The Effect of Wall Compliance on Aortic Hemodynamics in the Mouse: Implications for AAA Pathogenesis

S. Amirbekian[1], R. C. Long[1], J. Suo[2], W. R. Taylor[2,3], D. P. Giddens[2], and J. N. Oshinski[1,2]

[1]Radiology, Emory University, Atlanta, GA, United States, [2]Biomedical Engineering, Georgia Tech, Atlanta, GA, United States, [3]Medicine (Cardiology), Emory University, Atlanta, GA, United States

Introduction. Abdominal Aortic Aneurysm (AAA) is a significant medical problem associated with high mortality. Oscillatory wall shear stress (WSS) has been shown to be important in the localization of the initial atherosclerosis underlying AAA pathogenesis. Previous reports based on computational fluid dynamics (CFD) have indicated that vessel compliance plays a role in creating the complex helical flow patterns leading to oscillatory WSS seen in the human aorta (*Jin, et al, J Biomech Eng 2004*). CFD studies of the hemodynamics of the human aorta have been extensive, but comparable studies in mice are lacking. The purpose of the current study was: 1) to use CFD modeling based on MRI to investigate the hemodynamic environment of the mouse aorta and, 2) to determine the effect of vessel wall compliance on oscillatory WSS patterns in the mouse aorta.

Methods. CFD modeling requires determination of the vascular geometry and specification of the time-dependant inlet and outlet flow patterns to the vascular segment under study. To specify the murine aortic geometry, a non-contrast time-of-flight (TOF) magnetic angiography (MRA) sequence was used. Slices were acquired in a transverse orientation, perpendicular to the aorta. Three-dimensional reconstructions were created from the images by semi-automated segmentation and reconstruction techniques implemented in MATLAB 2006a (*Mathworks, Natick, MA*). To measure the inlet and outlet flow conditions in the aorta and branch vessels, we developed a phase contrast magnetic resonance imaging (PC-MRI) sequence to acquire cine velocity maps of blood flow into and out of the mouse aorta. ECG gating was used to acquire ten frames equally spaced over the cardiac cycle. Using the PC-MRI cine magnitude images, we measured of aortic wall compliance. All imaging was performed using a 4.7 Tesla Varian INOVA MRI scanner (Varian, Palo Alto, CA) with a 37-mm-diameter, birdcage quadrature coil. MRA and PC-MRI scans were acquired in 5 normal C57BL/6J mice. CFD simulations were performed using CFD-CADanalyzer (ESI Group, Paris, Fr).

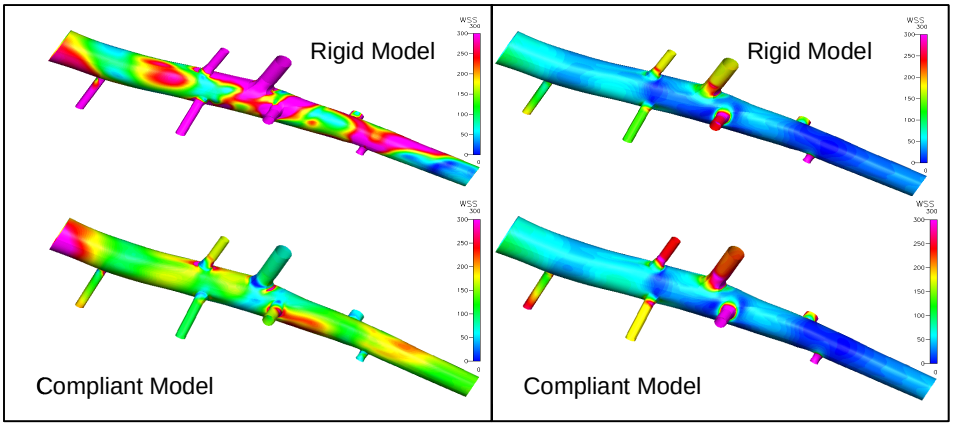

Figure 1. (A)*WSS profiles in the Rigid and Compliant model at the same time point during early systole. Note the relatively higher values of WSS in the Rigid model compared to the Compliant model, especially near branching vessels.* ***(B)****A similar comparison of WSS during early diastole. At this time point the higher values of WSS are exhibited by the compliant model as the aortic wall constricts causing higher WSS.*

To study the effect of compliance, two models were created. The first model had a constant diameter set at the maximum diameter measured from the PC-MRI data (Rigid Model). The second model was created with a compliant vessel wall, where the wall motion was based on the PC-MRI magnitude data (Compliant Model). Flow was equivalent in the two models and flow values in the branch vessels were equal.

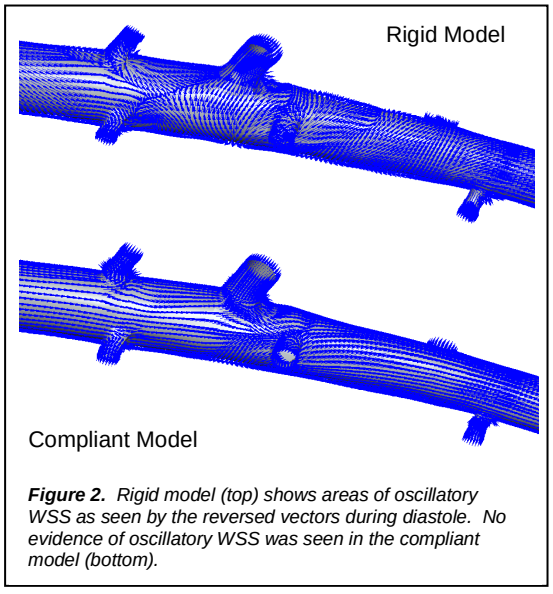

Figure 2. *Rigid model (top) shows areas of oscillatory WSS as seen by the reversed vectors during diastole. No evidence of oscillatory WSS was seen in the compliant model (bottom).*

Results. TOF MRA images and PC-MRI velocity measurements were successfully obtained in all mice. Time averaged infra-renal flow was 7.4±4.4 ml/min and supra-renal flow was 15.2±7.9 ml/min. CFD simulation was performed and time-dependant regional WSS in the rigid and compliant models was determined. Peak WSS values were over 150 dynes/cm^2. Note these values are many times greater than the values of WSS seen in the human aorta. In early systole, the rigid model had areas of WSS almost double those seen in the compliant model. During early diastole, differences in WSS between the models are reversed and smaller. The rigid model exhibits a greater number of areas of oscillatory shear stress than the compliant model as shown by the WSS vector fields. These areas of oscillatory WSS are seen in the supra-renal aorta of the rigid model. Oscillatory WSS is not seen in the compliant model.

Conclusion. Using CFD modeling based on MRA and PC-MRI scans, we were able to show that the rigid model of the aorta has areas of oscillatory WSS during diastole in the supra-renal segment. These oscillatory WSS characteristics are not apparent in the compliant model. From this study we conclude that: 1) inclusion of wall compliance changes the WSS values and patterns seen in CFD modeling of the mouse aorta, 2) the inclusion of wall compliance is needed to accurately model mouse aortic hemodynamics, 3) rigid aortic walls, as seen in diseased or aged mice, may develop areas of oscillatory WSS in the supra-renal aorta.