Improved Aortic Pulse Wave Velocity Assessment with Inplane Velocity-Encoded MRI: Validation and Reproducibility

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Introduction

Aortic Pulse Wave Velocity (PWV), defined as the propagation speed of the systolic blood pressure or flow wave through the aorta, is associated with arterial wall compliance in cardiovascular diseases and connective tissue disorders such as hypertension, diabetes and Marfan syndrome. PWV can be acquired accurately intra-arterially during catheterization but this invasive method is not suited for screening. Non-invasive 1-directional (dir) velocity-encoded MRI is widely used to determine PWV based on the transit-time method, but this method shows only moderate correlation and relatively high variation when compared to pressure measurements.

Purpose

2-dir VE MRI with high temporal resolution is introduced to determine PWV along the full course of the aorta. Accuracy is assessed in patients by comparing with invasive pressure measurements during catheterization and reproducibility is determined by repeated acquisition in healthy volunteers.

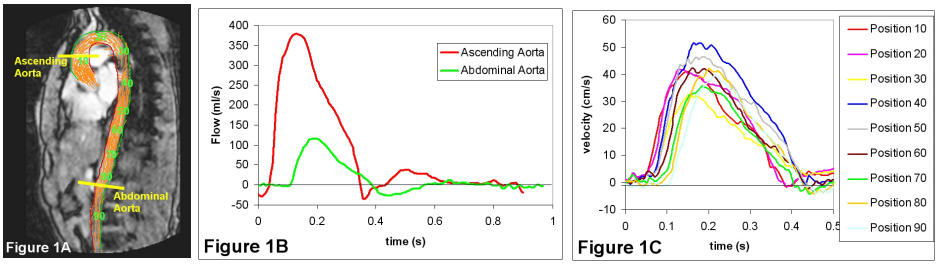

Figure 1: A) sites for PWV-assessment along the aorta, with 2-dir velocity vector field plotted inside the aorta; B) propagation of the flow wave assessed with 1-dir VE MRI at two sites along the aorta; C) propagation of the velocity wave assessed with 2-dir VE MRI at 100 sites (10 plotted) along the centerline of the aorta.

Material and Methods

The local ethics committee approved this study and all patients and volunteers gave informed consent. MRI was performed on a 1.5T Gyroscan ACS/NT15 MRI (Philips, Best, The Netherlands).

PWV-method 1: Through-plane 1-dir VE MRI was determined at two sites perpendicular to the aorta (Fig. 1A), at the ascending and abdominal aorta. Scan parameters: FOV 300mm, acquisition voxel size 2.3×2.3×8.0 mm^3, velocity sensitivity V_{enc} 200 cm/s, maximal number of reconstructed phases (temporal resolution 5-10 ms). Acquisition at the abdominal aorta was performed similarly, except for using V_{enc} 150 cm/s and the body coil for signal reception instead of the 5-element phased-array cardiac coil. The distance between both measurement sites was determined along the aortic centerline. PWV was determined from the ratio of this distance and the transit-time of the flow wave (Fig. 1B) (assessed fully automatically at the start of the upstroke of the propagating wavefront, by detecting the intersection of the constant diastolic flow and the increase in flow at systole, modeled by linear regression).

PWV-method 2: 2-dir VE MRI was performed in a double-oblique stack of three consecutive slices with slice thickness 10mm, FOV 450mm, acquisition voxel size 3.5×3.5×10.0 mm^3, velocity sensitivity V_{enc} 200 cm/s in AP and FH direction, maximal number of reconstructed phases (temporal resolution 5-10 ms). From the 2-dir VE data, the 2D velocity vector field of the blood flowing through the aorta is constructed. The aorta was segmented and the maximal velocity along the centerline of the aorta was measured over time at 100 equidistant measurement sites along the centerline (Fig. 1C). The PWV averaged over the aorta was determined from the distance between each measurement site and the transit-time of the wave (again assessed fully automatically at the start of the upstroke of the velocity wavefront).

Validation: In 15 patients (mean age 57±9 years) scheduled for catheterization, pressure measurements were acquired during pullback with a 6F saline filled catheter (Cordis Corp., Miami Lakes, FL). The catheter was advanced through the aorta until just distal to the aortic valve and then pulled backward. Pressure waves were recorded at ten locations 5.8 cm apart. The PWV averaged over the aorta was determined from the distance between measurement locations and the transit-time for the pressure wave, fully automatically determined from the minimal blood pressure, just before upstroke of the systolic pressure wavefront. The patients underwent an MRI examination 16±13 days later. PWV was assessed with both MRI-methods and compared with the PWV assessed from pressure measurements.

Reproducibility: In 15 healthy volunteers (mean age 30±10 years), PWV was assessed with both MRI-methods twice, with repeated scanning after repositioning.

Results

Validation: In Fig. 2A, the PWV assessed with both MRI-methods are presented versus PWV assessed with pressure measurements. In Fig. 2B, the differences between MRI and pressure are presented. 1-dir VE PWV shows a trend in underestimating higher PWV-values when compared to pressure measurements. 1-dir VE PWV is significantly different from PWV pressure (mean difference 0.7 m/s, p=0.05), with a wide confidence interval (CI) -3.2m/s to +1.8m/s and a coefficient of variation (COV) of 20%. Intraclass correlation for absolute agreement (ICC) = 0.65 (p=0.02). 2-dir VE PWV is not significantly different from PWV pressure (small CI -1.3m/s to +0.8m/s), COV=9% and ICC=0.97 (p<0.001).

Reproducibility: Repeated PWV-assessment showed good reproducibility for both methods, with 2-dir VE MRI performing slightly better. For 1-dir VE PWV: ICC=0.81 (p=0.001), CI -0.8m/s to +1.2m/s and COV=11%. For 2-dir VE PWV: ICC=0.88 (p<0.001), CI -0.8m/s to +1.0m/s and COV=10%.

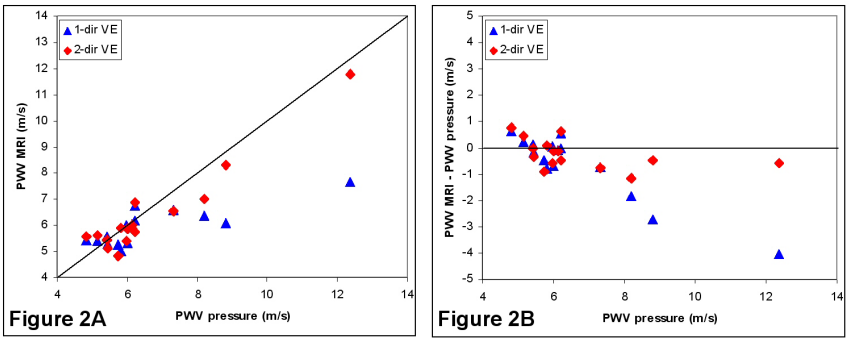

Figure 2: A) PWV assessed with both MRI-methods vs. PWV assessed with pressure measurements (gold standard); B) the differences in PWV-assessment between both modalities.

Conclusion

Pulse Wave Velocity assessed from 2-directional inplane velocity-encoded MRI over the full course of the aorta is very accurate when compared to the gold standard (invasive pressure measurements) and can be performed reproducibly. The widely used 1-directional through-plane velocity-encoded MRI is less accurate and shows more variation than 2-directional velocity-encoding.

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