MRI Measurements of Wall Shear Stress in the Infrarenal Aorta in the Young and Old

A. L. Wentland[1], E. T. Bieging[2], A. Frydrychowicz[2], M. L. Schiebler[2], T. M. Grist[1], O. Wieben[1], and C. J. Francois[2]
[1]Medical Physics, University of Wisconsin School of Medicine & Public Health, Madison, WI, United States, [2]Radiology, University of Wisconsin School of Medicine & Public Health, Madison, WI, United States

INTRODUCTION

Studies have shown that low peak wall shear stress (WSS) contributes to the formation of atherosclerotic plaques [1]. Additionally, Lee *et al.* demonstrated that low peak WSS correlates with high atherosclerotic indices [2]. However, the magnitude of WSS in older subjects, who have a greater incidence of atherosclerosis, requires further investigation. The purpose of this study was to compare the magnitude of peak longitudinal WSS in the infrarenal abdominal aorta in subjects younger than 40 years of age and in subjects older than 60 years of age.

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 [3], a radially undersampled acquisition with three directional velocity encoding, was used to acquire data on a 1.5T MR scanner (GE Healthcare, Waukesha, WI) in seven subjects younger than 40 years old (5 males; 2 females; average age = 22.9 years) and eight subjects older than 60 years old (4 males; 4 females; average age = 69.5 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, VENC of 40 - 80 cm/s, TR/TE/flip = 8.7ms/2.8ms/10º, cardiac and respiratory gating, scan time ~ 10 min. No contrast was used.

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 aorta immediately inferior to the renal arteries to immediately superior to the iliac bifurcation (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 twelve segments and across the cardiac cycle was plotted for each of the subjects. The greatest (peak) average WSS from each time frame for each segment was compared between young and old subjects with a Student's t-test ($p < 0.05$). Additionally, the percent increase in WSS from baseline to peak was compared between young and old subjects with a Student's t-test ($p < 0.05$).

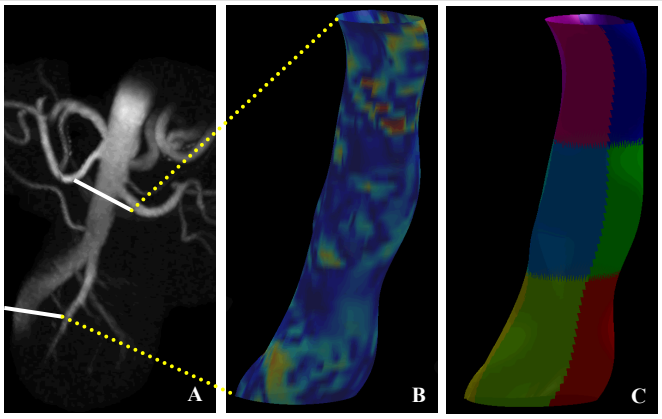

Figure 1. (A) Maximum intensity projection of the infrarenal aorta. (B) Map of wall shear stress measurements in the infrarenal aorta in a single time frame for a subject less than 40 years old. (C) The twelve segments used to bin wall shear stress measurements in the infrarenal aorta for all subjects.

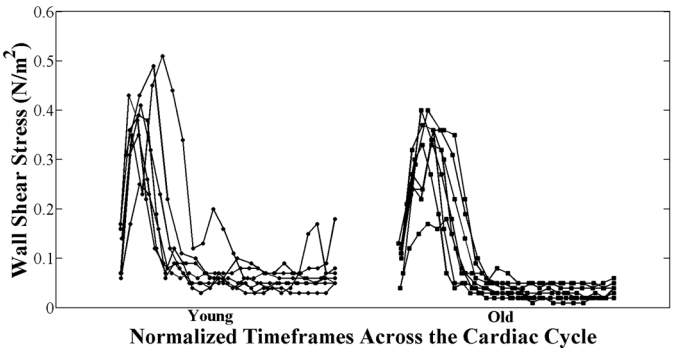

Figure 2. Average wall shear stress in the infrarenal aorta over the cardiac cycle in seven subjects less than 40 years old and eight subjects greater than 60 years old.

RESULTS

Average WSS over the cardiac cycle is shown in Fig. 2 for all subjects. Measurements of (peak) average WSS tended to be lower in older subjects than younger subjects, although this was significant for only the medial-middle segment (Table 1). The percent increase in WSS from baseline to peak was not significantly different between young and old subjects for each of the twelve segments (p-values ranged from 0.27-0.95). Values of percent increase averaged over all twelve segments were similar in young (average = 703%) and old (average = 770%) subjects.

Table 1. Average peak wall shear stress over the cardiac cycle in twelve segments in the infrarenal aorta of seven subjects less than 40 years old and eight subjects greater than 60 years old.

	WSS (N/m^2) in Young/Old			
	Lateral	Medial	Anterior	Posterior
Upper	0.44/0.41	0.41/0.36	0.45/0.37	0.39/0.41
Middle	0.44/0.37	0.43/0.32	0.44/0.39	0.43/0.37
Lower	0.46/0.39	0.33/0.33	0.40/0.36	0.38/0.35

CONCLUSIONS

Studies have demonstrated an association between the distribution of atherosclerotic lesions and low wall shear stress [4]. Our study showed that longitudinal wall shear stress in the infrarenal aorta tended to be lower in older subjects than younger subjects, although this tendency was significant for only 1/12 segments. This study is limited by small subject groups; a study with a larger number of subjects may demonstrate a significant difference between the WSS in the young and old. Alternatively, the atherosclerotic plaques present in the older subjects may serve to compensate for a previously lower wall stress, which initially created the plaque.

The limited spatial resolution of MR flow measurements results in an underestimation of the actual WSS parameters as derived by CFD simulations [5]. However, it is likely to be a surrogate parameter of the actual WSS. Measurements with PC VIPR provide high spatial resolution with isotropic voxel sizes, making this approach well suited for such multidirectional hemodynamic analysis.

ACKNOWLEDGEMENTS

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