Semi-automated pulse wave velocity measurement in the thoracic aorta using 4D flow MRI

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Target audience: Radiologists and researchers interested in measuring vessel stiffness as a predictor for cardiovascular disease.

Purpose: Pulse wave velocity (PWV) provides a measure of vessel compliance, and has been shown to be a reliable marker for atherosclerosis, as well as the changes in vessel stiffness with age[1,2]. In a recent longitudinal meta-analysis, PWV derived using Doppler and catheter measurements was shown to be a robust predictor for cardiovascular events and all-cause mortality[3]. 4D flow MRI has been applied to assess PWV with full volumetric coverage of the aorta, but the analysis was labor intensive and may be limited by the low temporal resolution of a standard 4D flow acquisition. The aims of this study were (1) to validate a fast semi-automated technique for extracting PWV from 4D flow data, (2) to compare the results to PWV derived from corresponding 2D phase contrast (PC) measurements with high temporal resolution, and (3) to assess the effect of temporal resolution on the PWV measurements.

Methods: Nine normal volunteers (ages 27-57) were scanned on a 3T MRI system (MAGNETOM Skyra, Siemens AG, Erlangen) with informed consent and IRB approval. Navigator gated 4D flow data[4] of the thoracic aorta were acquired with three directional velocity encoding, venc = 150 cm/s, voxel size = 2.3x2.3x2.3 mm^3, a k-t GRAPPA[5] acceleration factor R = 5, temporal resolution = 20.0-20.4 ms. Additional high temporal resolution 2D PC data with through plane velocity encoding was also acquired. 2D PC measurements were made in the ascending aorta, and both proximal and distal descending aorta (Figure 1a), with parameters: venc = 150 cm/s, voxel size = 1.7x1.7x8 mm^3, GRAPPA acceleration factor R = 2, temporal resolution = 8 ms. 4D flow data were imported into an investigational 4D Flow Evaluation Tool[6] (Siemens AG, Erlangen), and a semi-automated centerline extraction and aortic lumen segmentation was performed[7-8]. One hundred evaluation planes were then automatically reconstructed along the centerline, and flow-time curves were automatically calculated for each plane based on the segmentation contours (Figure 1b). The centerline coordinates and flow waveforms were imported into a custom MATLAB (Mathworks, Natick, MA) tool, where PWV was derived from the data automatically by fitting a plane to the upslope of all flow waveforms in a least square sense (Figure 2)[9]. The orientation of the fitted plane, i.e. the slopes along the temporal and spatial direction, was used as a measure of changes in waveform timing across all analysis planes and thus resembled global aortic PWV. The 2D flow data and vessel centerline scanner coordinates were also imported into MATLAB. For each of the three planes, flow-time curves were calculated by manually segmenting the aortic lumen for all time-frames and the corresponding PWV was derived using the same technique as for the 4D flow data. PWV was also derived using the 4D flow data after 1-4 fold temporal sub-sampling to assess the effect of temporal resolution on the upslope curve fit.

Results: Figure 3 shows a good correlation with age for PWV derived from the 4D flow data, and a moderate agreement between PWV assessment using 2D and 4D flow data. The mean PWV for all volunteers was 3.0±0.8 m/s, 2.9±0.6 m/s, 2.8±0.7 m/s, and 1.9±0.3 m/s after temporal sub-sampling by factors of 1, 2, 3 and 4, respectively.

Discussion: Using vessel centerline detection and early systolic upslope detection algorithms, we have presented a rapid and semi-automated technique for extracting PWV measurement from 4D flow data (only a single point on the proximal ascending and distal descending aorta needs to be identified manually). The measured PWV's correspond well with the literature[1-3,9]. As expected, increasing the temporal resolution increases the number of upslope points for the fitting, which has an effect on the measured PWV.

References: 1.Circulation 1991; 83:1754–1763; 2. Br Med Bull 1989;45:968–990; 3. JACC 2010;55: 1318–1327; 4. JMRI 2007;25: 824–831; 5. MRM 2011; 66(4): 966-975; 6. Proc. ISMRM 2012, 4148; 7. Gulsun and Tek, MICCAI 2008; 8. Gulsun and Tek, SPIE 2010; 9. JMRI 2012; 35: 1162-1168.

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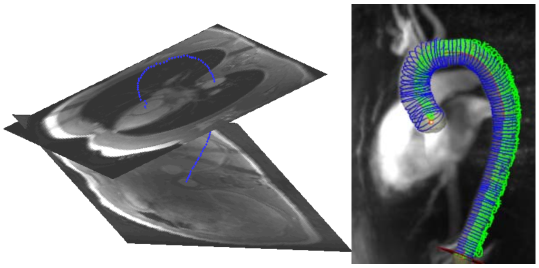

(a) (b)

Figure 1. Automatically extracted (a) lumen centerline coordinates (blue) relative to the 2D flow acquisition planes, and (b) corresponding analysis planes.

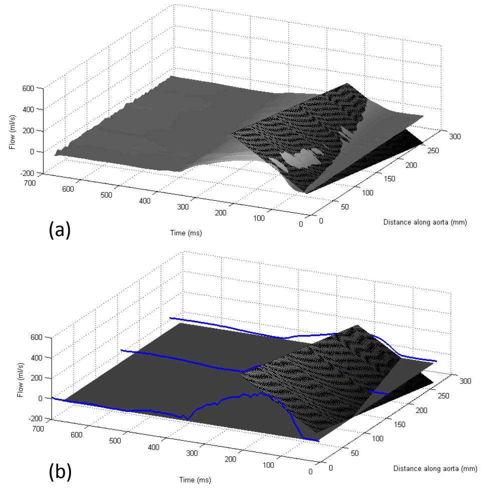

Figure 2. Plane fitting for (a) 4D flow and (b) 2D flow data. The PWV corresponds to the distance along the vessel centerline divided by the time lag of the fitted plane.

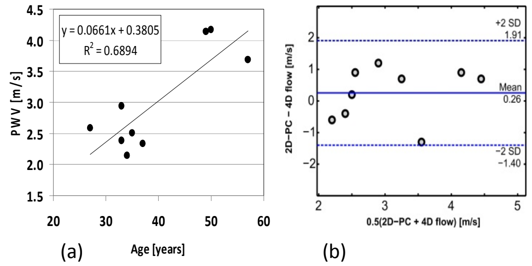

Figure 3. (a) PWV vs Age for the 4D flow data. (b) Bland-Altman plot of PWV derived from 2D vs 4D flow data.