Aortic Compliance and Pulse Wave Velocity by MRI: Effects of Pulse Pressure Amplification and Reflection

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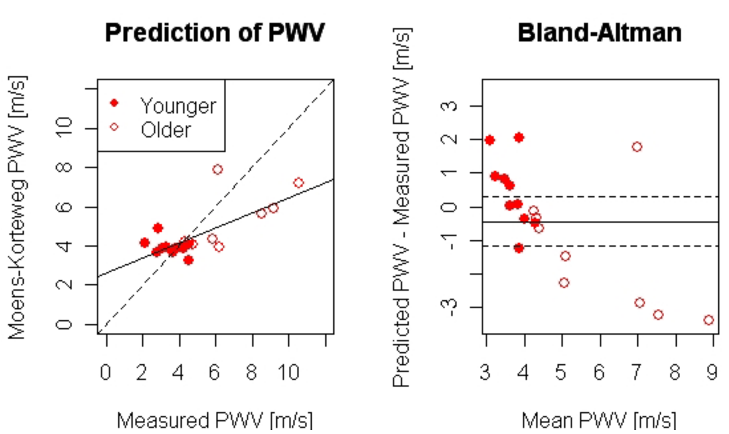
Introduction: The biophysical properties of the aortic wall seem to play a significant role in the pathogenesis of cardiovascular disease such as atherosclerosis, hypertension, aneurysm formation, and Marfan's syndrome. Aortic compliance and aortic pulse wave velocity are two parameters that are closely tied to the function of the aorta as buffer to the pulsatile output from the heart, which results in steady flow to capillary beds. The Moens-Korteweg equation establishes a relationship between compliance and pulse wave velocity, which has not been tested for combined measurements of aortic compliance and pulse wave velocity by MRI. The goal of this study was to determine in a group of volunteers the agreement between direct measurements of PWV and estimates of PWV based on the Moens-Korteweg (MK) equation.

Methods: Pulse wave velocity (PWV) and aortic compliance in the descending aorta were measured with MRI in ten young (mean±SD: 25 ± 2 years) and ten older (mean±SD: 56 ± 6 years) normotensive male subjects. Aortic dimensions in the descending aorta were determined with a cine sequence with steady state free precession [TR/TE/flip angle = 2.4/1.6 ms/50º, 5 mm slice thickness, FOV ~ 320 mm x 260 mm, 256 (read-out) x 208 (phase-encodings) matrix, and segmented acquisition of phase-encodings with effective temporal resolution of 32 ms]. Non-invasive blood pressure measurements were performed at the beginning and at the end of the cine acquisitions with inflatable arm-cuff (Invivo, Orlando, FL). The largest and smallest cross-sectional areas of the descending aorta were determined by manual tracing (ImageJ; http://rsb.info.nih.gov/ij/), and cross-sectional compliance (CC) was calculated as the change in area divided by the peripheral arm pulse pressure [CC = (end systolic area – end diastolic area) /pulse pressure)]. PWV was measured in the descending thoracic aorta with a phase-contrast (PC) cine sequence [TR/TE/flip angle = 24/2.8 ms/30º, 5 mm slice thickness, field of view of 340 mm x 230 mm, acquisition matrix of 256 (read-out) x 163 (phase-encodings], and velocity encoding strengths of up to 200 cm/s in the foot-head direction. Three PC cine data sets, acquired sequentially with ECG-trigger delays of 0, 8, and 16 ms, were temporally interleaved for post-processing with a resulting time resolution of approximately 8 ms. PWV was quantified by generation of velocity versus time curves for 64 locations along a center-line in the descending aorta. At each location, the time at which the velocity reaches its peak rate of change was used to determine the foot of the velocity wavevorm by backward linear extrapolation. The MK equation [$PWV^2=Area/(CC\cdot\rho)$] was used to predict the PWV from the cross-sectional area and the aortic compliance in the descending aorta at approximately the mid-point of the center line used for estimation of the PWV.

Results: PWV was significantly higher in the older group (p=0.004). Pulse wave velocity remained significantly associated with age (increase of 0.066±0.03 m/s per year of age; p=0.042, with MAP=100 mmHg), when the PWV was simultaneously adjusted for differences in heart rate and MAP. The PWV predicted by the MK relationship from the aortic CC and aortic cross-sectional area showed a highly significant correlation with the measured pulse wave velocity (r = 0.70; p<0.001). The Moens-Korteweg based prediction of PWV tended to result in an overestimate relative to the measured PWV in younger subjects (+0.43 m/s; n.s.), and an underestimate in the older subjects (-1.4 m/s; p<0.01), as can be seen in Figure 4. The difference between predicted and measured PWV grew in older subjects as a function of the PWV. The difference between predicted and measured PWV was significantly correlated with age (r = -0.53; p=0.02), and also with heart rate (r = -0.51; p=0.03).

Discussion: It has previously been shown that pressure amplification occurs as the pressure waveform travels towards the periphery. In younger subjects, the brachial artery measurement of pulse pressure would overestimate central pulse pressure. In older subjects, the reflected pulse pressure wave will augment central peak diastolic pressure, leading to an overestimate of the cross-sectional compliance. Our comparison of PWV measured directly by MRI, and the pulse wave velocity predicted with the MK equation from the measured compliance, supports the hypothesis of relative underestimates and overestimates of compliance in the younger and older groups, respectively. The observed differences in aortic compliance between younger and older subjects may be larger than the true differences in compliance, in part due to the reliance on peripheral arm pressures as surrogate measures of central aortic pressures.



Left panel: Pulse wave velocity was predicted from aortic compliance and cross-sectional area with the Moens-Korteweg equation, with the identity relationship shown as dashed line. **Right panel**: The Bland-Altman plot on the right (C) indicates that the predicted PWV tends to exceed the measured PWV in younger subjects, and significantly underestimate the actual PWV in older subjects. The dashed lines show the 95% confidence intervals for the mean of the difference. The observed pattern consistent with a higher pulse pressure amplification in younger vs. older subjects, and central diastolic pressure augmentation due to wave reflections in older subjects.