Velocity-encoded MRI for assessment of pulmonary arterial stiffness: comparison of techniques

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Introduction: The pulmonary artery (PA) plays an essential role in smoothing the transition from right ventricular (RV) pulsatile flow to the nearly steady flow at the capillary level. The loss of PA compliance has considerable pathophysiological relevance, with elevated RV workload. Velocity-encoding MRI is an effective technique for assessing pulse wave velocity (PWV) by measuring the disturbances in flow or vessel diameter the pressure wave causes [1]. Two methods have been proposed for measuring PWV: transit-time (TT) and flow-area (QA) [2,3]. Nevertheless, no data is available that compares the two methods, especially over a wide range of PWV values, or at 3.0-Tesla, which is the purpose of this study.
Methods: Twenty-five volunteers, 15 males and 20 females, (Table 1) were scanned on 3.0-Tesla Siemens Tim Trio scanner. Two velocity-encoding sequences were applied to each subject. The first sequence was optimized for high temporal resolution (# heart phases = 128, pixel size = 1.25 mm, venc = 150 cm/s), and implemented twice: at a proximal main PA, and either right or left distal PA cross-sectional sites, perpendicular to the blood flow (Figure 1). The second sequence was optimized for high spatial -resolution (# heart phases = 80, pixel size = 0.6 mm, venc = 150 cm/s), and implemented once at the main PA location (Figure 1). The images were analyzed offline with programs created in MATLAB. In the TT method, PWV was measured as the ratio between the traveling-distance (Δx) and traveling-time (Δt) between the two measurement sites (Figure 2) [2]. In the QA method, PWV was measured as the ratio between the PA flow change (ΔQ) and cross-sectional area change (ΔA) during early systole (Figure 3) [3]. Inter-method, inter-observer and intra-observer variabilities were calculated using Bland-Altman analysis.
Results: The MRI exam lasted for 15-20 minutes. Image analysis lasted for 1 and 4 minutes for the TT and QA methods, respectively. The TT and QA methods showed good agreement ($P > 0.1$). The Bland-Altman analysis resulted in mean ± SD of 0.13 ± 0.35 m/s for the measurement differences. All the differences lied within the ±2SD limit. The correlation coefficient between the two methods r=0.93. The repeated measurements showed low inter- and intra-observer variabilities (Figure 4). The mean ± SD of the TT/QA measurement were -0.05±0.2 / -0.01±0.38 m/s and 0.02±0.27 / 0.02±0.4 m/s for inter- and intra-observer, respectively. The corresponding correlation coefficients were r = 0.96/0.92 and r = 0.94/0.90.
Discussion and Conclusions: The TT and QA techniques showed good agreement in estimating PWV, although the QA method resulted in larger variabilities than in TT. Due to the short length of the PA, the single-slice QA method seems to be inherently suitable for measuring PWV in the PA. Nevertheless, a long processing time is required, mostly for identifying the vessel cross-section boundary. On the other hand, the TT method requires double the imaging time as in the QA method due to the acquisition of two separate slices. The use of 3.0-Tesla scanner allowed for improving the temporal and spatial resolutions in the TT and QA sequences, respectively. In conclusion, each technique has its own advantages and disadvantages. The encouraging results in this study should be confirmed in a larger longitudinal study.
References: [1] Milnor et al, Circ Res 1969, 637-649. [2] Bradlow et al, JMRI 2007, 974-981. [3] Peng et al, JMRI 2006, 1303-1310.

Table 1 - Diversity in the study group (mean ± SD)

Parameter	Mean ± SD
Age, years old	52 ± 16
Weight, kgm	82 ± 16
Height, cm	167 ± 9
Heart rate, bpm	69 ± 11
Blood pressure, mm Hg	139±14 / 83±10
LV ejection fraction, %	57 ± 12

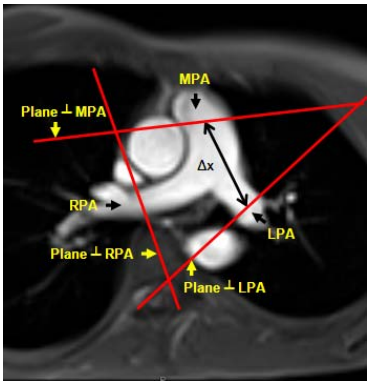

Figure 1. Planning of the pulmonary flow imaging planes. An axial slice showing the main, right, and left pulmonary arteries (MPA, RPA, and LPA). Two planes are prescribed perpendicular to the flow direction. Plane 1 is perpendicular to MPA, while plane 2 is perpendicular to either LPA or RPA. The distance between the two measuring sites (Δx) is used in calculating PWV.

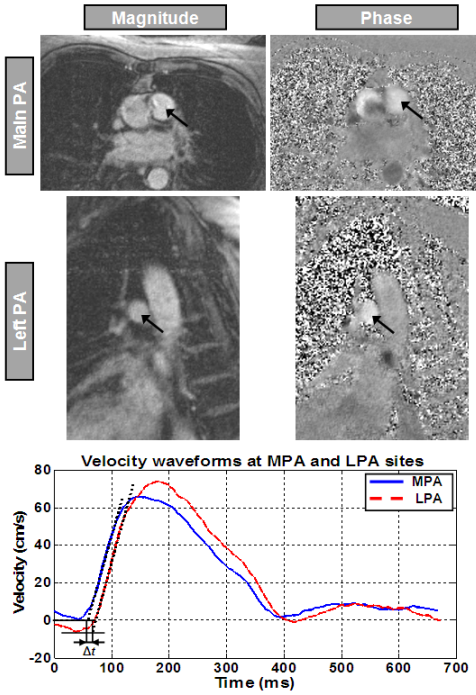

Figure 2. The Transit-Time method for measuring PWV. Anatomical (left) and velocity-encoding (right) images showing cross sections of the main PA (up) and left PA (down). The curves show the velocity waves at MPA and LPA sites. The transit time (Δt) is measured between the curves feet. The curve foot is determined as the intersection of the baseline velocity (solid horizontal line) and the up-steeping edge (dotted line). PWV is determined as the ratio of the travelling distance (Δx) and Δt.

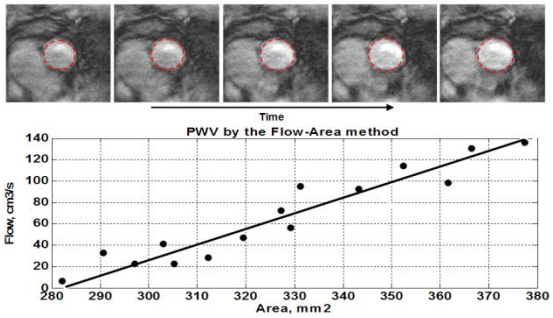

Figure 3. The Flow-Area method for measuring PWV. A succession of cross-sectional images showing the main PA distending during early systole. The vessel cross-sectional area and flow are measured at each frame during early systole. The plotting shows the measured areas versus flow. A line is fitted to the data, where PWV is determined as the line slope.

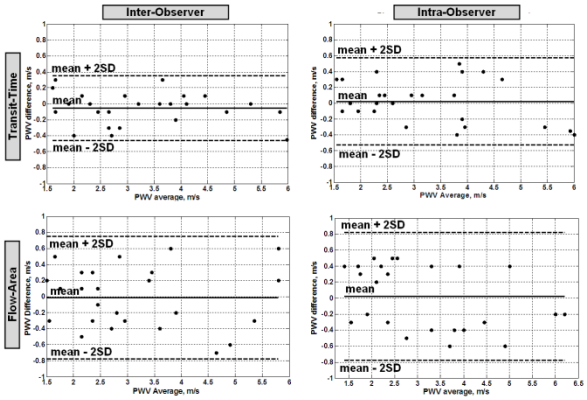

Figure 4. Bland-Altman plots of inter-observer (left) and intra-observer (right) variabilities for the transit-time (up) and flow-area (down) methods for estimating PWV.