Quantification of Pulse Wave Velocity From Phase-Contrast MRI Data Using Fourier Analysis

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Introduction

Pulse wave velocity (PWV) is related to arterial compliance and has been shown to increase in systemic and also pulmonary hypertension. Although measurement of PWV in systemic arterial circulation is widely used clinically, its application in pulmonary circulation is limited due to the lack of robust non-invasive methodologies. Approaches using phase contrast (PC) magnetic resonance imaging (MRI) have been proposed to measure PWV in pulmonary circulation. Invasive PWV measurement generally relies on measurement of pressure at two different spatial points in the artery obtained from cardiac catheterization. The transit time between the two points is measured by calculating the time difference between corresponding points on the two pressure profiles. The PWV is the measured distance between the two points divided by transit time.

Conventional approach for MRI derived non-invasive PWV also relies on a similar concept as shown in Figure 1 where transit time is calculated for the corresponding two spatially distinct points using respective velocity profiles. However, the temporal resolution of PC-MRI data is typically a factor of 10 or more coarse than catheterization data. Also, arterial compliance, bifurcations, and other factors cause the velocity waveforms to change shape as they move through an artery, which makes it difficult to find a pair of homologous points on the two waveforms. The relatively coarse resolution and change in shape can result in considerable variability in transit time measurements from PC-MRI data.

In this abstract, we propose a frequency domain approach, similar to that used by Latson, et al[1], for catheterization data, to the measurement of PWV from PC-MRI data that uses all points in the two waveforms to compute the transit time.

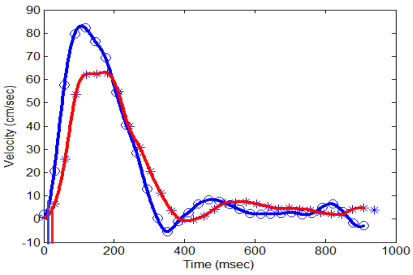

Figure 1: Measurement of transit time at 10% onset between PC-MRI velocity curves acquired in the MPA(blue) and RPA(Red)

Background

Consider a velocity waveform measured in an artery at two points, v1(t) and v2(t). If there is no change in the shape of the velocity waveform, then v2(t) will be just a time-shifted version of v1(t). Therefore, the quotient of the two respective Fourier transforms V2(f)/V1(f) will have a linear phase characteristic with a slope of $-2\pi\Delta t$, where Δt is the transit time between the two points. If there is a change in shape in the waveform between the two points, the quotient will be approximately linear at low frequencies. In this abstract, we measure the transit time from the slope of the quotient at low frequencies (Fig 2) and compare it to point-to-point measurements of transit time in the pulmonary artery in a normal cohort and patients with pulmonary hypertension, a patient group that is known to have increased stiffness in the pulmonary artery compared to normal.

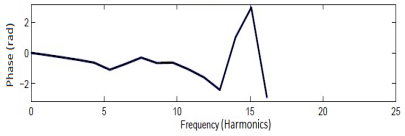

Figure 2: Phase plot of transfer function. Transit time is obtained from the slope of the first 5 harmonics

Methods

Four normal volunteers and eight patients with pulmonary hypertension underwent cardiac MRI. PC-MRI velocity data was acquired in the main pulmonary artery (MPA) proximal to the pulmonic valve and in the right pulmonary artery (RPA). MRI was performed on a 1.5T MRI scanner optimized for cardiac imaging. A free breathing non-segmented cine PC gradient echo was used to obtain data from the MPA and RPA with the following general parameters: 32 phases, encoding velocity of 150-200cm/s, slice thickness of 6mm, field of view of 32-40cm scan matrix 256 x 128, flip angle 20°, NEX 2-3, TR 18 ms, TE 5.4ms. The transit time was measured by the frequency-domain technique and by the point-to-point method. In the point-to-point method, the time difference was calculated between corresponding points on the onset of the velocity wave in both waveforms. Transit times were calculated for 10%, 20%, 30%, 40%, and 50% onset as well as peak velocity and peak velocity rate.

Results

Table 1 shows transit times for the peak-to-peak method at various corresponding points on the two profiles and the frequency domain method. The transit times measured by the various peak-to-peak methods vary considerably and the variation with each patient group is larger in the peak-to-peak method than in the frequency domain method. Finally, the differences in transit time in the peak-to-peak methods between the two groups did not reach statistical significance whereas they were significantly different in the frequency domain method

Table 1: PWV (Mean ± std err) measured in m/s from PC-MRI data acquired in the MPA and RPA

	10%	20%	30%	40%	50%	Peak	Peak Accel	Freq
Normal	-29.6 ± 65.9	19.3 ± 32.5	4.3 ± 6.1	6.4 ± 3.2	6.3 ± 3.4	6.9 ± 2.9	11.6 ± 26.5	4.5 ± 1.3
PAH	3.4 ± 1.6	4.2 ± 1.7	6.2 ± 2.9	7.1 ± 3.4	6.2 ± 3.5	7.8 ± 3.9	7.5 ± 4.6	6.3 ± 1.1
P vs Normal	0.031	0.168	0.102	0.218	0.0928	0.317	0.0883	0.0401

Discussion and Conclusion

The frequency domain method is an effective method for measuring transit time in PC-MRI data and is more robust to changes in shape of the velocity curve as it travels down the artery. Further research is needed to validate the frequency domain technique against invasive transit time measurements from invasive cardiac catheterization data.

References

1. Latson, TW et al . Circulation Research 1988, 62:884-890