Free-Breathing Radial 2D Phase Contrast MRI for Aortic Pulse Wave Velocity Measurements in Healthy Older Adults

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Purpose: Pulse wave velocity (PWV) is related to arterial stiffness, an early indicator of cardiovascular disease[1]. Phase contrast (PC) MRI with breath-holds (BHs) can assess aortic PWV, however, in certain populations, BHs may be difficult. We present a method to measure aortic PWV using a free-breathing (FB) radial 2DPC sequence.

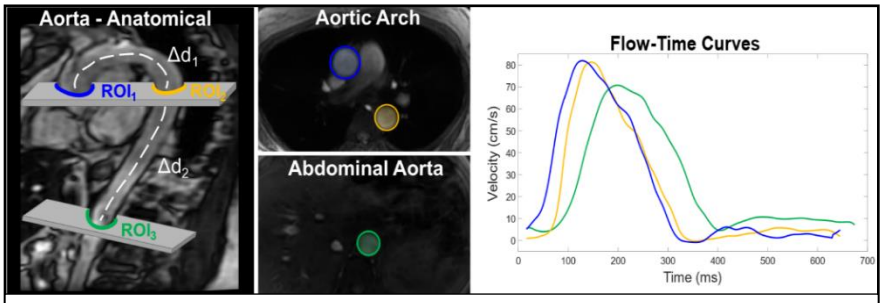

Fig 1: Sag. bSSFP for plane placement and Δd calculations (left). Three ROIs (middle) from 2 PC planes allow for Δt measures from flow-time curves (right).

Methods: Eighteen healthy subjects (13F/5M, mean age=57y [23-72y]) were scanned with both a radial FB 2DPC sequence and a Cartesian BH 2DPC product sequence at 3T (Signa Premier, GE Healthcare, Waukesha, WI) using a 30-channel anterior AIR™ coil. For both sequences, two axial planes were placed in the aorta: one in the aortic arch and the second in the abdominal aorta (Fig 1). Cartesian BH 2DPC scans were acquired with prospective peripheral pulse oximeter gating (PG) gating: scan time=13s (breath-hold); TR=5ms; TE=3ms; flip=25˚; slice=6mm; V_{enc}=150cm/s. Radial FB 2DPC scans were acquired with retrospective PG/respiratory gating: scan time=2:27; projections=10,000; TR=7ms; TE=4ms; flip=25˚; slice=6mm; V_{enc}=150cm/s. Resolutions from both scans were matched for comparison purposes: spatial res.=1.4mm^2; cardiac frames=40; temporal res.=15-33ms. Gating quality was assessed for every scan and velocity aliasing correction[2] was applied when necessary. Additionally, FB anatomical balanced steady-state free precession (bSSFP) images were acquired to manually draw centerlines for distance calculations: scan time=10s (breath-hold); TR=3.3ms; TE=1.5ms; flip=45˚; spatial res.=0.94mm^2; slice=3.6mm. Radial scans were retrospectively subsampled to 2,500 projections (corresponding to a 0:37 scan time) to test a locally low rank reconstruction[4] for scan time reductions. A regularization parameter of 0.003 was empirically chosen on the basis of image quality after testing various regularization parameters. Circular ROIs were drawn around each vessel (3 measurements total) to construct flow-time waveforms and were further smoothed with a Gaussian filter (width 7 pixels) to decrease velocity noise. Centerlines were calculated from bSSFP images by manually placing seed points in the aorta over multiple image slices and fitting the points to a 3D b-spline. Time-to-foot, time-to-upstroke, time-to-point, and cross-correlation methods[3] were used to calculate time shifts in flow waveforms. Measured time shifts were plotted against measured centerline distances between ROI flow measurements and linear regression was used to fit the 3 data points (inverse of the fitted slope is PWV). PWV measures from the 10,000- and 2,500-projection radial datasets were compared to Cartesian PWV measures using a two-sided, paired t-test. Likewise, an f-test was used to assess differences in variance. Significance was defined as p<0.05.

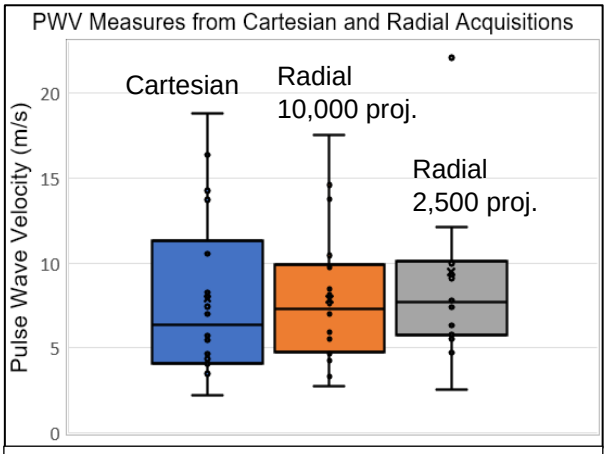

Fig 2: Box plots of Cartesian and radial acquisition-derived PWV measures for all subjects

Results: Fifteen subjects were successfully scanned with 2 radial and 2 Cartesian PC scans in the aortic arch and abdominal aorta. Three subjects were scanned with only 1 plane through the aortic arch due to acquisition errors. The mean PWV (±standard deviation) for each acquisition are as follows: Cartesian=7.90±4.88 m/s; Radial 10,000 proj.=7.85±4.07 m/s; Radial 2,500 proj.=9.46±6.03 m/s. Box plots (Fig 2) show distributions of each acquisition. Paired t-tests showed no significant differences between either the 10,000 projection (p=0.97) or 2,500 projection scans (p=0.58) and the Cartesian scans. Additionally, no differences in variance were found (all p>0.4).

Discussion: FB PC-derived PWV measures were comparable to the PWV measures obtained from BH Cartesian PC scans, demonstrating the feasibility of FB acquisitions for PWV assessment. This may be particularly useful in severely diseased, demented, or hearing-impaired populations who cannot hold their breath when evaluating global or regional vessel stiffness. Despite longer FB scan times, actual exam times for BH exams are substantially longer than 12s, requiring additional time for patient preparation and recovery around the BH scan (~1 min). Furthermore, locally low rank reconstructions can be used to reduce scan time or improve image quality, velocity data, and increase temporal resolution. Further studies are warranted to compare acquisitions to ground-truth standards such as pressure measurements in an aortic phantom or animal model.

References: [1] Calvacante, JL, et al. *J Am Coll Cardiol*. 2011; 57:1511–22. [2] Zhao, Z, et al. *Meas. Sci. Technol.* 2018; 30(1). [3] Dogui, A, et al. *J Magn Reson.* 2011; 33:1321-1329. [4] Rivera LA, et al. *JCBFM*. 2020.