Hemodynamic Assessment of Kinking vs. Non-kinking Abdominal Aorta

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INTRODUCTION:

Recently, there is increasing evidence that the appropriate hemodynamic stimulation to the vascular endothelium highly contributes to the health of the vessel walls. Vascular wall shear stress (WSS), calculated as the product of the velocity gradient and the viscosity adjacent to the vessel wall, is drawing attention as the hemodynamic stimulation. Low WSS has been postulated to lead to atherosclerosis .

Time-resolved 3D phase contrast (PC) image (4D flow) allows measurements of the blood flow velocities within the entire geometry within the vasculatures throughout the cardiac cycle *in-vivo*. Using this 4D flow technique, we previously reported that WSS of the aneurismal wall of the abdominal aorta was significantly low, which may be provoking further growth of the aneurysms.

PURPOSE:

We hypothesized the progress of atherosclerosis (ultimate phenotypes are arteriosclerosis obliterans (ASO) or abdominal aortic aneurysm (AAA) in the abdominal aorta is related to hemodynamic abnormalities, which is initiated by tortuosity of the abdominal aorta. The aim of this study was to assess the relationship between the tortuosity of the aorta and the hemodynamic patterns as well as the related changes of the WSS in the patients with vascular diseases with various degrees of tortuosities in the abdominal aorta

PATIENTS AND METHODS:

Written informed consent was provided in all cases for this IRB approved study. Nine patients (six males and three females; 22-79 years), who underwent MR examinations with 4D flow for the reasons other than AAA or ASO.

MR imaging: All examinations were performed on 1.5T MR scanner (Signa TwinSpeed with Excite or Signa HD, GE Healthcare, WI, USA). Gadolinium enhanced 3D MRA was performed prior to the 4D flow. 4D Flow is based on a SPGR sequence encoding flow velocities in three orthogonal directions. The parameters used were TR/TE/FA/NEX of 4.5-5.0/1.6-2.0/15/1, FOV of 30-34 cm, Matrix of 224-256x160-224, 2-3 mm thickness, 12 phases during one cardiac cycle. The value of velocity encoding was determined by the flow velocimetry performed with axial 2D phase contrast image. Acquired data were post processed with flova (flow analysis software), and we could delineate streamlines and pathlines or WSS.

IMAGE ANALYSIS

The minimum curvature radius of abdominal aorta (: Radius) and the mean aortic flow velocity measured at the level of the renal artery (: Velocity) were measured. Mean WSSs in each cardiac cycle of the infrarenal abdominal aorta were calculated and the average (: Ave WSS), the maximum value (: Max WSS), and the minimum value (: Min WSS) were used in obtained WSSs. The correlation coefficients between Radius and each WSSs and between Velocity and each WSSs were calculated. The patients were divided into 2 groups in terms of the tortuosity, i.e.15 cm or over and less than 15cm of Radius. Hemodynamic abnormalities were evaluated in terms of the presence or absence of turbulent or vortex flow using obtained streamlines and pathlines in three cardiac phases.

RESULT

The correlation coefficient between Radius vs. Min WSS was 0.69 ($p<0.05$), between velocity vs. Ave WSS was 0.92 ($p<0.05$) and between Velocity vs. Min WSS was 0.69 ($p<0.05$) (Table 1). In all cases turbulence was recognized in end-diastolic phase. Turbulence in end-systolic and early-diastolic phase was recognized at frequency from 50 to 100% regardless of differences of Radius or Velocity. Most of them were localized and seen at the inner curvature of the aorta. The WSS of the area with turbulence was lower than other area.

Vortices were prominent in early-diastolic phase of the small Radius group (75% (3/4)), as compared to the large Radius group (20% (1/5)). (Table 2) The generations of vortices were seen in flexural area, downstream area and upstream area, too. These vortices affected flow dynamics at the upstream or downstream blood stream and decreases WSS of the aortic wall in the vicinity (Figure 1).

DISCUSSION

We hypothesize that at the most initial stage of AAA or ASO, elongation and the tortuosity of the aorta occurs, which affects aortic hemodynamics and decreases WSS. In this preliminary study, we observed that the kinking aorta causes vortices, which affect flow dynamics at the local and upstream or downstream blood stream, which decreases WSS of the aortic wall of the local and in the vicinity. This may be a supporting evidence of our hypothesis.

CONCLUSION

According to not-dilated abdominal aorta the high degree of the kinking and low velocity caused the decrease of WSS. Even if the velocity is high, high degree of kinking may generate vortexes and the WSS of the near area may decrease. These have the possibility of seeing one process of the aortic aneurysm generation

Table 1 The correlation coefficient

	AVE WSS	MAX WSS	MIN WSS
Radius	0.34	-0.11	0.69*
Velocity	0.92*	0.50	0.69*

* $p < 0.05$

Table 2 turbulent and vortex

R	WSS (± SD)			vortex		
(cm)	AVE	MAX	*MIN	end-sys	early-dia	end-dia
R < 15	0.20 (±0.06)	0.48 (±0.18)	*0.09 (±0.01)	50% (2/4)	75% (3/4)	0% (0/4)
R≧15	0.25 (±0.02)	0.62 (±0.14)	*0.14 (±0.03)	0% (0/5)	20% (1/5)	0% (0/5)

* $p < 0.05$

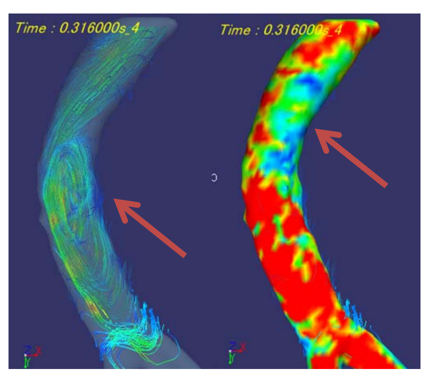

Figure 1 4D flow in early-diastolic phase
75 years old male with kinked abdominal aorta.
left: streamline: A large vortices were seen at the distal of flexural area
right: Wall Shear Stress image: The low WSS area was recognized at the proximal portion of the inner curvature.