Analysis of Wall Shear Stress of Carotid Bifurcation using Time-Resolved Three-Dimensional Phase-Contrast MR Imaging

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Purpose: Wall shear stress (WSS) of the arterial wall affects the development of vascular lesions such as atherosclerosis. To maintain a healthy arterial wall, adequate WSS is required. WSS is defined as blood viscosity times the velocity gradient. If we could measure the velocity gradient of the carotid bifurcation, we could calculate the WSS. The purpose of our study was to analyze WSS of the carotid bifurcation using Time-Resolved Three-Dimensional Phase-Contrast MRI (4D-Flow) and our in-house software.

Materials and Methods: MR examinations were carried out for one healthy volunteer and two patients with stenosis at the carotid bifurcation with a 1.5T MR unit. The 4D-Flow was based on radio frequency-spoiled gradient-echo sequence and velocity encoding was performed along all three spatial directions. Four-dimensional data including time dimension were obtained. Measurements were retrospectively gated to the electrocardiographic cycle and CINE series of three-dimensional data sets were generated. Utilized imaging parameters were as follows; TR/TE/NEX = 7.2-8.5 msec/2.8-3.0 msec/1, FA = 15, RBW = 62.5kHz, FOV = 16x16 cm, Matrix = 160x160, slice thickness = 1mm, number of slices = 64, VENC = 60-90cm/sec, acquisition time = 10-15minutes (with the aid of GRAPPA; reduction factor = 2). To detect the contour of the arteries we used the data of simultaneously performed 3D TOF MRA. Imaging parameters of 3D TOF MRA were TR/TE/NEX = 40 msec/2.2 msec/2, FA = 30, RBW = 31.25kHz, FOV = 16x16cm, Matrix = 160x160, slice thickness = 2mm (with 1mm overlap), number of slices = 64, acquisition time = 4minutes. We analyzed 4D-Flow data using our in-house software.

Results: Using the data obtained with 4D-Flow, we visualized the hemodynamics with 3D streamlines and 2D velocity vector fields. After the interpolation of the velocity data, we calculated the WSS of carotid bifurcation and displayed the change of WSS related to ECG cycle. In a healthy volunteer, WSS at the outer wall of the carotid bifurcation was lower than that at the inner wall (Fig.1 a, b). Flow separation was observed at the outer lateral portion of the carotid bifurcation (Fig.1 c). In patients with carotid bifurcation stenosis WSS at the stenotic portion was relatively high (Fig.2 a, b). Flow separation was observed at the segment distal to the stenotic portion (Fig.2 c).

Conclusion: Using the 4D-Flow data we analyzed in vivo WSS and hemodynamics of the carotid bifurcation. Low WSS was thought to be related to the occurrence of atherosclerotic lesions, while high WSS was thought to be related to the rupture of vulnerable plaque. After verifying the accuracy of 4D-Flow and our in-house software in calculating WSS, we hope to predict the risk of vascular lesions and be able to make accurate prognosis of the disease.

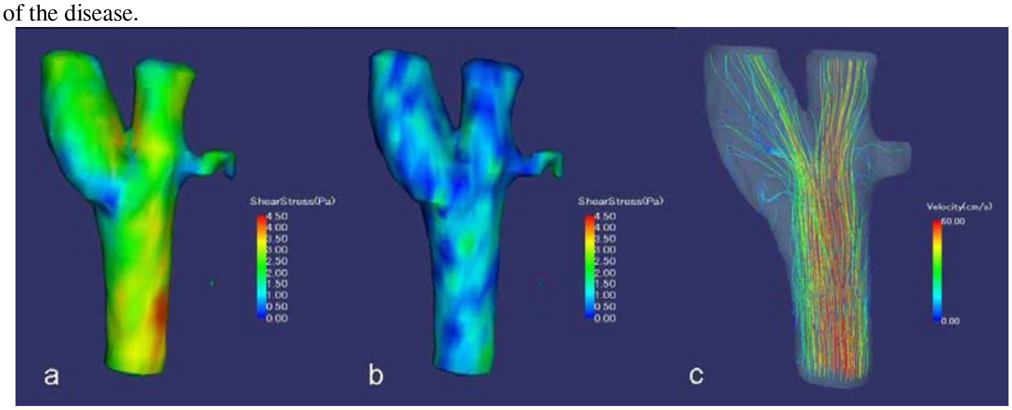

Fig.1 Right lateral view of WSS mapping and 3D streamlines of the right carotid bifurcation of a 29-year-old normal male volunteer.
a. WSS mapping at systolic phase **b.** WSS at diastolic phase **c.** 3D streamlines at systolic phase
WSS at the outer wall shows relatively lower value than that at the inner wall. Flow separation is observed at the outer lateral portion of the carotid bifurcation.

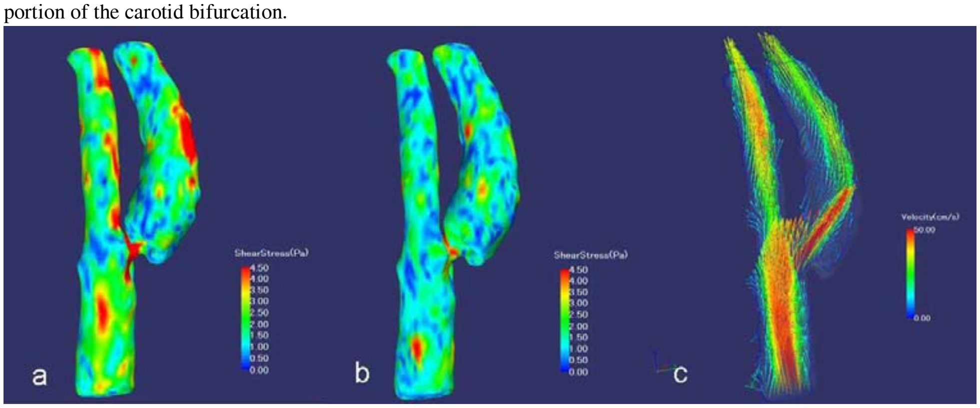

Fig.2 Left lateral view of WSS mapping and 2D velocity vector field of the left carotid bifurcation of a 57-year-old male patient with stenosis at the origin of the left internal carotid artery.
a. WSS mapping at systolic phase **b.** WSS at diastolic phase **c.** 2D velocity vector field at systolic phase
WSS at the stenotic portion shows relatively high value. Relatively high velocity flow is observed at the stenotic portion and flow separation is observed at the segment distal to the stenotic portion.