

Effects of Respiration on Aortic Pulse Wave Velocity using Retrospective Respiratory Gated Radial 2D Phase Contrast MRI

Grant S Roberts¹, Zach S Bernhardt², Sarah Lose², Alyssa Pandos², Kevin M Johnson^{1,3}, Laura B Eisenmenger³, Ozioma Okonkwo², and Oliver Wieben^{1,3}

¹Dept of Medical Physics, University of Wisconsin - Madison, Madison, WI, United States, ²Dept of Medicine, University of Wisconsin - Madison, Madison, WI, United States, ³Dept of Radiology, University of Wisconsin - Madison, Madison, WI, United States

Synopsis

Pulse wave velocity (PWV) is a non-invasive biomarker related to vascular stiffness and cardiovascular risk. Cine 2D phase contrast (2DPC) MRI can be used to assess aortic PWV. However, the effects of respiration on PWV measures remain unexplored. Here, we assessed the effects of respiration by retrospectively gating free breathing radially sampled 2DPC MRI data in both inspiration and expiration. Two axial slices were obtained in the aortic arch and abdominal aorta and time shift methods were used to calculate PWV between the ascending and abdominal aorta. PWV measurements from inspiration (7.58m/s) were significantly decreased relative to expiration (8.42m/s).

Introduction

Pulse wave velocity (PWV) is the velocity of blood pressure pulsations through arterial vasculature and is inversely related to arterial compliance via the Moens-Korteweg equation¹. Cine 2D phase-contrast (2DPC) MRI has been successfully used to non-invasively determine aortic PWV by measuring temporal shifts in flow waveforms between imaging planes and calculating the aortic centerline distances between planes². Typically, these 2DPC exams are performed under breath-hold conditions at end-expiration. However, pressure tonometry studies have shown that carotid-radial PWV measures obtained during peak inspiration are decreased relative to expiration³, an effect that has not been demonstrated using MRI. Recently, free-breathing methods using radially sampled 2DPC MRI have been introduced for aorta PWV measurements for patients unable to hold their breath or follow commands in the bore and to increase patient comfort. Coupled with retrospective respiratory and cardiac gating^{4,5}, such continuous radial acquisitions enable flexibility in the reconstruction of cine PC series to user-selected respiratory phases. Here, we utilize free-breathing radial 2DPC MRI to retrospectively reconstruct data during both inspiration and expiration to measure their effects on MRI-derived aortic PWV measurements.

Methods

Forty-five healthy subjects (35F/10M, mean age=64y) were analyzed from a cohort of late-middle-aged subjects enriched with risk for late-onset Alzheimer's disease. Free-breathing radial 2DPC MRI chest scans were performed at 3T (Discovery MR750, GE Healthcare, WI) using an 8-channel chest coil. Two axial planes were placed in the aorta: one in the aortic arch and the second in the abdominal aorta (Figure 1). Cine 2DPC scans were acquired with: peripheral pulse oximeter gating (PPG); TR/TE=7.5/4.3ms; flip=25°; # radial projections=10,032; slice thickness=6mm; VENC=150cm/s; reconstructed cine cardiac frames=40; non-interpolated mean temporal res.=25.2ms; scan time=2.5min. Additionally, ungated, Cartesian, free-breathing anatomical FIESTA images (sagittal, coronal, and axial) were acquired to semi-automatically trace centerlines for distance calculations. Respiratory gating signals were acquired with a respiratory belt. Two separate cine reconstructions of the radial data were performed with a 50% acceptance window that continuously adapted to (1) expiration and (2) inspiration positions, as shown in Figure 2. PPG and respiratory gating signal quality was assessed for each subject and for each imaging slice.

A customized user-interface (available on Github) was developed in MATLAB (Mathworks, MA) to calculate centerlines and process 2DPC data to computed PWV. 3D b-spline centerlines were traced from the anatomical FIESTA images by manually placing points in the aorta over all image slices where the aorta was visualized. Centerline distances were kept constant for inspiration and expiration. From the first 2DPC plane in the aortic arch, both ascending and descending aorta were transected thus providing two ROI data measurements. Circular ROIs were drawn around each vessel and flow waveforms were constructed over all time frames. Obtained flow waveforms were smoothed with a Gaussian filter (width 7 pixels) and linearly interpolated (20x). Cross correlation (Xcorr)⁶ methods were used to calculate time shifts in flow waveforms. Measured time shifts were plotted against measured centerline distances between planes and linear regression was used to fit the 3 data points, where the inverse of the fitted slope is the estimated global aortic PWV (Figure 2B). Two-tailed paired t-tests were performed to assess differences between PWV values obtained from inspiration and expiration.

Results

Inspiration- and expiration-gated 2DPC data were successfully obtained in 44 subjects. One subject was excluded due to poor respiratory gating signal. After statistical analysis, global aortic PWV values reconstructed during inspiration (mean=7.58, SD=2.91 m/s) were significantly lower ($p=0.003$, CI=[-1.25,-0.278]) compared to PWV values reconstructed during expiration (mean=8.42, SD=3.38 m/s). Box plots for inspiration and expiration data are shown in Figure 4.

Discussion

This study demonstrated a significant decrease (9.9%) in aortic PWV measurements obtained with 2DPC MRI during inspiration versus expiration. These results are consistent with findings from a pressure tonometry study evaluating carotid-radial PWV under deep, prolonged inspiration and expiration, where they also found a decrease between expiration and inspiration³. However, in our study, subjects underwent normal respiration, which may show different effects relative to deep, sustained respiration. The physiological mechanisms for this are unclear, however, it is known that respiration acts on (1) intrathoracic pressure, (2) atrial filling and cardiac output, (3) arterial pressure, (4) arterial baroreceptors, and (5) blood flow rates. Additionally, sustained breath-holds induce additional pressure changes and may create short-term hypoxic conditions that affect vascular tone and vessel dilation⁷. These findings have an important implication for both 2DPC PWV studies, which are typically performed under breath-hold conditions, and for free-breathing 2DPC and 4D flow MRI PWV studies, which are typically gated on expiration.

Conclusion

We found that aortic PWV measurements obtained during inspiration were around 10% lower than expiration using retrospectively gated, free-breathing, radial phase contrast MRI. Future studies look to increase sample size, validate these findings with breath-hold 2DPC exams in both sustained inspiration and expiration, and evaluate volumetric flow rates and area changes in both respiratory phases.

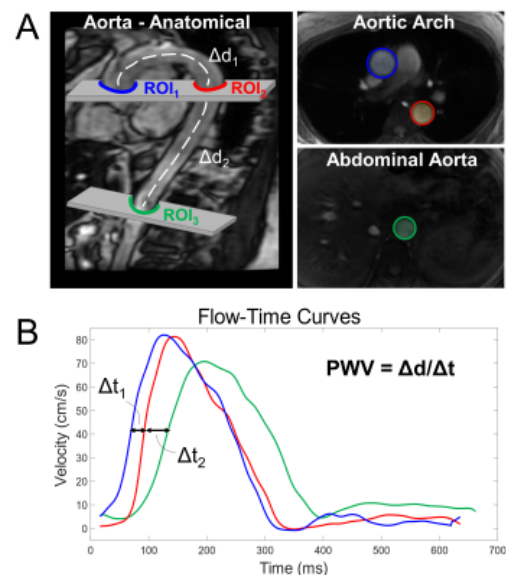
Acknowledgements

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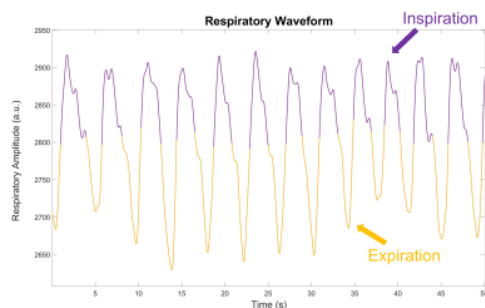
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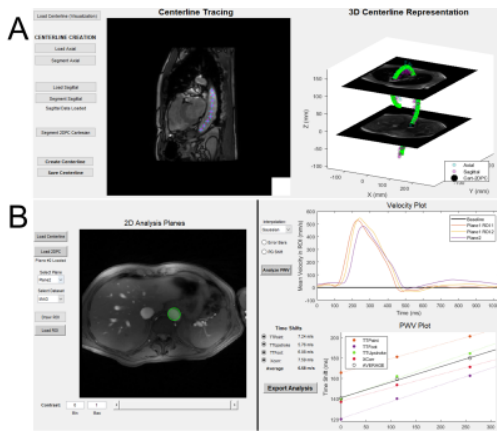
Figures



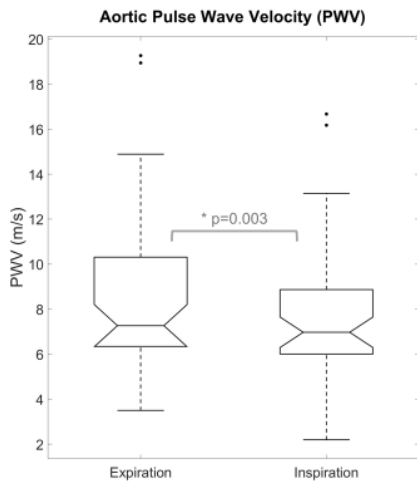
(A) Sagittal balanced steady-state free-precession image highlighting two axial 2D phase contrast (2DPC) slices with three associated region of interest (ROI) measurements and distances (Δd) between each ROI. Circular ROIs were manually placed in ascending, descending, and abdominal aorta from the 2DPC magnitude images. (B) Time-resolved flow waveforms for each ROI, depicting temporal shifts along the aorta.



Respiratory waveform generated from the respiratory bellows signal acquired simultaneously with MRI data. A segment of 50 seconds (of 150 seconds total) is shown to demonstrate inspiration (purple) and expiration (yellow) portions of the waveform, defined by a 10 second sliding window thresholding method. Radial projections were retrospectively sorted and reconstructed into inspiration and expiration datasets.



(A) Semi-automatic aorta centerline tracing from both axial and sagittal (shown) images over multiple slices. Selected points are converted to a common 3D space (relative to scanner coordinates) and a 3D b-spline centerline is generated (green). (B) ROIs are manually drawn over each 2DPC slice and flow waveforms are plotted. A plot of centerline distance versus time shift is created and a line is fit to these data, in which the inverse of the slope is the estimated global aortic pulse wave velocity.



Box plots of pulse wave velocity (PWV) calculations from data reconstructed in inspiration and expiration (N=44 healthy, older subjects). PWV values retrospectively gated on inspiration were significantly lower relative to expiration.