Real-Time, Self-Gated Spiral Flow Imaging Using Sliding-Window Phase Matching Reconstruction

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TARGET AUDIENCE Researchers and clinicians seeking to quantify blood flow in real time in various clinical applications will benefit from this abstract.

PURPOSE Prospective and retrospective ECG gating is commonly used when imaging blood flow in vivo due to its pulsatile nature. However, cardiac gating can be impractical due to the lack of an accurate ECG signal for various reasons, such as physical conditions of the patients and the nature of the applications. A few real time flow imaging sequences have been proposed in the past, most of which uses a spiral readout trajectory[1-3]. The purpose of this work is to demonstrate the ability of a real-time, self-gated phase contrast sequence using spiral readout, separate flow encodings and sliding window phase matching reconstruction that can be used to accurately monitor temporal flow behaviors with a high temporal resolution.

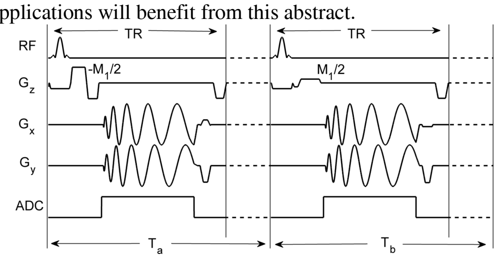

Figure 1. The diagram for the real time self-gated sequence. T_a : negative reference block; T_b : positive acquisition block. Generally $T_b >> T_a$.

METHODS Experiments were performed on a 3T Siemens Verio scanner (Siemens Healthcare, Erlangen, Germany) equipped with a 12-channel phased array. Seven normal volunteers participated in the study after providing informed consent. All procedures were approved by the local Institutional Review Board. The proposed sequence is shown in Figure 1. Both flow encoding gradients are played out along the slice direction and combined with slice rephrasing gradients to minimize TE. The acquisition was composed of two blocks, a shorter block of duration T_a with negative flow encoding ($-M_1/2$) (hereafter referred to as the negative reference block) and a longer block of duration T_b with positive flow encoding ($M_1/2$) (hereafter referred to as the positive acquisition block). The spiral trajectory was designed to be a variable density spiral with a specified number of interleaved spirals and other imaging parameters. A pseudo-random ordering of the spiral interleaves was used to reduce swirling artifacts. During both negative and positive flow encoding blocks of data acquisition, k-space is sampled by the spiral readout gradients in a continuously rotating fashion. This allows a view-sharing reconstruction with a high temporal resolution of a single TR although the effective temporal resolution is much lower. The design parameters for the spiral sequence include: field-of-view (FOV) = 20cm, flip angle (FA) = 15°, echo time (TE) = 3.3 ms, repetition time (TR) = 22.7ms, resolution = 1.0 × 1.0 mm2, slice thickness= 6 mm, ADC dwell time = 6 µs, oversampling factor = 2.0, 12 spiral interleaves and maximum encoding velocity (VENC) = 50 cm/s. For the scans on seven volunteers, the negative reference block was played out for 3 seconds, after which the positive acquisition block was played out for 5 seconds. This was followed by a conventional retrospective gated PCMRI sequence at the same slice position with the following parameters: FOV = 25.6 cm, FA = 20°, TE = 10ms, bandwidth = 192Hz/pixel, resolution = 0.57 × 0.57 mm2, and slice thickness of 2.5mm. Density compensation and gridding was used to reconstruct two series of gradient echo images. Then, a segment of the images (about 3s) from the positive acquisition block were shifted with different offsets that span a duration of 1.2s against the negative reference block and phase contrast image series were computed. Blood flow through two major vessels was quantified over these series and flow profiles were examined. It can be shown mathematically that a maximum peak to valley flow difference occurs only when the two blocks are correctly aligned in cardiac phase. Once correctly aligned, a local search was performed around an approximate cardiac cycle value to find the optimal cardiac cycle value that will lead to the best periodicity in vessel flow profiles over the entire length of the positive acquisition block. Flow measurements from the proposed method were compared against conventional retrospectively gated PCMRI sequence. Furthermore, on one volunteer, repeated scanning during different breathing patterns was performed 10 times. This included normal breathing, breathe in and hold (BIH), and breathe out and hold (BOH). Again the negative encoding segment was played out for 3 seconds. But the positive encoding segment was played out for 20 seconds. A total of six repeats of the conventional gated PCMRI scans were also performed interspersed with the spiral imaging scans under normal breathing conditions.

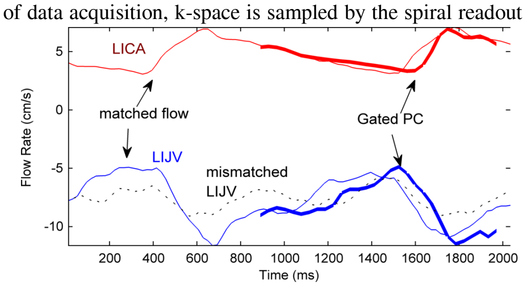

Fig.2. Flow profiles for two vessels at the lower neck level from a normal volunteer. Matched flow profiles (thin solid lines) and an example of a mismatched flow profile (black dotted line) are shown. The flow profiles from conventional gated PCMRI sequence (thick solid lines) is superimposed on the real-time flow profiles to show their

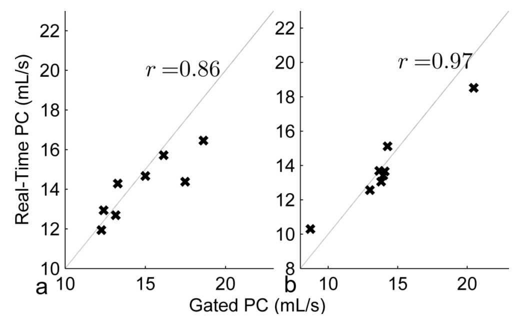

Figure 3. Scatter plots of both arterial and venous flow measured using the proposed method and the conventional gated PCMRI sequence at lower neck level for 7 volunteers (8 scans, one volunteer was imaged in two sessions at different neck levels): (a) arterial flow; (b) venous flow.

RESULTS AND DISCUSSION Flow profiles for two major vessels with correct and incorrect phase matching between the two acquisition blocks are shown in Figure 2. Maximum peak to valley flow difference was observed for the correct phase matching, while a much flatter curve was seen for the incorrect phase matching. The flow profile for the same vessels showed close resemblance between the proposed method and the conventional gated PCMRI sequence. Figure 3 shows the scatter plots of arterial and venous flow measurements on 7 volunteers and their correlation coefficients between the two methods. A good correlation was observed for both arterial and venous flow measurements (0.86 and 0.97, respectively). For the breathing experiment, there was no significant difference under normal breathing for either arterial or venous flow between the proposed sequence and the conventional gated PCMRI sequence (*P*=0.51 and 0.12, respectively). However, change of breathing pattern did change the flow. Both arterial and venous flow under BIH were smaller than under normal breathing (P=0.01 and 0.001, respectively). This is reasonable since the increased intra-thoracic pressure under breathe in and hold can lead to reduced venous return, which in turn reduces arterial input to the head. It is also seen that the arterial and venous flow under BOH was also reduced compared to normal breathing, although only the arterial flow reduction was statistically significant (P=0.02).

CONCLUSION We have presented a novel real-time self-gated phase contrast sequence and shown that the sequence can quantify blood flow in the neck vessels accurately through comparison with the conventional retrospectively gated PCMRI sequence. Breath hold experiments demonstrated that the proposed sequence can detect small changes in blood flow induced by varying intra-thoracic pressure. Volunteer experiments in vivo showed the consistency of the proposed sequence in quantifying real-time flow profile.

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