Noninvasive Assessment of Carotid Artery Stenoses by the Principle of 3D-0D Blood Flow Modelling

Alena Jonášová, Jan Vimmr
Faculty of Applied Sciences, NTIS, University of West Bohemia, Pilsen, Czech Republic
jonasova@ntis.zcu.cz, jvimmr@kme.zcu.cz

Abstract

In recent years, the computer-aided imaging methods in combination with mathematical modelling have opened up new possibilities in diagnosis and treatment of cardiovascular diseases. One of the most promising diagnostic techniques is the determination of the fractional flow reserve derived from computed tomography [1]. Abbreviated as $\mathrm{FFR_{CT}}$, this non-invasive technique has not only proven successful in diagnosing hemodynamically significant coronary artery stenoses [2], but has also been found to provide valuable information on the flow field, and with it associated hemodynamical wall parameters such as wall shear stress (WSS) and oscillatory shear index (OSI). Essentially, the principle of $\mathrm{FFR_{CT}}$ is not only restricted to the coronary arteries, but is also applicable to peripheral arteries including the carotid ones [3], stenoses of which are one of the main reasons for the occurrence of traumatic brain stroke. Following the idea behind the $\mathrm{FFR_{CT}}$ technique [1], the objective of the present study is to develop a CFD-based tool for the non-invasive assessment of functional significance of intermediate carotid artery stenoses. This objective is achieved by means of multiscale modelling of pulsatile non-Newtonian blood flow in patient-specific models of great arteries, consisting of the aortic arch and both the left and right carotid bifurcations. The 3D blood flow simulations are carried out using verified in-house software [4], algorithm of which is based on a stabilised variation of the projection method and the cell-centred finite volume method formulated for hybrid unstructured tetrahedral grids. To be able to simulate the response of a real downstream vascular bed to any potential changes in flow and pressure brought about by the presence of carotid artery stenoses, appropriate lumped parameter models are coupled with the aforementioned 3D arterial models. The lumped parameters are estimated on the basis of in-vivo measurements. The study was supported by the project LO1506.

References

1. C.A. Taylor and T.A. Fonte and J.K. Min. Computational fluid dynamics applied to cardiac computed tomography for noninvasive quantification of fractional flow reserve: Scientific basis. J. Am. Coll. Cardiol. 61 (2013) 2233-2241.
2. R. Nakazato and H.B. Park and D.S. Berman et al. Noninvasive fractional flow reserve derived from computed tomography angiography for coronary lesions of intermediate stenosis severity: Results from the DeFACTO study. Circ. Cardiovasc. Imaging 6 (2013) 881-889.
3. J. Vimmr and A. Jonášová and O. Bublík et al. Multiscale blood flow modelling as a means for noninvasive quantification of hemodynamically significant carotid artery stenoses. Proc. 14th World Congress of IFToMM, Taipei, 2015, doi:10.6567/IFToMM.14TH.WC.OS1.013.
4. J. Vimmr and A. Jonášová and O. Bublík. Numerical analysis of non-Newtonian blood flow and wall shear stress in realistic single, double and triple aorto-coronary bypasses. Int. J. Numer. Method. Biomed. Eng. 29 (2013) 1057-1081.