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Stresses Variation due to the Anomalies in Circle of Willis

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Abstract The aneurysm is a complex phenomenon which is affected by different factors, such as the biological diseases and the blood flow parameters. The wall shear stress and pressure are the main factors in the establishment and growth of cerebral aneurysm. The circle of Willis is a prevalent location for aneurysm. On the other hand, the anomalies of circle of Willis cause variations in flow field pattern and also the wall shear stress and pressure. In the present study, the effects of some anomalies in the flow pattern are investigated using three dimensional simulation of the Circle of Willis. The simulations are conducted using commercial ANSYS FLUENT. The obtained results show the major anomalies cause increase wall shear stress and pressure on the wall of circle of Willis. This factor can lead to increase the risk of aneurysm.

Keywords: Biomechanics, Wall Shear Stress, Circle of Willis, Aneurysm.

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Introduction

The Circle of Willis (CoW) is a vital part of cerebrovascular system, which is located at the base of the brain. The CoW is a prevalent location for aneurysm with high mortality risk. About 85% of reported cerebrovascular aneurysms have been observed in the CoW, about 30% in Anterior Communicating Artery (ACoA), 30% in Internal Carotid Artery (ICA) , and 22% in Middle Cerebral Artery (MCA)[1].

The stresses are the known influential factors on aneurysm establishment. The forces on the vessel walls are generated by normal stresses due to blood pressure and shear stress due to blood flow. Therefore, the pressure and flow characteristics, i.e. velocity and direction, have crucial effects on the vessel wall tensions and deformations. The normal stresses due to the blood pressure are transferred to all vessel wall layers (intima, media and adventitia). But, just the inner layer of arterial wall, i.e. the vascular endothelium, is exposed to the Wall Shear Stress (WSS) [2]. Ghodsi et al. proposed the Blood Flow Vectoring Control (BFVC) to change the main form of flow streamlines and the distributions of pressure and WSS using a partial clamp [3].

Very low WSS causes the loss of permeability of the endothelial cell membrane. On the other side, high WSS affects their proliferation and migration and change the endothelial cell expression [4].

Kayembe et al. [5] showed that the variation of CoW is a certain cause of aneurysm development. Lazzaro et al. [6] concluded that the investigation of flow field characteristics can help to identify the effects of variations in the aneurysm development and rupture.

Approximately, at least 40 to 50% of the people confront with the CoW's anomalies [7]. There are different types of CoW anomalies, including: hypoplastic Anterior Communicating Arteries (AcoA), hypoplastic Posterior Communicating Arteries (PcoA), hypoplastic PcoA and AcoA, Bilateral hypoplastic PcoAs and etc [8].

The PCoAs are the prevalent positions of variations. The PCoAs are small or absent in many patients. One fourth of MR angiograms and one third of all anatomic dissections show the hypoplasia of one or both PCoAs [9]. In the current study, the effects of absence of one and both PCoAs in the flow pattern and also the amount of WSS and pressure are investigated.

Model Specifications

The schematic view of CoW is shown in Figure 1. There are 4 inlets and 6 outlets, including: Vertebral arteries (VA) and Internal Carotid Arteries (ICA) as the inlets and Posterior Cerebral Arteries (PCA), Middle Cerebral Arteries (MCA) and Anterior Cerebral Arteries (ACA) as the outlets. Also there are four communicating arteries, including: PCoAs and ACoAs.

The simulation of cerebral blood flow requires consideration of different aspects [10]. In the present study, the simulation is performed in a three-dimensional domain. The unsteady flow field is simulated in a laminar condition. The boundary conditions in inlets and outlets are mass flow and static pressure, respectively.

The boundary conditions are set according to the experimental data. Ford et al. [11] reported the volumetric flow rate waveforms for both ICA and VA. Two pulsation periods is simulated, i.e. about 1.7 second, and the computational time step is considered as 10^{-5}.

The simulations are conducted using commercial AVL FIRE® and also ANSYS FLUENT.

The geometry of CoW is generated from the CT Angiography of a patient (as shown in Figure 2)

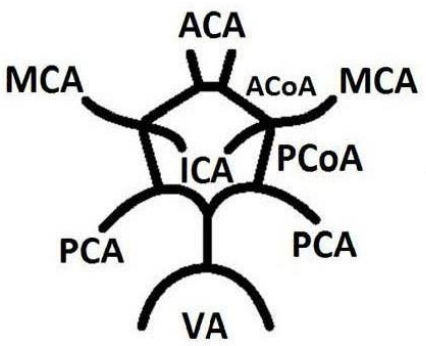

Figure 1. **The schematic view of CoW.**

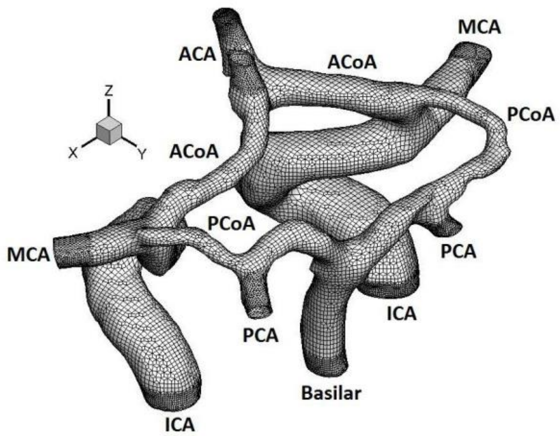

Figure 2. **3-D view of the geometry of CoW.**

Results

In order to investigate the effects of anomalies on the aneurysm establishment and growth, two major cases of abnormal condition in CoW are studied. The absence of one or both of PCoAs is reported frequently. The anomaly causes changing the flow field pattern. In Figure 3, the streamlines in three studied cases of CoW are shown. Although the flow between MCA and PCA is cut off, the other vessels compensate the blood flow. The dominant blood flow providers for PCA and MCA are VA (Basilar) and ICA, respectively.

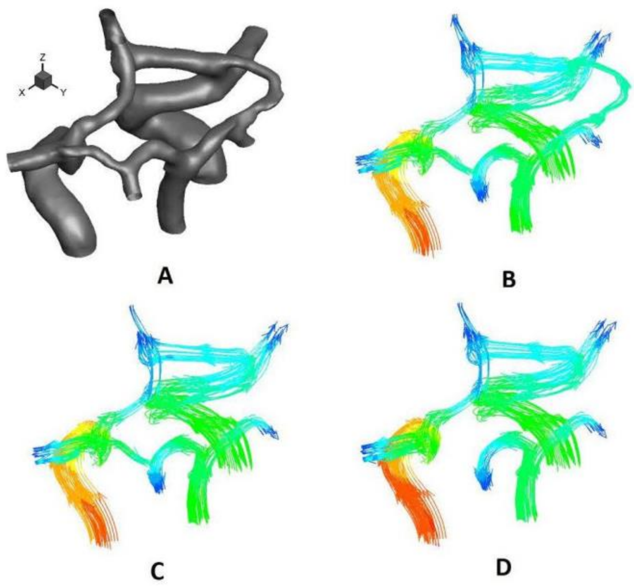

Figure 3. **The streamlines in the CoW: A) the geometry, B) Complete CoW, C) Absence of one PCoA, and D) Absence of two PCoAs.**

As mentioned, the WSS and the normal force of blood on the wall of arteries can leads to deformation over long periods of time. In Figure 4, the changes in WSS due to the anomalies are demonstrated. In two locations, the differences are observable, i.e. near the PCA outlets. The absence of PCoA changes the curves of streamlines and as result the WSS rises. On the other sides of CoW, the WSS is not changed considerably.

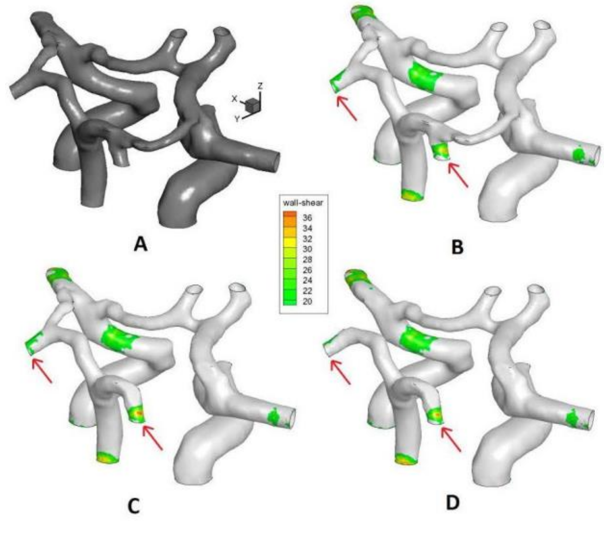

Figure 4. The WSS [Pa] on the walls of the CoW: A) the geometry, B) Complete CoW, C) Absence of one PCoA, and D) Absence of two PCoAs.

The other important feature is the pressure, which cause normal stress on the wall.

Although the order of magnitude of pressure is greater than the WSS, the effect of WSS is not ignorable because of the long time exposing. In Figure 5, the pressure near the wall of CoW in three cases is shown. The interesting point is increasing pressure in the MCA when the PCoA is omitted.

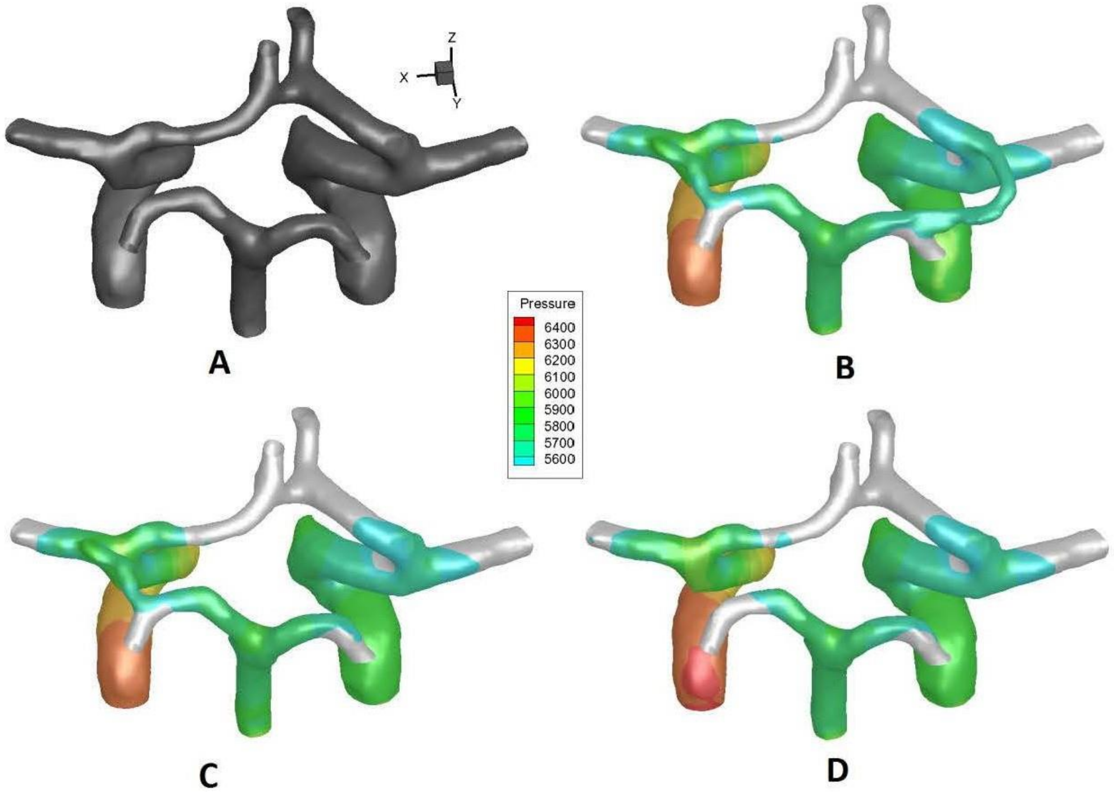

Figure 5: The pressure [Pa] on the walls of the CoW: A) the geometry, B) Complete CoW, C) Absence of one PCoA, and D) Absence of two PCoAs.

Conclusion

In current study, the effects of two prevalent anomalies of CoW, i.e. absence of one and two PCoA, in the flow field pattern are investigated using three-dimensional simulation of Circle of Willis. The increase of WSS causes the amplification of risk of aneurysm establishment and enlargement. The obtained results shows that the anomalies cause increase WSS and also pressure in different locations of Circle of Willis.

References

[1] Gasparotti, R., & Liserre, R. (2005). Intracranial aneurysms. European radiology, 15(3), 441-447.

[2] Papaioannou, T. G., & Stefanadis, C. (2005). Vascular wall shear stress: basic principles and methods. Hellenic J Cardiol, 46(1), 9-15.

[3] Ghodsi, S. R., Esfahanian, V., Shamsodini, R., Ghodsi, S. M., & Ahmadi, G. (2013).Blood flow vectoring control in aortic arch using full and partial clamps.Computers in biology and medicine, 43(9), 1134-1141.

[4] Lasheras, J. C. (2007). The biomechanics of arterial aneurysms. Annu. Rev. Fluid Mech., 39, 293-319.

[5] Kayembe, K. N., Sasahara, M., & Hazama, F. (1984). Cerebral aneurysms and variations in the circle of Willis. Stroke, 15(5), 846-850.

[6] Lazzaro, M. A., Ouyang, B., & Chen, M. (2011). The role of circle of Willis anomalies in cerebral aneurysm rupture. Journal of neurointerventional surgery, jnis-2010.

[7] Papantchev, V., Hristov, S., Todorova, D., Naydenov, E., Paloff, A., Nikolov, D., & Ovtscharoff, W. (2007). Some variations of the circle of Willis, important for cerebral protection in aortic surgery—a study in Eastern Europeans. European journal of cardio-thoracic surgery, 31(6), 982-989.

[8] Eftekhar, B., Dadmehr, M., Ansari, S., Ghodsi, M., Nazparvar, B., & Ketabchi, E. (2006). Are the distributions of variations of circle of Willis different in different populations?–Results of an anatomical study and review of literature.BMC neurology, 6(1), 22.

[9] Osborn, A. G. (1999). Diagnostic cerebral angiography. Lippincott Williams & Wilkins.

[10] Ghodsi, S. R., Esfahanian, V., & Ghodsi, S. M. (2014). Modeling Requirements for Computer Simulation of Cerebral Aneurysm. Journal of Computational Medicine, 2014.

[11] Ford, M. D., Alperin, N., Lee, S. H., Holdsworth, D. W., & Steinman, D. A. (2005). Characterization of volumetric flow rate waveforms in the normal internal carotid and vertebral arteries. Physiological measurement, 26(4), 477.