Hemodynamics in the Mouse Aorta - a combined MRI US and CFD study

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Introduction Atherosclerosis, like many other diseases, has been a target for mouse modeling[1]. Although there exist physiological differences between mice and humans (mice have higher heart rates and smaller arteries) the atherosclerotic patterns observed in the mouse closely resemble those in humans[2]. Due to the well known relation between atherosclerotic patterns and local hemodynamics[3], it is of interest to compare mouse and human aortic hemodynamics. Computational fluid dynamics (CFD) simulations which can predict distribution and magnitudes of wall shear stress along the aorta require knowledge of boundary conditions in terms of input velocities and flow splits from the aorta to the carotid arteries. In this study both phase contrast MRI and Doppler ultrasound (US) are used to measure the velocity and flow in the different vessels during the cardiac cycle. While Doppler US provides high temporal resolution, color coded Doppler providing spatial velocity profiles is currently unavailable for mice. This in turn is provided by MRI velocity measurements. Data from both modalities was used for input and validation of numerical simulations.

Materials and Methods

C57BL/6 Mice were anesthetized with a mixture of 1.2-1.6% isofluorane and oxygen. ECG monitoring and gating was performed with a commercial system (SA Instruments Inc.). ECG triggered two-dimensional spoiled gradient echo imaging with a bipolar gradient encoding the velocity normal to the slice was performed at several positions perpendicular to the vessel along the aorta and at the carotids. The imaging was repeated for every 5ms during systole and every 10ms during early diastole up to 100ms. The temporal sampling of the cardiac cycle was not done simultaneously due to gradient duty cycle limitations. TR was somewhat variable depending on the cardiac cycle (typically 130-170ms in anesthetized mice), TE=2ms Flip angle=40°. A voxel size of 150µm x 150µm was used in the aorta and 133µm x 133µm for the carotids. Slice thickness was 0.75mm. Manual segmentation of the vessels done separately on the magnitude image at each time point was used for calculating the total flow. Doppler US was performed at the ascending aorta and the aortic arch at 3 points across the lumen, while in the carotids the Doppler sample volume covered the whole lumen.

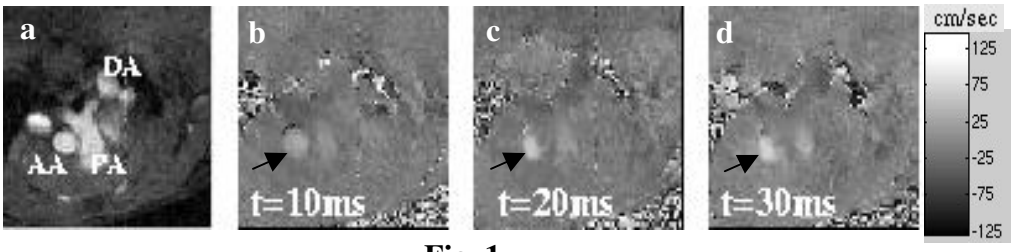

Fig. 1

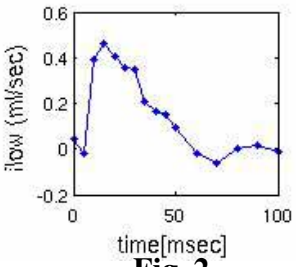

Fig. 2

Results Fig. 1a shows a magnitude image for anatomical orientation.A velocity map of the ascending aorta at three time points is shown in figure 1b,c,d. The time is relative to QRS peak. The skewing of the velocity profile towards the outer wall from mid systole is clearly noticeable (Fig. 1c,d). Fig. 2 shows the time dependence of the total flow in the ascending aorta obtained by integration of the velocities over the segmented vessel. Fig. 3b shows results of a Doppler US measurement positioned at the center of the ascending aorta (3a). Doppler measurements preformed at the outer walls show skewing similar to that seen by MRI. Both magnitude and time dependence of the velocity measurements in MRI and US are comparable, with differences of less than 20%.

Discussion Combining MRI and US can provide detailed spatial and temporal information on aortic blood flow in mice. CFD simulations performed with boundary conditions provided by these measurements show interesting differences between human and mouse wall shear stress profiles. CFD slice profiles and MRI maps show good agreement and MRI will be helpful in further validation of the CFD parameters.

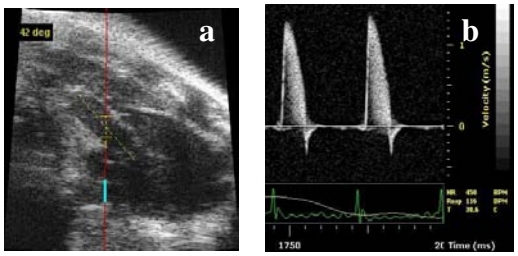

Fig. 3

References:

[1]A. Daugherty, "Mouse Models of Atherosclerosis", Am J Med Sci 2002; 323:3-10 .

[2] P.A. VanderLaan, C.A. Reardon, G.S. Getz, "Site Specificity of Atherosclerosis", Arterioscler Thromb Vasc Biol 2004;24:12-22.

[3] D.M. Wootton, D.N. Ku, "Fluid mechanics of vascular systems, diseases and thrombosis", Annu. Rev. Biomed. Eng. 1999; 1:299-329.