Comparison of Techniques for Pulse Wave Velocity Calculation by MRI

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Introduction Several quite different methods have been proposed for determining the Pulse Wave Velocity from MR data [3,4,5,6], but this is the first study to compare all these approaches. Aortic pulse wave velocity (PWV) reflects vessel stiffness and is a predictor of coronary heart disease and stroke in apparently healthy subjects [1]. Pulse wave velocity can be measured non-invasively by velocity-encoded magnetic resonance imaging. The reproducibility of these 5 methods is compared here using volunteer data and verified approaches for extraction of the area and flow-rate functions.

Methods All studies were performed on a 1.5T clinical MR scanner (Siemens Sonata). MR images were acquired of five normal volunteers (all male, age range 28-38 years, mean 32 years). Bright blood SSFP cine MR images were acquired in a plane showing the ascending and proximal descending aorta at the level of the pulmonary artery. Phase velocity cine FLASH images were acquired in the same plane. The block of these two sequences was repeated every 10 minutes for 5 repetitions for each of the volunteers while the volunteer remained in the scanner. Brachial blood pressure readings were taken at each repetition.

Five techniques for the calculation of pulse wave velocity were compared. The compliance and pressure technique (CP) calculates PWV directly from compliance (measured semi-automatically using the SSFP images using the method validated in [2] and using brachial blood pressure values). CP is described and used by Ganten in [3] and by Vulliemoz in [4]. The transit time (TT) method uses the time taken for the flow wave to travel between the positions of the ascending and proximal descending aorta measurements, and is described in [5] and used in [4]. The systolic flow and area technique (FA) uses curves of the total flow against area in early systole to calculate PWV and is described and used by Vulliemoz in [4]. A modification to the flow and area technique is described by Laffon in [6] and uses maximum blood flow (MF method) rather than total blood flow. Laffon compares the MF method with one that estimates aortic pulse pressure from the flow data and then uses the relationship between compliance and PWV (used in CP) to calculate another estimate for PWV (this is designated the PA method). In our analysis, vessel contours obtained semi-automatically from the SSFP images were mapped to the flow images in order to extract the flow data (see Figure 1). All values for PWV were calculated for the ascending aorta, except values from the TT method that were calculated around the aortic arch.

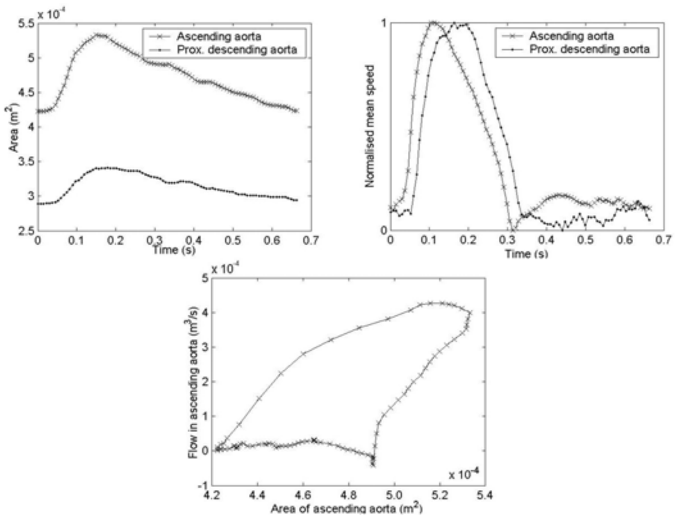

Figure 1: Example area/time, flow/time and flow/area curves

Mean calculated PWV values (m/s)				
CP	TT	FA	MF	AP
4.52	4.27	4.19	2.63	3.58

Mean coefficient of variation				
CP	TT	FA	MF	AP
11%	9%	10%	13%	17%

Correlation coefficients				
	CP	TT	FA	MF
TT	0.17			
FA	**0.74**	0.01		
MF	0.38	-0.39	0.70	
AP	0.21	-0.35	0.23	0.31

P-values (probability that data is not correlated)				
	CP	TT	FA	MF
TT	0.417			
FA	**0.000**	0.944		
MF	0.061	0.054	0.000	
AP	0.310	0.088	0.277	0.128

highest correlation

Figure 2: Repeatability and correlation results for five methods for PWV calculation

Results: Average PWV values and variation coefficients were calculated Figure 2 shows repeatability and correlation results for all five methods. Correlation coefficients and p-values were calculated between each possible pair of methods.

Discussion: The methods evaluated in this work use different underlying assumptions and hence formulae to evaluate the important PWV parameter. The accuracy of these methods will affect the mean PWV, and the sensitivity to noise of the methods will affect the coefficient of variation. McDonald [7] gives values for the pulse wave velocity in the normal adult ascending aorta which were measured invasively of 5.20, 3.87, 5.45 and 4.40m/s. Hence, the CP, TT, FA and AP methods give results for PWV in the normal range, whereas the MF method is too low. The coefficients of variation were also larger for the MF and AP methods.

There was a strong correlation between results from the CP and FA methods. Both methods used the same area measurements but CP used brachial blood pressure readings and FA used flow data to calculate PWV. The high correlation between the two methods suggests they are measuring the same physiological parameter and supports the usefulness of both techniques. Results from the FA and MF methods were also highly correlated but this could be expected as both techniques use the relationship between area and flow to calculate PWV, FA using total flow and MF using maximum flow. The TT method uses fewest assumptions about the PWV and returned values that were close to the values from the CP and FA methods but there were no correlation between individual results. This may be because TT was used to calculate PWV across the aortic arch whereas CP and FA methods were used to calculate PWV at the position of the ascending aorta, but may also be due to the low variation between subjects.

Conclusions This study indicates that the CP and FA techniques are the most accurate and reproducible. The FA technique, however, assumes that the pulse wave is unidirectional and reflectionless in early systole and further work will investigate this in patients.

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