Assessment of the Wall Shear Stress (WSS) of the Abdominal Aortic Aneurysm Using Time-Resolved Three-Dimensional Phase-Contrast MRI (4D-Flow) and a New WSS Mapping Application (Flova)

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Background

Hemodynamic wall shear stress (WSS) is defined as blood viscosity times velocity gradient near the vascular wall. It is an important determinant of endothelial function and phenotype. Arterial wall shear stress over 15 dyne/cm^2 (1.5 Pa) is said to induce endothelial quiescence and an atheroprotective effect, while low shear stress less than 4 dyne/cm^2 stimulates an atherogenic phenotype and apoptosis of vascular smooth muscle cells, which promote atherosclerosis. Atherosclerosis ultimately leads arterial wall to various sorts of vascular diseases including aortic aneurysm or arteriosclerosis obliterans.

Purpose

Purpose of this preliminary study was to assess if time-resolved three-dimensional phase-contrast MRI (4D-Flow) postprocessed by a new application "Flova" (flow visualization and analysis, R's tech, Japan) can provide information concerning the 4-dimensional WSS mapping of the abdominal aortic wall affected or unaffected by the aneurysm.

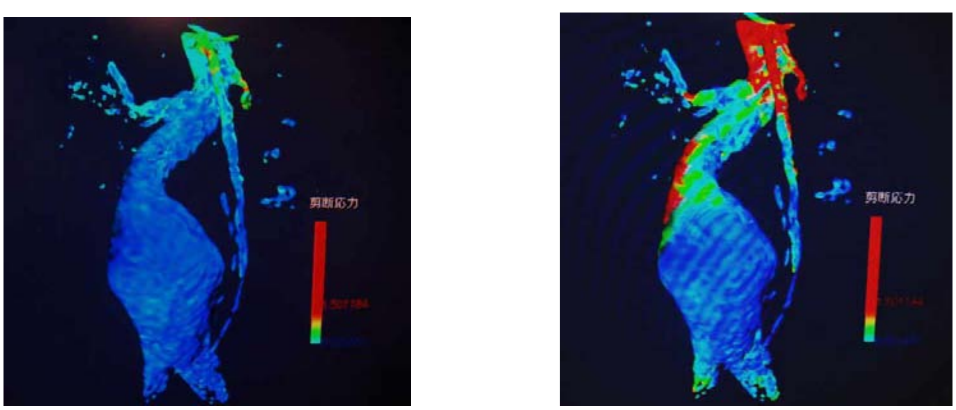
Materials and Methods

Three consecutive patients with infrarenal abdominal aortic aneurysm (AAA) were recruited and included in the study. All examinations were performed on 1.5T MR scanner (Signa TwinSpeed with Excite, GE Healthcare, WI, USA). Before the flow measurements, time resolved contrast enhanced 3 dimensional MR angiography (Gd3DMRA) was performed with a bolus injection of gadolinium chelate (0.1 mmol/kg). A 3D data set of arterial dominant phase was picked out and was used to determine the boundary of the inner wall of the aorta. Then, 4D-Flow was performed. The 4D-Flow is based on a SPGR sequence encoding flow velocities in three orthogonal directions. The parameters used were TR/TE/FA/NEX of 4.3/1.7/15/1, FOV of 30 cm, Matrix of 256x160, 4mm thickness, 28 partitions, 20 phases during one cardiac cycle and imaging time of 20 min. ECG gating and respiratory compensation were also combined. Velocity encoding (VENC) was optimized based on the values measured with 2D phase contrast cine study performed prior to the 4D-Flow. Acquired data were transferred to a workstation and were postprocessed with Flova. The velocity data derived from 4D-Flow and the geometric data of the boundary of the aortic wall determined by Gd3DMRA were interpolated, and we could calculate the WSS of the abdominal aorta and overview the change of WSS related to cardiac cycle as color maps (figures).

Result

The WSS assessed by our method indicated that the WSS of the abdominal aortic aneurysm was significantly lower (less than 0.2 Pa) than that of non-aneurismal wall near the aneurysm (over 1.5 Pa) in all patients. The wall of the aneurysm was considered to be suffering from further risk of arteriosclerosis and apoptosis of vascular smooth muscle cells.

Figures:



WSS maps depicted with Flova in 71 y.o. male with abdominal aortic aneurysm. From diastolic cardiac cycle (above left) and from systolic cycle (above right). Note aneurismal wall is consistently suffering from lower WSS throughout the cardiac cycle. On color maps, red or green indicates higher WSS over 1.5 Pa, whereas blue indicates lower WSS below 0.2 Pa.

Conclusion

Combined use of the 4D-Flow and Flova enabled WSS mapping of the abdominal aortic aneurysm. The WSS of abdominal aortic aneurism was significantly lower than that of unaffected segment, which may reflect that the aneurismal wall is continuously affected by the growing risk of aneurismal growth and rupture.