Real-time, free-breathing measurement of in-plane velocities: a comparison with ECG-triggered, segmented, breath-hold acquisition.

Ning Jin[1], Juliana Serafim da Silveira[2], and Orlando Paul Simonetti[2,3]

[1]*Siemens Healthcare, Columbus, Ohio, United States,* [2]*Department of Radiology, Ohio State University, Columbus, Ohio, United States,* [3]*Department of Internal Medicine, Ohio State University, Columbus, Ohio, United States*

Target audience: Biomedical engineers and informatics specialists working on the development of imaging tools and data processing for the study of cardiovascular diseases, and health care practitioners with an interest in cardiovascular imaging.

Introduction: Velocity measurement based on ECG-triggered, segmented phase-contrast imaging (PC-MRI) is recognized as a valuable and accurate technique to assess hemodynamics in a variety of clinical applications. However, this method requires reliable cardiac gating, regular cardiac rhythm, and either signal-averaging, respiratory gating, or breath-holding to suppress respiratory motion artifacts. Furthermore, the resulting velocity information is a weighted temporal average of information acquired over multiple cardiac and respiratory cycles. Real-time phase contrast magnetic resonance imaging (RT-PCMRI) overcomes the aforementioned limitations and can measure hemodynamic variations across cardiac cycles; this can be extremely useful in patients with respiratory restrictions and arrhythmia. While the accuracy and utility of through-plane RT-PCMRI has been previously demonstrated (1, 2), measurement of in-plane velocities can also be important in the assessment of valvular and vascular stenoses.

Purpose: The purpose of this study was to describe a technique for real-time measurement of in-plane velocities and to compare in-plane peak velocity measurements in the aorta with results obtained using a conventional, ECG-triggered, segmented k-space PC-MRI sequence.

Methods: *Sequence:* The RT-PCMRI sequence capable of velocity encoding in frequency and phase-encoded directions was implemented using a gradient-echo, echo-planar-imaging (GRE-EPI) sampling strategy. Shared-velocity encoding (SVE) was utilized with two-sided velocity encoding; equal and opposite velocity encodings were acquired and shared between two adjacent frames, yielding an improvement of the effective temporal resolution by the factor of 2 (1). The GRE-EPI sequence was implemented with echo-train-length = 9 and linear k-space reordering to reduce off-resonance artifacts. A 15° rapid binomial water excitation pulse was used to provide fat suppression and high receiver bandwidth of 2400 Hz/pixel resulted in TE = 7.5 ms and TR = 13.2 ms at a VENC of 170cm/s. Four shots per image were used to collect a total of 36 k-space lines, resulting in a temporal resolution of 52.8 ms. TGRAPPA acceleration rate 3 was used to reconstruct 108 lines per image.
Imaging: Experiments were conducted in five healthy volunteers using a 1.5 T MAGNETOM Avanto clinical scanner (Siemens Medical Solutions, Erlangen, Germany) using body matrix and spine coils for signal reception. Scout images were used to locate the sagittal oblique, left anterior oblique candy cane view including ascending, transverse and descending aorta (see Figure 1). Two separate RT-PCMRI scans with velocity encodings in the frequency and phase-encoding directions were acquired during free-breathing. For comparison, images were acquired in the same view using the standard clinical ECG-triggered, segmented, spoiled GRE-PC sequence with frequency and phase-encoded velocity encoded images acquired in separate breath-holds. To achieve a similar temporal resolution, five k-space lines per segment were acquired, yielding a temporal resolution of 55 ms within a breath-hold of 17 heart beats.
Analysis: ROIs were drawn on the aortic arch to evaluate velocity in the phase-encoded direction, and in the descending aorta to evaluate velocity in the frequency-encoded directions. ROI's were manually adjusted to account for any frame-to-frame vessel motion. RT-PCMRI data spanned multiple cardiac cycles, so peak velocity measurements were averaged across multiple heartbeats and compared to the peak velocity obtained with the segmented, breath-hold sequence. Student's t-test was used to assess the statistical significance of differences between measurements.

Results: The data showed no significant difference between peak velocities measured using RT-PCMRI and conventional segmented PC-MRI both in the phase-encoded ($p = 0.89$) and in the frequency-encoded directions ($p = 0.58$). Phase images and peak velocity measurements from two different volunteers are shown in Figures 1 and 2. ROIs were drawn in the aortic arch or in the descending aorta depending on the velocity encoding direction. Graphs of peak velocities over time demonstrate that peak velocity values for both real-time sequence and segmented sequence were similar.

Conclusion: This study shows that RT-PCMRI provides in-plane peak velocity measurements similar to those obtained using conventional ECG-triggered, segmented PC-MRI. RT-PCMRI utilizing GRE-EPI with SVE is a promising imaging method that should offer advantages over segmented acquisitions in patients with decreased respiratory capacity and arrhythmia.

References: [1] Lin HY et al. Magn Reson Med 2012;68:703-710, [2] Thavendiranathan P., et al., JACC Cardiovasc Imaging. 2012 Jan;5(1):15-24.

Figure 1. Phase images and velocity measurements in the phase-encoded (anterior-posterior) direction are shown for real-time (A,B) and segmented (C,D) sequences. ROIs were drawn in the aortic arch. **Figure 2.** Phase images and velocity measurements in the frequency-encoded (head-foot) direction are shown for real-time (A,B) and segmented (C,D) sequences. ROIs were drawn in the descending aorta. Note that peak velocity values for both sequences were similar.

Figure 1

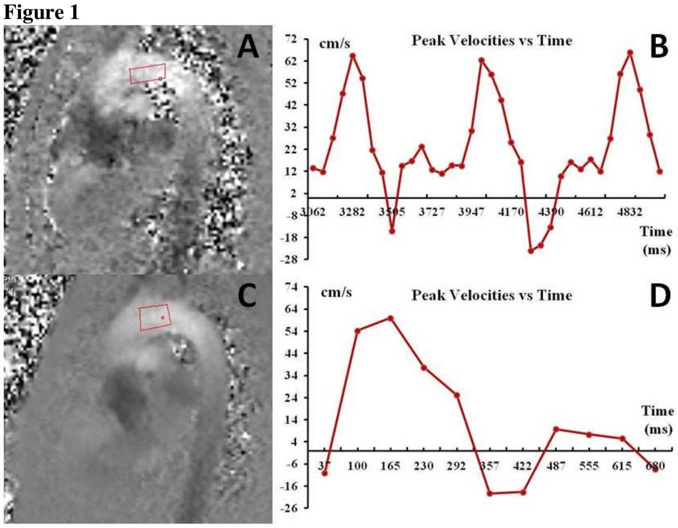

Figure 2