Aortic Pulse Wave Velocity Assessed with Velocity-Encoded MRI: Validation with Catheterization and Clinical Applicability

J. J. Westenberg[1], H. B. Grotenhuis[1], P. Steendijk[2], D. Hendriksen[1], T. A. Kaandorp[1], R. J. van der Geest[1], J. W. Jukema[2], J. J. Bax[2], J. H. Reiber[1], and A. de Roos[1]

[1]Radiology, Leiden University Medical Center, Leiden, Netherlands, [2]Cardiology, Leiden University Medical Center, Leiden, Netherlands

Introduction

Aortic Pulse Wave Velocity (PWV) is a surrogate marker for arterial wall compliance and is defined as the propagation speed of the systolic blood pressure wave through the aorta. PWV can be acquired intra-arterially during catheterization but this invasive method, although accurate, is not well-suited for screening or follow-up.

Purpose

Validation of PWV assessed non-invasively with Velocity-Encoded (VE) MRI by comparing with invasive pressure measurements during catheterization. Also, reproducibility in PWV-assessment with MRI as well as the physiological variation in PWV is tested. Furthermore, clinical applicability is tested and cut-off values are defined for aortic PWV as a discriminating marker for coronary disease.

Material and Methods

MRI was performed on a 1.5T Gyroscan ACS/NT15 (Philips, Best, the Netherlands). Through-plane VE MRI perpendicular to the aorta was determined at three locations: 1. ascending aorta proximal to the aortic arch (AA); 2. start of descending aorta (DA) just distal to AA; 3. distal aorta near the bifurcation. Measurements at site 1 and 2 were acquired during the same acquisition, with the acquisition plane positioned just below the AA (Figure 1). 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 6-10 ms). Acquisition at site 3 was performed similarly, except for using the body coil for signal reception instead of the 5-element cardiac coil and V_{enc} 150 cm/s was used. The distance between measurement sites was determined along the aortic centerline. Data from VE MRI was presented in flow graphs (Figure 1). The arrival time of the systolic flow wave was determined from the foot of the wave by the intersection of the constant diastolic flow and the systolic upslope. PWV of the AA (PWV_{AA}) was determined from the distance between site 1 and 2, and the difference in arrival time of the respective waves. PWV of the DA (PWV_{DA}) was similarly determined between site 2 and 3.
This study is divided into three parts:

1. PWV-assessment with MRI versus catheterization

In 18 patients (mean age 58±10 years) selected for catheterization, pressure measurements were acquired during pullback with a 6F pressure tip catheter (Cordis Corp., Miami Lakes, FL). Pressure waves were recorded at the ascending aorta, in the DA just distal to AA and above the bifurcation. The distance between these sites was determined from catheter pullback. The arrival time of the systolic pressure waves was determined from the minimal blood pressure, just before the rise in pressure.

2. Reproducibility of PWV assessed with MRI and physiological variation in PWV

Ten healthy volunteers (mean age 30±8 years) were selected to test the reproducibility of PWV-assessment with MRI and the physiological variation in PWV. Subjects were scanned twice on the same day, and once one week later. PWV_{AA} and PWV_{DA} were determined on all occasions and compared for reproducibility and variation.

3. Clinical applicability

ROC-analysis was performed to determine cut-off values for PWV_{AA} and PWV_{DA} for discriminating coronary disease. Thirteen patients (mean age 55±7 years) with proven coronary disease (either from delayed contrast enhancement MRI or from catheterization) and 11 healthy volunteers (mean age 49±8 years) were included.

Results

1. PWV-assessment with MRI versus catheterization

In Figure 2, the results PWV assessed with MRI and invasive pressure measurements are presented. PWV_{AA} and PWV_{DA} show good agreement between both modalities (correlation r=0.62 for PWV_{AA}; r=0.92 for PWV_{DA}) with no statistically significant bias for PWV_{AA} (difference between MRI and pressure 0.03 m/s). For PWV_{DA}, difference between MRI and pressure was statistically significant but small (mean bias -0.8 m/s). Coefficient of variation was 15% for PWV_{AA} and 12% for PWV_{DA}.

2. Reproducibility of PWV assessed with MRI and physiological variation in PWV

Reproducibility for repeated PWV assessment on the same day was high: r=0.89 for PWV_{AA}; r=0.58 for PWV_{DA} with no statistically significant bias (difference 0.2 m/s for PWV_{AA}; 0.1 m/s for PWV_{DA}). Coefficient of variation was 11% for PWV_{AA} and 13% for PWV_{DA}. Physiological variation was higher: coefficient of variation 18% for PWV_{AA} and 24% for PWV_{DA}.

3. Clinical applicability

Patients show statistically significant ($p<0.05$) increased PWV_{AA} (6.1±0.9 m/s) and PWV_{DA} (6.1±1.0 m/s) versus volunteers (4.8±1.4 m/s and 5.5±0.8 m/s). ROC-analysis shows that PWV_{AA}>4.9 m/s discriminates coronary disease with a sensitivity of 85% and specificity of 73% and PWV_{DA}>5.5 m/s discriminates coronary disease with a sensitivity of 85% and specificity of 64% (Figure 3).

Conclusion

Non-invasive acquisition of aortic PWV with VE MRI shows good agreement with invasive pressure measurements and can be determined accurately and reproducibly within the limits of the physiological variations. By introducing cut-off values for PWV assessed with MRI, coronary disease can be discriminated in selected patients.

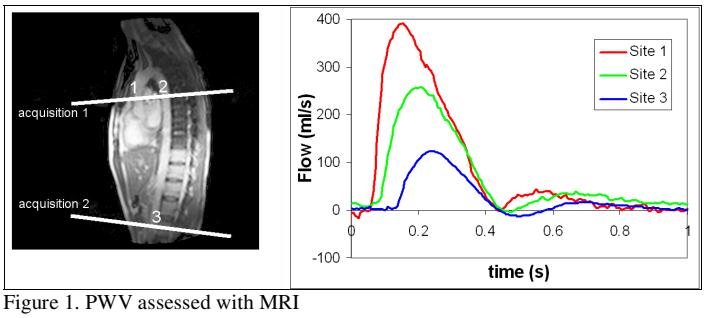

Figure 1. PWV assessed with MRI

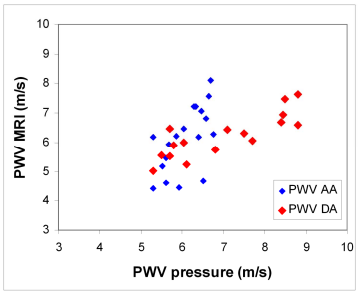

Figure 2. PWV-assessment with MRI versus pressure measurements

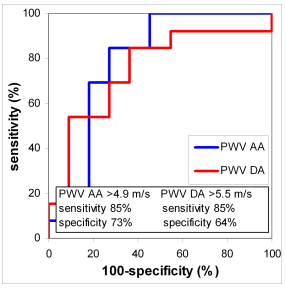

Figure 3. ROC-analysis