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HEMODYNAMIC ANALYSIS OF THE DEVELOPMENT OF HUMAN CEREBRAL ANEURYSMS

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Cerebral aneurysm is an important cerebrovascular disease since aneurysm rupture is the most common cause of subarachnoid hemorrhage, which is well known by its very high mortality. Although it is still unclear how cerebral aneurysms initiate, grow, and rupture, hemodynamic factors have been thought to be important in its pathogenesis. Computational fluid dynamics (CFD) can provide detailed information in three-dimensional hemodynamic field. In particular, the combination of CFD and the image-based modelling technique has been widely accepted as a powerful tool for the hemodynamic study in large arteries. To identify the hemodynamic factor that is responsible for cerebral aneurysm development, many hemodynamic studies of human cerebral aneurysm with this combination technique have been conducted, and quantitative comparisons of hemodynamic metrics, such as wall shear stress (WSS) and oscillatory shear index (OSI), between individuals have been reported. However, the sensitivity of arterial wall (endothelial cells (ECs)) to hemodynamic stimuli might differ inter-individually; the quantitative comparisons of the metrics between individuals can be misleading in some situations. For this reason, we virtually reconstructed arterial geometries of human middle cerebral arteries (MCA) just before aneurysm development by artificial removal of the aneurysm, and then the metrics were compared between an aneurysm-developed side and a non-developed normal side from a patient so that we can avoid the issue of inter-individual differences in the hemodynamic sensitivity of arterial wall.

We employed four pairs (aneurysm-developed side and non-developed normal side) of anatomically realistic MCA geometries, which were segmented from the volume data set of CT angiographic images. An aneurysm of each case was artificially removed with previously developed and verified tools [1] to reconstruct arterial geometries just before aneurysm development. Pulsatile blood flow was simulated using a CFD software package, CFX (ANSYS Inc.), based on the incompressible Navier-Stokes equations. Blood was treated as a Newtonian fluid, and the wall was assumed to be rigid. At the inlet boundaries, flow velocity waveforms scaled with a velocity waveform of a healthy subject and individual flow velocity measurements using Doppler ultrasonography were imposed. We computed the following hemodynamic metrics on the wall surface from a velocity field data set obtained during a pulsatile CFD simulation: time-averaged wall shear stress (TAWSS), oscillatory shear index (OSI) [2, 3], normalized transverse wall shear stress (NtransWSS; originally proposed as transWSS [4]), and gradient oscillatory number (GON) [5]. The spatial average of these metrics were also computed around the aneurysm-developed site and the corresponding site, respectively, and they were compared between the two sites.

The spatial average of TAWSS was higher in the aneurysm-developed side than the normal side in three of the four cases, while that of OSI was higher in the aneurysm-developed side than the normal side in only one case. Interestingly, the spatial averages of NtransWSS and GON in the aneurysm-developed side were higher than the normal side for all the four cases, respectively. NtransWSS is a hemodynamic metric intended to quantify the multidirectional character of disturbed blood flow [4], and GON has been designed to quantify the disturbance of the blood flow-induced tangential forces acting on the arterial wall surfaces in pulsatile flow [5]. When considering these, the results suggest that the unstable biomechanical environment of ECs due to large temporal fluctuations in hemodynamics stimuli may be associated with the development of cerebral aneurysms.

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