Different techniques for measuring aortic pulse wave velocity using magnetic resonance imaging

E. H. Ibrahim[1], K. R. Johnson[1], and R. D. White[1]

[1]University of Florida, Jacksonville, FL, United States

Introduction: The aorta is a basic determiner of the total systemic compliance. Maintaining the viscoelastic properties of the aorta is essential for proper biological functioning (1). Reduced aortic compliance has shown to correlate with different pathologic states. The assessment of aortic stiffness is increasingly used in the clinical assessment of cardiac patients.

Invasive techniques using pressure catheters are historically the gold standard for measuring aortic stiffness, but recently, noninvasive measurements have been made with MRI. MRI measures the blood pulse wave velocity (PWV) inside the vessel, which is inversely related to arterial stiffness. Transit-time (TT) (2), flow-area (QA) (3), and cross-correlation (CC) (4) are common techniques used for measuring PWV using MRI. However, the reproducibility and behavior of these different techniques have not yet been studied. In this work, the three techniques are tested on human subjects with different cardiac conditions and compared to each other. Inter-observer, intra-observer, and scan-rescan variabilities are reported, along with the advantages and disadvantages of each technique.

Methods: Fifteen consecutive cardiac patients (8 males and 7 females; age = 51±18 years) referred to our imaging center, along with five healthy volunteers, were scanned on a 3T MRI Siemens scanner. Phased-array coil was used with ECG gating. Three velocity-encoded (venc) cine images of the descending aorta were acquired: one (candy cane) series along the aortic path and two cross section series with about 12 cm in-between. The imaging parameters were: TR = 39 ms; TE = 2.8 ms; flip angle = 15º; slice-thickness = 6 mm; pixel-size = 1.1×1.1 mm^2; temporal resolution = 15 ms; and venc = 150 cm/s. Venc was adjusted to avoid aliasing if observed.

In-house software was created with Matlab for analyzing the images with user interface capabilities. Figures 1, 2, and 3 shows images of the same person, where PWV was calculated with TT, CC, and QA method, respectively. Five of the conducted MRI scans were repeated twice with different position markers and scouting images to compute the scan-rescan variability. Two experts analyzed the images for computing PWV using the TT, QA, and CC techniques. The results were used to determine inter-observer variability for each method. One of the experts analyzed the images twice to compute the intra-observer variability. Paired *t*-tests and Bland-Altman analysis were conducted to measure the differences significance between the results. P<0.05 was considered statistically significant.

Results: The measured PWV values ranged from 2 to 12 m/s. The inter-observer / intra-observer variabilities were low as indicated by the interclass correlation coefficient r = 0.94/0.95; 0.87/0.86; 0.83/0.85 for the TT, QA, and CC methods, respectively. The results from the TT and CC methods were closer together than the QA method (P=0.01). The scan-rescan results did not show significant difference (P>0.2). Bland-Altman analysis showed no significant difference between three methods results. The mean differences between the measurements by the two observers / same observer were -0.35/0.69; 0.34/-0.16; 0.31/-0.57 m/s for TT, QA, and CC methods, respect.

Discussion and Conclusions: The proposed work shows different methods for non-invasively measuring PWV from MRI images. Each method has its own advantages and disadvantages. The TT method produced the most reproducible (least variability) measurements with minimal user interface. The CC method has the shortest processing time. However, high temporal resolution is required, and the measurements could be affected if the seed points are selected very close to each other. The QA method is unique in that only the images at one cross-section are required, which is suitable for curved arterial paths, like the aortic arch. However, high spatial resolution images are required, besides the more-involved user interface. In conclusion, the choice of the analysis technique to be used depends on the geometry of the vessel segment at which PWV is measured and on the resulting image quality. If possible, high spatial and temporal resolution images should be acquired, with concomitant increase in scan time, which gives the flexibility of choosing any of the three analysis techniques. The analysis should be repeated in case the calculated PWV value is significantly different from expected measurements available in the literature.

References

[1] P B Dobrin, Phys Rev 58:397-460.
[2] R Mohiaddin et al., J Appl Physiol 74:492-497.
[3] S Vulliemoz et al, MRM 47:649-654.
[4] S W Fielden et al, JMRI 27:1382-1387.

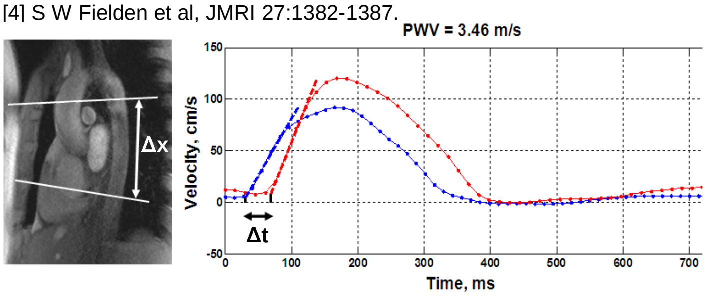

Fig1. TT method. The aorta and locations of the two cross sections. The curves show the velocity waveforms at the two sites. PWV is calculated as the ratio of the traveling distance (Δx) and traveling time (Δt).

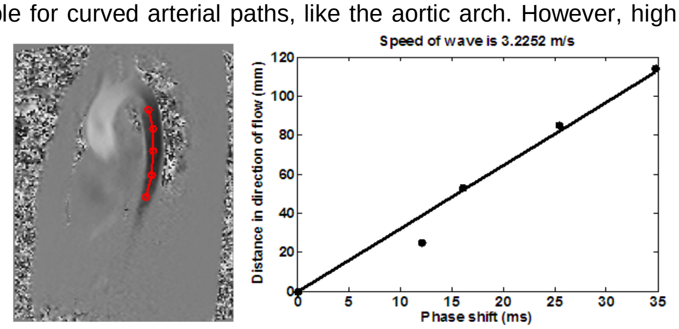

Fig2. CC method. Phase image of the aorta and the sites at which the flow waveforms are measured. The graph shows acquired data (black dots) at different sites. A line is fitted to the data to estimate PWV.

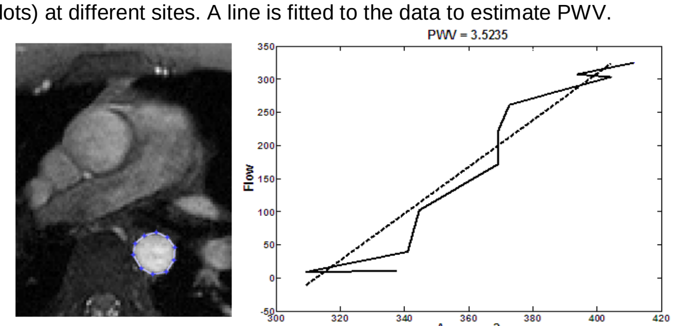

Fig3. QA method. Cross section of the aorta, where the user marks the boundary. The curve shows the cross sectional area and flow values at different frames during the initial slope of the velocity wave.