Accuracy and repeatability of Fourier velocity encoded M-mode and 2D cine phase contrast for pulse wave velocity measurement in the descending aorta

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Introduction: Aortic pulse wave velocity (PWV) is an independent predictor of coronary events and strokes after adjustment for traditional cardiovascular risk factors [1]. Two-dimensional cine phase contrast (PC) with through-plane velocity encoding is a commonly used technique for PWV evaluation. Fourier velocity encoded (FVE) M-mode is an interleaved 1D technique which represents as an alternative method for fast PWV measurements in relatively straight vessels [2]. Several techniques to extract PWV from velocity data have been proposed [3-7], however it is still unclear which one performs best in terms of accuracy and repeatability.
The aim of this work was to determine accuracy and repeatability of FVE M-mode and 2D PC with through-plane velocity encoding for PWV evaluation in the descending aorta, using 5 different analysis techniques previously reported in the literature.

Methods: *Repeatability experiment.* Twenty healthy volunteers aged 24-57 years (mean age: 37 years) gave written informed consent to participate in the study. Each subject was scanned 3 times on 2 different occasions. During the first visit, after completion of the MR protocol, each subject was removed and repositioned into the magnet bore and the same MR protocol was repeated. During the second visit, after one week, the MR protocol was repeated a third time.
Images were acquired on a 1.5T whole-body imaging system (Signa HDx, GE Healthcare, Waukesha, WI) using an 8-channel abdo-torso phased-array surface coil. After localization of the aorta (Figure 1a), FVE M-mode was performed as reported in [2] (Figure 1c). The sequence was gated to the cardiac R-wave and executed 32 times per heart cycle, with the bipolar gradient amplitude stepped through 32 velocity-encoding steps on each new trigger. Four interleaves of the data were acquired to obtain 128 cardiac phases covering the first 450ms of the cardiac cycle. A 24cm readout field of view (FOV) (matrix size = 256×32), a velocity FOV of 150cm/s and a 2cm diameter cylindrical excitation pulse achieved through an 8-cycle spiral trajectory were prescribed. ECG-gated 2D PC with through-plane velocity encoding was prescribed at the 4 locations indicated in Figure 1a-b (TR = 6.7ms, TE = 3.2ms, flip angle = 30°, FOV = 28cm, slice thickness = 5mm, velocity FOV = 150cm/s, signal averages = 2, views per segment = 1, 100 cardiac phases retrospectively reconstructed).

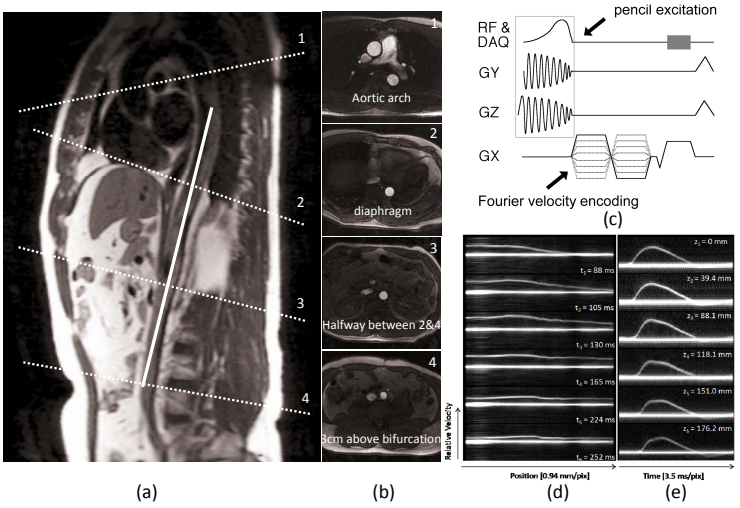

Figure 1

FVE M-mode images (Figure 1d) were reformatted to yield Doppler-like time-velocity traces along the vessel (Figure 1e) [5]. Time-velocity profiles were extracted at each spatial location using an automated line detector and visualized as a velocity surface, each point of which represented velocity at a given time and position. Bilinear interpolation and the gradient-based regularization technique implemented in the Matlab (The Mathworks, Inc., Natick, MA) function *gridfit* [8], were used to smooth the obtained velocity surface, with the smoothing parameter chosen for each subject on the basis of visual comparison with the original data points. Velocity profiles were extracted from 2D PC images using CV Flow v.3.1 (Medis, Leiden, The Netherlands). Five algorithms previously reported in the literature were implemented to compute the PWV from FVE M-mode and 2D PC velocity data: 1) Maximum of first derivative (1st der) [3]; 2) Maximum of second derivative (2nd der) [4]; 3) Early systolic fit (ESF) [5]; 4) Cross correlation (Xcorr) [6]; and 5) Velocity correlation (Vcorr) [7]. For 1st der, 2nd der and ESF, PWV was determined by best fit of the position of the foot of the wave as a function of position along the vessel. Xcorr and Vcorr were implemented as described in [5] and [7], respectively. Repeatability for each of the 5 algorithms as applied to FVE M-mode and 2D PC-derived PWVs was reported using intra-day and inter-day coefficients of variation (COV) expressed as a percentage relative to the group mean, and inter-scan within-subject variation (δ) as determined by a one-way analysis of variance random-effect model [9].
Accuracy experiment. PWV measurements were performed in a tubular polyvinyl alcohol cryogel (PVA-C) phantom integrated into a computer-controlled flow simulator [10]. Images were acquired using a 5-inch receive-only surface coil and were triggered using simulated R-R waveforms produced by the simulator. FVE M-mode was prescribed along the axis of the cylinder and 2D PC was performed at 3 axial locations 6cm apart. Imaging parameters were the same as for the repeatability experiment except: TR = 7.6ms, TE = 3.6ms, FOV = 14cm for 2D PC. Image analysis was performed as in the in vivo case. The gold standard was defined as the PWV value derived from the Moens-Korteweg equation after measurement of the elastic modulus of the tube by uniaxial tensile testing (Instron 5544, High Wycombe, Bucks, UK).

Results: Results for the repeatability experiment are summarized in Table 1. The inter-scan within-subject variation (δ) was lower for FVE M-mode than for 2D PC independently of the algorithm used, meaning a better repeatability of FVE M-mode. For both MR techniques, the ESF algorithm was found to be the most repeatable (FVE M-mode: δ=0.096; 2D PC: δ=0.386). Figure 2 shows FVE M-mode and 2D PC-derived PWVs in the flow phantom against the Moens-Korteweg-derived PWV value (6.6±0.7m/s). For FVE M-mode, ESF was the most accurate method (6.8±0.4m/s). For 2D PC, the 1st der. method proved to be the most accurate (6.8±1.1m/s).

	FVE M-mode				2D PC			
	PWV(±SD) (m/s)	Intra-day COV (%)	Inter-day COV (%)	δ (m^2/s^2)	PWV(±SD) (m/s)	Intra-day COV (%)	Inter-day COV (%)	δ (m^2/s^2)
1st der.	4.74 (±0.751)	1.00	1.31	0.107	4.85 (±0.776)	2.74	2.01	0.431
2nd der.	4.47 (±0.714)	1.47	2.15	0.196	5.26 (±0.956)	2.59	2.43	0.690
Xcorr.	5.18 (±0.855)	1.48	1.54	0.143	5.62 (±1.356)	3.56	2.71	1.412
Vcorr.	5.03 (±0.677)	1.43	1.78	0.152	4.30 (±0.833)	3.48	3.36	0.543
ESF	4.94 (±0.674)	0.70	1.62	0.096	4.68 (±0.698)	2.82	2.15	0.386

Table 1

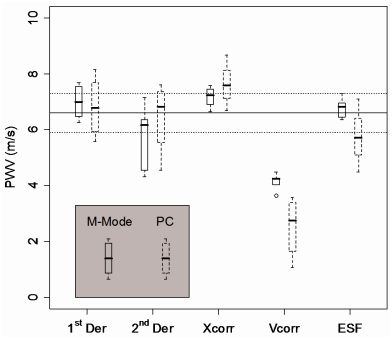

Figure 2

Conclusion: The in vitro experiment demonstrated that similarly accurate results can be obtained from both 2D PC and M-mode, provided the optimal algorithm is used. In vivo, FVE M-mode allowed repeatable central PWV evaluation when the ESF algorithm was used. In vitro, 2D PC and the 1st der method provided accurate measurements of PWV, however, the 2D PC in vivo results were less repeatable than M-mode, regardless of the analysis technique used.

References: [1] Laurent S, et al. Eur. Heart J. 2006; 27: 2588-605. [2] Hardy CJ, et al. MRM 1996; 35(6):814-9. [3] Millasseau SC, et al. Hypertension 2005; 45(2): 222-6. [4] Hermeling E, et al. Ultrasound Med Biol 2007; 33(5): 774-81. [5] Hardy CJ, et al. ISMRM08. [6] Fielden SW, et al. JMRI 2008; 27(6): 1382-7. [7] Urchuk SN, et al. JMRI 1995; 5(6): 628-34. [8] FileEx: 8998. [9] Quan H, et al. Biometrics 1996; 52(4): 1195-203. [10] Taviani V, et al. ISMRM09.