

Evaluation and Validation of Pulse Wave Velocity Measurements from 2D and 4D PC MRI in Swine with Familial Hypercholesterolemia: Initial Results

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Target Audience: Clinicians and imaging scientists interested in MR flow imaging and the derivation of biomarkers from phase contrast data sets

Purpose: In recent years phase contrast magnetic resonance imaging (PC MRI) has been used to estimate pulse wave velocity (PWV) for the evaluation of atherosclerotic disease burden. However, validation of MRI-derived PWV¹, especially using 4D PC MRI, has been limited. The purpose of this study was to evaluate PWV measurements derived from both 2D and 4D PC MRI in a familial hypercholesterolemic (FH) swine model of atherosclerosis and to compare these measurements to those derived from gold standard intravascular pressure probes. We hypothesized that 2D and 4D PC MRI would provide similar PWV measurements compared to measurements from the pressure probes.

Methods: Swine (n = 5; mean age ± 1SD = 8.5 ± 0.6 months; mean mass ± 1SD = 45.0 ± 5.5 kg) with and swine (n = 6; mean age ± 1SD = 12.7 ± 7.2 months; mean mass ± 1SD = 50.6 ± 25.1 kg) without a balloon catheter-induced vascular injury were used in the study. The lesions were induced by the denudation (injury) of the vascular endothelium of the supra- and infrarenal aorta using an angioplasty balloon, and then maintaining the animals on a 20% fat and 2% cholesterol diet for four weeks prior to the MR study. The combination of the balloon injury, hypercholesterolemic genetic disease, and high fat/cholesterol diet provided a highly accelerated model of atherosclerosis. The study protocol was approved by our Institutional Animal Care and Use Committee.

Two fiber optic pressure probes (opSens, Quebec, Canada) were bound together with the tips separated by 10 cm and positioned in the abdominal aorta centered on the takeoff of the renal arteries. Probes provided a sampling frequency of 1000 Hz. PWV was computed from the pressure waveforms for cardiac cycles averaged over a 20 s window using a custom MATLAB tool (The MathWorks, Natick, MA, USA). The pressure probe data were acquired during the PC MR acquisitions.

Swine were imaged on a 3T clinical MR scanner (MR750, GE Healthcare, Waukesha, WI, USA) using a 32-channel torso coil (NeoCoil, Pewaukee, WI, USA). Five 2D PC slices were placed evenly along the abdominal aorta and acquired with standard Cartesian sampling (scan time = ~24s; temporal resolution = ~25 ms) and prospective ECG gating as well as with a radially undersampled 2D PC acquisition² (scan time = ~28s; temporal resolution = ~12 ms) with offline retrospective ECG gating. A 4D PC MRI (scan time = ~10.5 minutes; reconstructed temporal resolution = ~31 ms) data set was also acquired in the abdominal vasculature using PC VIPR (phase contrast MRI with vastly undersampled isotropic projection reconstruction)³. A VENC of 150 cm/s was used for all PC MR acquisitions.

PWV was derived from the 4D PC and the Cartesian and radial 2D PC data sets using the time-to-foot and cross-correlation PWV algorithms. The 4D PC and the Cartesian and radial 2D PC data were compared to the pressure probe-derived PWV measurements with Bland-Altman analysis and Pearson correlation. MR- and pressure probe-derived PWV measurements were compared between the injured and uninjured groups with an unpaired Student's t-test (p < 0.05).

Results: Box plots and raw data for PWV measurements are shown in Figure 1. Bland-Altman analysis revealed that the 4D PC MRI technique (Figure 2), the radial 2D PC technique, and the Cartesian 2D PC technique tended to underestimate PWV compared to the gold standard pressure probe measurements, with a mean bias (±2SD) of -0.9 ± 3.1 m/s, -0.3 ± 8.1 m/s, and -0.4 ± 6.8 m/s, respectively. Correlation between the pressure probe PWV measurements and the MR-derived PWV measurements revealed good correlation with 4D PC MR data (R = 0.73; p = 0.04); however, aberrant values led to poor correlation with the radial 2D PC data (R = -0.58; p = 0.13) and the Cartesian 2D PC data (R = -0.22; p = 0.63). No significant differences were found between injured and uninjured PWV values for the radial 2D PC MRI data (p = 0.99) or the Cartesian 2D PC MRI data (p = 0.70). Injured versus uninjured PWV values approached significance for the 4D PC MRI (p = 0.08) and pressure probe data (p = 0.09).

Discussion: The 4D PC MRI and the radial and Cartesian 2D PC MRI techniques underestimated PWV compared to the gold standard pressure probe-based PWV measurements. Underestimation of these measurements is likely secondary to both lower temporal resolution and temporal blurring from the acquisition of MR data over numerous heart beats. However, the 95% limits of agreement for the 4D PC MRI Bland-Altman differences (Figure 2) were substantially lower than the limits of agreement for the radial and Cartesian 2D PC PWV measurements. The discrepancy between 2D and 4D PC data is likely due to the difference in which data are analyzed. With 2D PC each slice is acquired with a separate scan and therefore sampling of the true flow waveforms might vary from one slice to another, e.g. due to normal changes in the RR cycle; this factor may lead to variations in computations in PWV. In comparison, the planes from 4D PC MRI are all from a single data set and thus it is less likely that sampling of the flow waveforms will vary from one plane to the next. Thus, PWV values are likely to be more consistent with 4D PC MRI.

Conclusion: The 4D PC MRI acquisition provided a promising means of computing PWV in a swine model of atherosclerosis. Compared to gold standard pressure probe-based PWV measurements, 4D PC MRI provided similar values and provided less variability than 2D PC techniques. While the study population was small, the PWV measurements from the 4D PC technique and pressure probes approached significance (p = 0.08-0.09) in comparing values from injured and uninjured swine. Further evaluation of PWV measurements is needed in the form of a longitudinal study with a larger population of injured and uninjured age-matched swine. Such a study in which PWV is evaluated multiple times in the same animals would allow for tracking of PWV over time and before and after injury. The age-matched uninjured group would serve to control for changes in PWV due to factors other than the injury, such as age and hemodynamic changes associated with development of the cardiovascular system with age.

References: ¹Westenberg JJM et al. Cardiovasc Magn Reson 2012;14:2. ²Barger et al. Magn Reson Med 2000;43:503-9. ³Gu T et al. Am J Neuroradiol 2005;26:743-749.

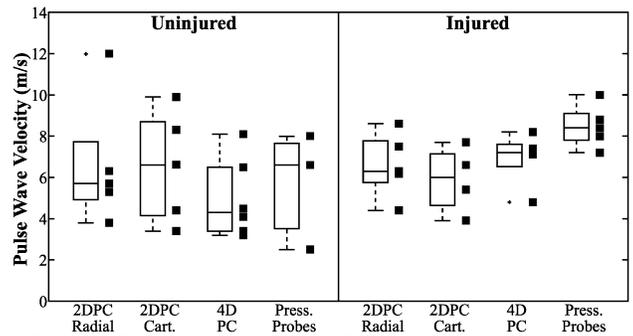


Figure 1. Box and scatter plots of PWV in swine with and without balloon catheter-induced injuries in the abdominal aorta.

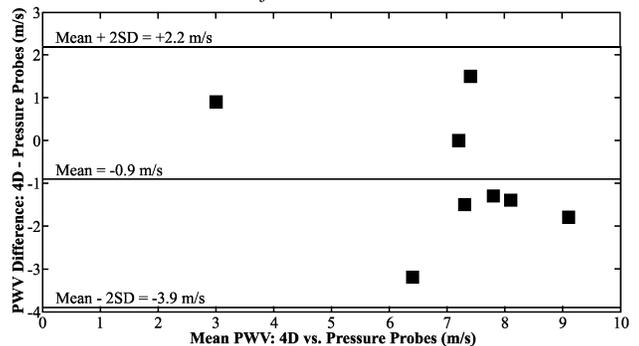


Figure 2. Bland-Altman plot for comparing PWV measurements from the 4D PC MRI technique against the gold standard pressure probe-based PWV measurements. The mean (± SD) Bland-Altman difference was -0.9 ± 3.1 m/s.