Evaluation of Different Techniques for Measuring Pulse Wave Velocity Using 3 Tesla MRI

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Introduction: The assessment of arterial stiffness is increasingly used for evaluating patients with a wide range of cardiovascular diseases. Arterial stiffness can be noninvasively estimated by measuring pulse wave velocity (PWV), which is directly related to vessel wall elasticity. Several methods have been proposed for measuring PWV using velocity-encoded MRI, including transit-time (TT) [1], flow-area (QA) [2], and cross-correlation (XC) [3] methods. However, the reproducibility and comparison of these different techniques have not yet been studied in a large diverse group of patients for relative durability and reproducibility, especially at 3 T field strength. In this work, the aortic PWV is measured in 50 patients, representing a wide range of cardiovascular conditions, to assess inter-observer, intra-observer, inter-scan, and inter-method variabilities using 3T MRI.

Methods: Fifty (32 males, 18 females) cardiovascular patients and six volunteers were scanned on a 3-Tesla MRI system (Siemens TIM TRIO, Erlangen, Germany) to acquire the necessary velocity-encoded images. The study group had clinical diversity as shown in Table 1. After plane scouting, three series of velocity-encoded images of the aorta were acquired. The first series was acquired in a sagittal position along the descending aortic path with head-to-foot velocity encoding. Then, two cross-sectional views on the descending aorta, at the levels of the pulmonary arteries and proximal to the renal arteries, were acquired with through-plane velocity encoding. The imaging parameters were: TR/TE = 13/3 ms; matrix = 256×256; flip angle = 15º; slice thickness = 8 mm; venc = 150 cm/s; # heart phases = 128 (temporal resolution ~ 8 ms); bandwidth = 350 Hz/pixel; pixel size = 1.1×1.1 mm^2; scan time = 26 s/slice of shallow breathing. The six volunteer scans were performed twice, but with different table positioning and plane scouting, to test inter-scan reproducibility. The images were analyzed in MATLAB using the TT, XC, and QA methods to determine PWV (Figs 1-3). Two experts analyzed the images to test inter-observer variability. The first observer analyzed the images twice to determine intra-observer variability. The measurements by the three methods were compared to each other to test inter-method variability. Bland-Altman and regression analysis were conducted on the results.

Results: Measured PWV values ranged from 1.5 m/s to 16 m/s. The average processing times were 23 s, 31 s, and 110 s for the TT, XC, and QA methods, respectively, on a 2.4 GHz personal computer. The Bland-Altman plots for inter-observer variabilities showed no bias between the two observers using the TT or XC methods. Mean (SD) PWV differences = -0.12 (1.3) m/s and 0.2 (1.3) m/s for the TT and XC methods, respectively. The QA method resulted in larger differences between the two observers (mean (SD) PWV difference = 0.6 (1.6) m/s). The correlation coefficients between the two observers confirmed the Bland-Altman analysis: r = 0.94, 0.88, and 0.83 for the TT, XC, and QA methods, respectively. The intra-observer Bland-Altman mean (SD) PWV differences were -0.04 (0.4) m/s, 0.09 (0.9) m/s, and 0.2 (1.4) m/s, and the correlation coefficients were 0.99, 0.94, and 0.92 for the TT, XC, and QA methods, respectively. The inter-scan results showed no bias between the repeated measurements for all three methods (r = 0.96 and mean (SD) PWV difference = -0.02 (0.4) m/s). The inter-method results showed strong correlation between TT and XC measurements (r = 0.95 and mean (SD) PWV difference = -0.12 (1.0) m/s). However, the TT and XC measurements showed less correlations with QA measurements (r = 0.87 and 0.89, and mean (SD) PWV differences = 0.8 (1.7) m/s and 0.65 (1.6) m/s for TT-QA and XC-QA, respectively). No significant differences were found between the different methods (P > 0.05).

Discussion and Conclusions: The TT method resulted in the most reproducible measurements and required the shortest processing time, followed by the XC, and then the QA methods. The measurements from the TT and XC methods were closer to each other than to the QA method. The TT method was the least dependent on user interaction, followed by the XC, and then the QA methods. The use of a 3-Tesla system allowed for achieving high spatial and temporal resolutions. In conclusion, each method has its own advantages and disadvantages, which makes it preferred in a certain application or measuring site.

References [1] R Mohiaddin *et al*, J Appl Physiol, 74:492-497.
[2] Vulliemoz *et al*, Magn Reson Med, 47:649-654.
[3] Fielden *et al*, J Magn Reson Imaging, 27:1382-1387.

Parameter	Min	Max	Mean
Age, years old	19	89	55
Heart rate, beats per minute	45	103	69
Systolic/diastolic blood pressure, mm Hg	99/51	175/110	140/78
LV ejection fraction (EF), %	25	82	55
End-diastolic LV mass, gm	72	276	150

Table 1: Study population diversity

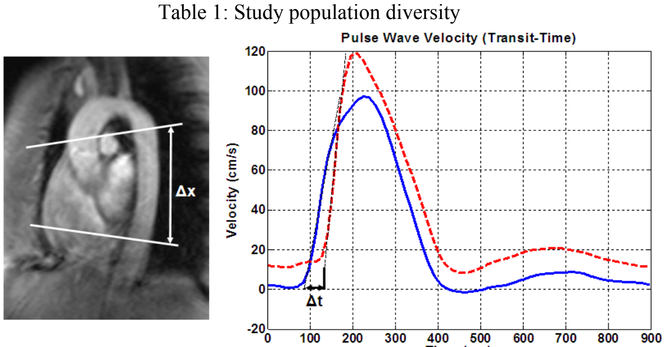

Fig 1. TT method. Velocity curves (right) are computed at two distant points along the descending aorta (left). PWV=Δx/Δt.

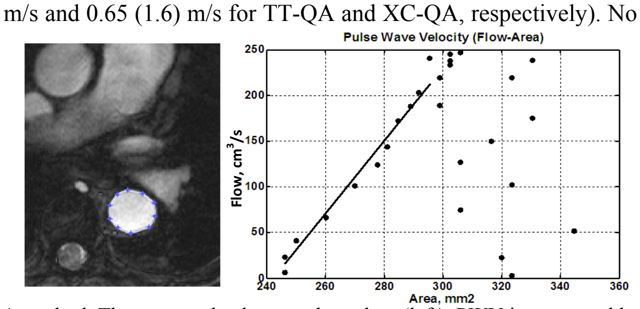

Fig 2. QA method. The user marks the aorta boundary (left). PWV is computed by dividing flow change (ΔQ) by change in aortic area (ΔA) at early systole (right).

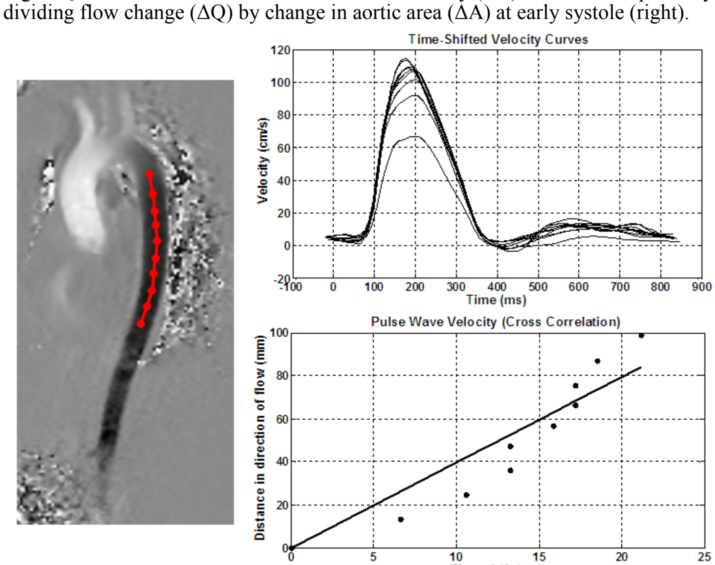

Fig 3. XC method. Flow patterns (up) are computed at several points along the aortic path (left). Cross correlation is used to estimate time shifts between consecutive points, from which PWV is computed by line fitting (down).