porous medium theory.

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References

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