Comparing Wall Shear Stress Measurements in the Descending Aorta Using Different Velocity Encoding Values

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INTRODUCTION

4D PC MRI allows for comprehensive assessment of vascular anatomy and velocity fields throughout the cardiac cycle. While this information can be used to derive additional hemodynamic parameters such as wall shear stress (WSS), it is critical to choose a velocity encoding (VENC) value that is adequate to avoid aliasing while providing a sufficient velocity-to-noise-ratio (VNR). WSS estimates are derived from velocity measurements in slowly flowing blood close to the vessel wall. Although the VENC setting is a critical parameter, the effects of different VENC values on WSS measurements remain largely unknown. The purpose of this study was to compare and determine any significant differences in measurements of WSS with VENC values of 80 and 120 cm/s in the descending aorta in healthy volunteers.

MATERIALS AND METHODS

This HIPAA compliant study was approved by our institutional human subjects review committee and written informed consent was obtained from all subjects. PC VIPR [1], a radially undersampled acquisition with three directional velocity encoding, was used to acquire data on a 1.5T or 3T MR scanner (GE Healthcare, Waukesha, WI) in nine healthy volunteers (6 males; 3 females; average age = 34.2 years). Scans were performed with the following parameters: imaging volume = 320 x 320 x 180 mm^3, readout = 256-320, 1.0-1.25 mm^3 acquired isotropic spatial resolution, VENCs of 80 cm/s and 120 cm/s, TR/TE/flip = 8.7ms/2.8ms/10º, retrospective cardiac gating and adaptive respiratory gating with an acceptance window of 50%, scan time ~ 10 min.

Vessel segmentation was performed manually with in-house software (MATLAB version 8.0, The MathWorks Inc., Cambridge, MA, USA). First, points were selected around the circumference of the vessel on complex difference images reformatted as axial to the vessel. From these points, a cubic spline was created. This step was repeated on axial slices ranging from the end of the aortic arch to immediately superior to the celiac artery (Figure 1A). From these axial splines, splines in the superior-to-inferior (SI) direction—along the length of the aorta—were also created. The intersection of the SI and axial splines created surface points along which an inward unit normal vector was computed; longitudinal wall shear stress was then calculated as the viscosity of fluid multiplied by the slope of the velocity along this unit normal vector (Figure 1B). Viscosity was assumed to be 4.0 cP for all subjects. This process was repeated for each time frame over the cardiac cycle.

Measurements of WSS for each surface were binned and averaged into twelve segments for each time frame (Figure 1C)—grouped into 4 circumferential regions at three SI levels. The average WSS over the cardiac cycle was plotted for each of the volunteers at each VENC. The greatest (peak) average WSS from the twenty time frames for each segment was compared for each volunteer at each VENC with a Student's t-test ($p < 0.05$). Additionally, the percent increase in WSS from baseline to peak, was compared for each volunteer with a Student's t-test ($p < 0.05$). Finally, the WSS averaged over all twenty time steps was compared for each volunteer with a Student's t-test ($p < 0.05$).

RESULTS

Figure 2 shows the average WSS over the cardiac cycle for all volunteers at both VENC settings. Measurements of peak WSS tended to be slightly larger at VENCs of 80 cm/s than at 120 cm/s for ten of twelve segments (Table 1) by 5.5% on average, though this increase was not statistically significant. The greatest (peak) average WSS over the twenty time frames was not significantly different between VENCs for each of the twelve segments. The percent increase in WSS from baseline to peak was significantly different for three of the twelve segments across VENCs (p-values < 0.05). Values of percent increase from baseline to peak tended to be larger at the lower VENC-80 (average = 1136%) than at the higher VENC-120 (average = 830%). Last, the WSS averaged over all twenty time steps was significantly different (p-value < 0.05) for five of the twelve segments.

CONCLUSIONS

Our study shows that the measured peak longitudinal wall shear stress in the descending aorta was not significantly different for the two VENC values of 80 and 120 cm/s. While imaging with a VENC of 120 cm/s ensured the absence of velocity aliasing, the measured WSS with VENC of 80 cm/s was larger, likely due to an improved VNR for the low velocities at the vessel wall. In future studies we plan to conduct a dual VENC acquisition with a VENC setting tailored to the velocities at the wall and a second VENC setting tailored to the peak velocities within the vessel of interest to allow for phase unaliasing of the low VENC data while maintaining a high VNR.

REFERENCES: [1] Johnson et al. *MRM*. 2008;60(6):1329-36.

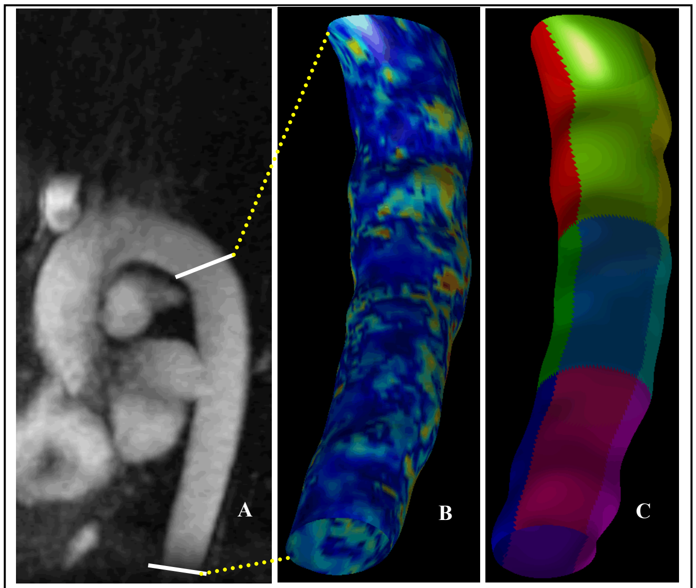

Figure 1. (A) Maximum intensity projection of the aorta. (B) Map of wall shear stress measurements in the descending aorta in a single time frame for a healthy volunteer. (C) The twelve segments used to bin wall shear stress measurements in the descending aorta for all subjects.

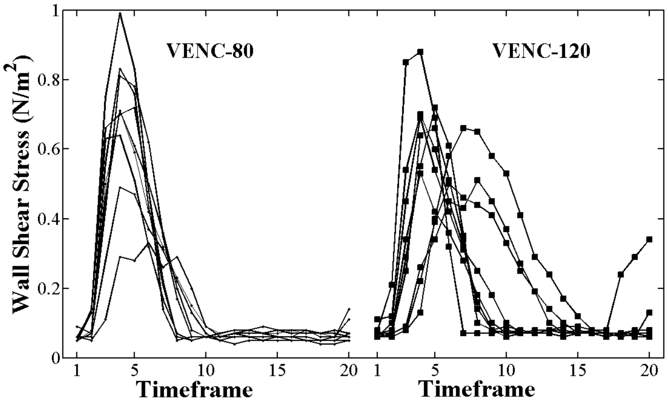

Figure 2. Average wall shear stress in the descending aorta over twenty time frames across the cardiac cycle in nine healthy volunteers at VENC-80 and VENC-120.

Table 1. Average peak wall shear stress over the cardiac cycle in twelve segments in the descending aorta of nine healthy volunteers at VENC-80 and VENC-120.

	WSS (N/m^2) in Volunteers at VENC 80/120			
	Lateral	Medial	Anterior	Posterior
Upper	0.56/0.50	0.74/0.70	0.81/0.68	0.67/0.59
Middle	0.72/0.69	0.80/0.81	0.81/0.77	0.69/0.68
Lower	0.72/0.66	0.74/0.70	0.70/0.73	0.66/0.61