Global Pulse Wave Velocity in 87 Patients with Acute Ischemic Stroke and Aortic Atherosclerosis

A. Harloff[1], W. Wallis[2], C. Strecker[2], S. Brendecke[2], J. Simon[2], C. Weiller[2], J. Hennig[3], and M. Markl[3]
[1]Neurology, University Hospital Freiburg, Freiburg, Baden-Württemberg, Germany, [2]University Hospital Freiburg, [3]Diagnostic Radiology/MR Physics

Introduction: Increased pulse wave velocity (PWV) as a measure of aortic stiffness is an important marker for changes in aortic compliance and is an independent predictor of cardiovascular mortality and stroke. Reliable measurement of PWV is of particular interest for monitoring the progression or regression of vessel compliance during therapy [1-3]. Phase contrast (PC) MRI provides a noninvasive estimate of PWV based on flow waveform measurements in analysis planes transecting the aorta. Transit-time (TT) methods are typically employed estimating temporal differences of specific flow waveforms features, e.g. timing differences of the foot of the waveform between two locations with known distance [4]. Recent methodological improvements include a more continuous evaluation along vessel center lines [5,6] or 3-directionally encoded 3D CINE PC techniques (flow-sensitive 4D MRI) with complete aortic coverage and multiple analysis planes [7,8]. However, previously reported techniques suffered from incomplete coverage and/or plane wise quantification of TT parameters which highly depend on the exact calculation of flow difference and distance between the measuring points. It was our purpose to evaluate the feasibility of a new method for estimating aortic PWV from flow- sensitive 4D MRI. PWV was calculated by fitting a plane to all available data of the upslope portion of multiple flow waveforms along the entire aorta. The diagnostic performance of the method was evaluated in a study with 99 subjects, including the assessment of reproducibility (repeated scan and analysis) as well as inter- and intra-observer variability in a subgroup of patients and volunteers.

Methods: After ethical approval and written informed consent 12 healthy volunteers (n=12, mean age =23±3 years) and 87 patients (mean age = 67±9 years) with proven atherosclerosis of the aorta (maximum plaque thickness = 5.1mm± 1.8mm as demonstrated by 3D GRE MRI) were examined on a 3T system (TRIO, Siemens, Germany). By ECG synchronized prospective gating and respiration controlled navigator gating flow-sensitive MRI was performed using a sagittal oblique 3D volume covering the entire thoracic aorta. Scan parameters were as follows: TE/TR = 2.6-3.5ms/5.1-6.1ms, flip angle = 7-15º, temporal resolution = 40.8ms, spatial resolution = 1.7x2.0x2.2mm^3.

Flow-sensitive 4D MR images were corrected for eddy currents, Maxwell terms, and velocity aliasing. The time-averaged magnitude (sum of squares) of the absolute velocities was used to calculate phase-contrast angiography (PC-MRA) data. PC-MRA was used for anatomic orientation in 3D (EnSight, CEI, USA) and to position equally spaced (distance = 10mm) analysis planes in the ascending aorta, arch, and proximal descending aorta (figure 1A). For each analysis plane, flow-time curves (figure 1B) were calculated by manually segmenting the aortic lumen for all time-frames (Matlab, The Mathworks, USA). For all analysis planes the time-to peak (TTP) flow was determined to define the upslope region ($t < TTP$). PWV was estimated by fitting a plane to the upslope region in a least square sense (figure 1C). 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.

Results: Repeated measurements and analysis of PWV in 10 subjects demonstrated good inter-scan reproducibility (Bland Altman analysis, mean = 0.25m/s, limits of agreement: -0.88m/s - 1.45m/s). As shown in figure 2, low inter-and intra-observer variability was found. As expected, global aortic pulse wave velocity in patients (PWV = 5.0 m/s ± 1.4 m/s) was significantly (unpaired t-test, $p<0.001$) increased compared to normal young volunteers (PWV = 3.4 m/s ± 0.7m/s) indicating reduced compliance associated with atherosclerosis. In agreement with previous studies, there was a significant relationship between increased age and higher PWV (figure 4). Moreover, changes in aortic geometry from normal to 'bishop' and more pronounced from normal to 'gothic' shaped vessels resulted in higher PWV.

Discussion: The results of this study confirm the feasibility of PWV estimation using flow-sensitive 4D MRI. The resulting PWV data correspond well with the existing literature [4-6] and were sensitive to changes in age, aortic shape and presence of disease. By incorporating data from multiple time frames and analysis planes (figure 1) the stability of the PWV analysis may be improved compared to other methods relying on single planes or timing parameters. In contrast to center-line techniques using single sagittal imaging slices, PWV estimation based on flow-sensitive 4D MRI was clearly advantageous in patients with complex aortic 'gothic' or 'bishop' shapes that are difficult to cover with a single 2D analysis plane.

Acknowledgements: Deutsche Forschungsgemeinschaft (DFG), Grant # MA 2383/4-1, Bundesministerium für Bildung und Forschung (BMBF), Grant # 01EV0706.

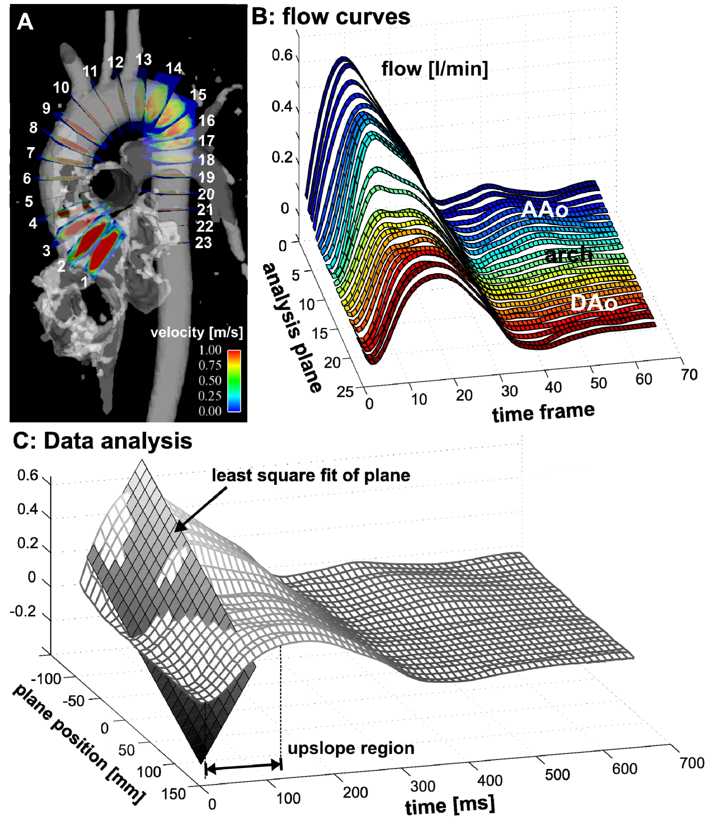


Fig. 1: Pulse wave velocity estimation based on flow-sensitive 4D MRI data. Equidistant analysis planes (A) were used to derive flow-time curves covering the entire thoracic aorta (B). Global PWV was estimated by fitting a plane to the upslope portion of the data from all slices (C).

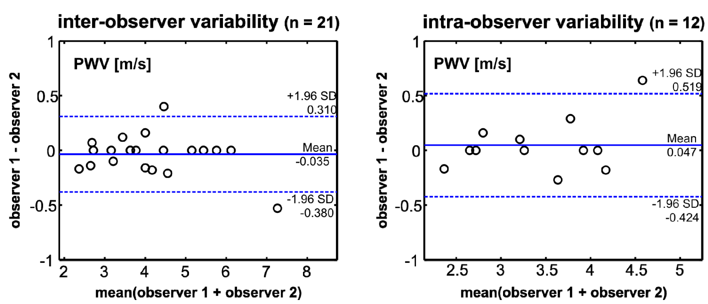
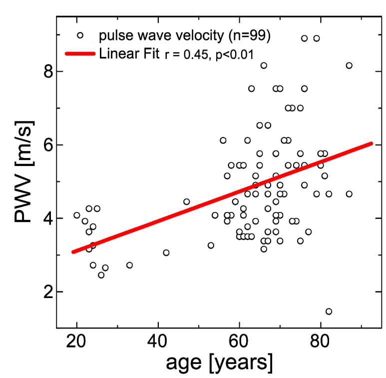


Fig. 2: Bland-Altman plot of inter- and intra-observer variability.



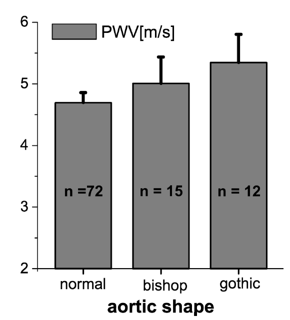


Fig. 2: Global aortic PWV) and aortic shape (mean & std. error)

Fig. 3: Pulse wave velocity for all subjects included in the study (n=99) as a function of age. A significant relationship between increases of PWV with increasing age can be observed.

References: **1.** Mohiaddin RH, et al. J Appl Physiol 1993;74:492–497 **2.** Farrar DJ, et al. Circulation 1991;83:1754–1763 **3.** Laurent S et al. Eur Heart J 2006;27:2588-2605. **4.** Vulliemoz S, et al. Magn Reson Med 2002;47:649–654 **5.** Yu HY, et al. Magn Reson Med 2006;56:876–883. **6.** Fielden SW et al.J Magn Reson Imaging 2008:27:1382–1387 **7.** Markl et al, J Magn Reson Imaging 2007;25:824-831 **8.** Markl M, et al. ISMRM 2009 p3941.