Assessment of the Flow Dynamics Changes in Splanchnic Arteries in Patients with Median Arcuate Ligament Compression Using Time-Resolved Three-Dimensional Phase-Contrast MRI (4D-Flow) and a New Flow Analysis Application (Flova)

Y. Takehara[1], H. Isoda[1], S. Yamashita[1], H. Takeda[1], Y. Ohkura[2], T. Kosugi[2], M. Hirano[3], M. Alley[4], R. Bammer[4], and H. Sakahara[1]

[1]Radiology, Hamamatsu University School of Medicine, Hamamatsu, Shizuoka, Japan, [2]R's Tech Co. Ltd, Hamamatsu, Shizuoka, Japan, [3]GE Yokogawa Medical Systems, Hino, Tokyo, Japan, [4]Radiology, Stanford University, Stanford, California, United States

Background

The median arcuate ligament of the diaphragm is formed by muscular fibers that connect the right and left crura of the diaphragm, and it defines the anterior margin of the aortic hiatus. The ligament usually passes superior to the origin of the celiac axis. However, in some people, the ligament inserts low and thus crosses the proximal portion of the celiac axis, causing compression of the celiac axis by this ligament, which is referred to as celiac artery compression syndrome or median arcuate ligament syndrome, and it has been reported to cause intestinal angina and in some cases, splanchnic artery aneurysm with or without rupture.

Purpose

Purpose of this preliminary study was to assess the flow dynamic changes and morphological changes occurring in splanchnic arteries in median arcuate ligament compression using time-resolved three-dimensional phase-contrast MRI (4D-Flow) postprocessed by a new application "Flova" (flow visualization and analysis, R's tech, Japan).

Materials and Methods

Three consecutive patients (31 y.o. female, 77 y.o. female and 78 y.o. male) with median arcuate ligament compression 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 arteries. 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, 3mm thickness, 38 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 arbitrary arteries within the field of view, and can overview the change of WSS related to cardiac cycle as color maps (figure).

Result

There was a significant alteration in terms of the flow directions in the pancreatic arcades or the common hepatic arteries. The blood flow within the superior mesenteric artery was stolen by the hepatic and/or splenic arterial blood supply. The collateral arteries were dilated in all cases. In two cases, there was a aneurysmal dilatation in the pancreatic arcade in one and dorsal pancreatic artery in one. Other case had only dilated collateral arteries.The WSS assessed by our method indicated that the WSS of the aneurysm was significantly lower (less than 0.2 Pa) in these two patients. The wall of the aneurysm was considered to be suffering from further risk of arteriosclerosis and apoptosis of the endothelium and vascular smooth muscle cells.

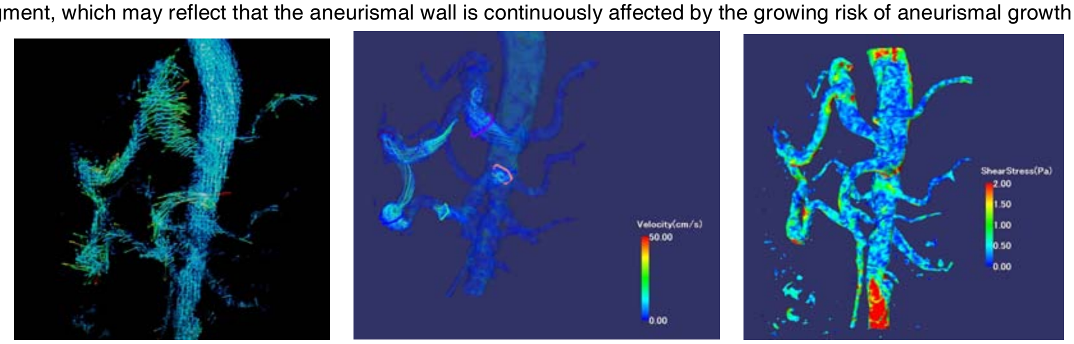
Discussion

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. It is intriguing that in two out of three cases, there was an aneurysm in the segment of collateral circulations with altered flow dynamics caused by median arcuate ligament compression. Our method identified that there was also a significant steal in blood flow from the superior mesenteric artery to the hepatic or splenic blood supply, which may potentially lower the blood supply to the small intestine and may cause abdominal angina.

Conclusion

Combined use of the 4D-Flow and Flova identified the significant alteration in the flow dynamics in splanchnic arteries in the median arcuate ligament compression. There was an aneurysm in two out of three cases of this condition and the WSS of the 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.

Figures:



78 y.o. male with median arcuate ligament compression. Vector map (left) depicts the alteration of flow direction in the pancreatic arcade and the common hepatic artery. The streamline map (middle) shows there is a vortex flow within the aneurysm arising in the pancreatic arcade. WSS map (right) demonstrates that the 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. The picture is one phase from the systolic phases.