Aortic Compliance of Mice at 7T Using Radial Phase Contrast Cine Imaging

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Introduction:

The Pulse Wave Velocity (PWV) and Wall Shear Stress (WSS) are well known indices of vessel compliance [1]. However, In vivo studies with transgenic animal models of arterial diseases are still needed to elucidate the exact role played by arterial diseases in the observed variations of PWV and WSS. Conventional MR techniques of acquiring velocity data lack both spatial and temporal resolution needed to accurately calculate PWV, WSS in small animals. To our knowledge, no non invasive study has been conducted in the past to measure PWV in in-vivo mice. In this work, we developed a radial phase contrast cine imaging technique to measure PWV and WSS in the mouse descending aorta. The technique is demonstrated on a standard atherosclerotic mouse model (ApoE KO).

Material and Methods:

A phase-contrast, under-sampled, radial acquisition cine sequence [2] was implemented on a Bruker 7T MR scanner. The scan was prospectively gated for ECG and respiration. TE/TR = 1.9/5.2msec, flip angle = 30°, pixel size = 0.093 × 0.093 mm, number of projections = 128, echo position = 15%, VENC = 140 cm/sec. To acquire as high a temporal resolution as possible, only one projection for each frame was acquired per trigger, the velocity encoded data and reference data were acquired separately from different R-R intervals. A custom made, single turn, solenoidal Radio Frequency coil (30mm diameter, 35mm length) was used. Five six-month-old mice (1-Wild Type, 4-ApoE KO, 2-male, 2-female) were scanned. Blood flow was measured at four to five axial slices along the descending aorta (figure 1) with 4mm gap. The acquired raw data was reconstructed [3] into a series of 2D magnitude and phase images (figure 2). The reconstruction process include: density compensation, gradient delay correction [4], regridding and FFT. The aorta was segmented on the magnitude image using a semi automated snake algorithm. The average phase of several ROIs surrounding the aorta was subtracted from the phase of the aorta on a pixel by pixel basis to correct the phase-offset error. For each time frame, the mean velocity among the pixels with velocity greater than a pre-set threshold (=80% maximum velocity in the lumen) was taken. The normalized flow velocity at different distances (D) along the descending aorta (figure 3) were plotted to determine the time delay (ΔT) in arrival of the pulse wave. The arrival time was defined as the point of half maximum velocity. The pulse wave velocity was calculated from the slope of the curve D vs. (ΔT) by a linear fit. The WSS was calculated from the velocity gradient [5] along the aortic lumen at approximately 1cm superior to the celiac artery bifurcation.

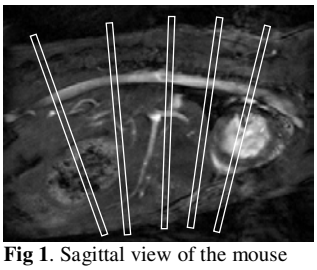

Fig 1. Sagittal view of the mouse aorta showing different flow image planes.

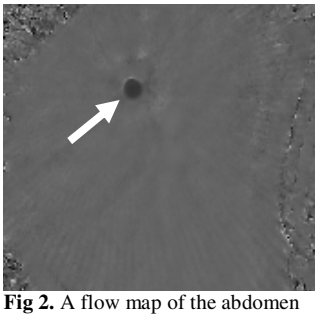

Fig 2. A flow map of the abdomen show no under-sample artifacts in the aortic lumen (arrow).

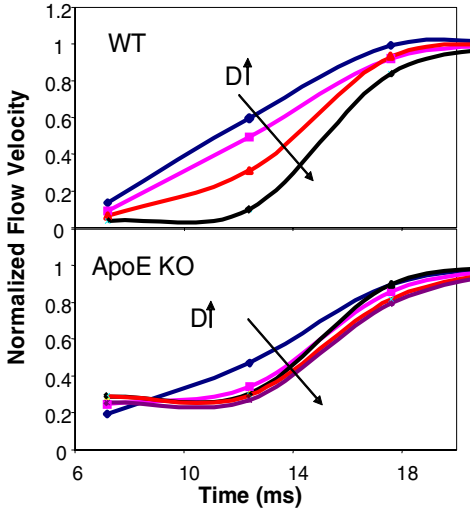

Fig 3. Normalized flow velocity of a wild type (top) and a ApoE KO mouse (bottom) during the early systole at different locations, D along the descending aorta.

Results and Discussion:

The average PWV of the ApoE KO mice (4.70±1.06m/s) was higher than that of the wild type mouse (2.97±0.37 m/s) indicating impaired aortic compliance in the ApoE KO mice. The aortic stiffness in the ApoE KO mice is probably due to endothelial dysfunction caused by atherosclerosis [6]. The presence of atherosclerotic plaques in the ApoE KO mice was confirmed with black blood images in the abdominal aorta in a separate study. Our results are consistent with the findings of Wang et al [6] who reported significantly higher PWV in ApoE KO mice compared to wild type mice in an invasive study using pressure transducers. We found that that the average WSS of the ApoE mice was (1.28 Pa) significantly lower than that of the wild type mouse (2.49 Pa). It is now widely accepted that low WSS leads to atherogenesis [7]. Our findings are consistent with these results.

	PWV (m/s)	WSS (Pa)
Wild Type	2.97±0.37	2.49
F1 ApoE KO	6.15±1.96	1.64
F2 ApoE KO	4.17±2.58	1.23
M1 ApoE KO	4.79±0.58	1.04
M2 ApoE KO	3.71±0.81	1.19

For the first time, this study demonstrates that MR based PWV and WSS can detect the impaired vascular function of an atherosclerotic mouse model. The extremely small diameter of the mouse aorta (~ 1mm) and the high heart rate of the mouse demand a flow measurement method that provides very high temporal and spatial resolution. The fractional radial acquisition phase contrast cine MR sequence presented in this study perfectly meets these requirements.

References:

1. K. Cruickshank et al, Circulation 106:2085-2090(2002) **2**. A. V. Barger et al, Magn. Reson. Med. 43:503-509(2000) **3**. D. C. Peters et al, Magn. Reson. Med. 43:91-101(2000) **4**. D. C. Peters et al, Proc. Intl. Mag. Reson. Med. 11 (2003) **5**. C. P. Cheng et al, Ann. Bio. Eng. 30:1020-1032(2002) **6.** Y. Wang et al, Am. J. Physiol. Heart Circ. Physiol. 278:H428-H434(2000) **7.** K. S. Cunningham et al, Laboratory Investigation 85:9-23(2005)