Novel Hybrid Real-Time Phase-Contrast Sequence

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Introduction – Real-time phase contrast (PC) imaging is a useful tool in the assessment of cardiovascular disease. However, the necessity to acquire alternate flow-encoded and flow-compensated frames for phase correction leads to a reduced temporal resolution. Previous studies have attempted to predict phase offsets without flow-compensated data [1,2]. Unfortunately, this is not feasible for intra-thoracic vessels due to the lack of stationary tissue. We have developed a hybrid real-time PC sequence that acquires real-time flow-encoded and flow-compensated data in alternating blocks. The flow-compensated data with the closest match to the flow-encoded data in the cardio-respiratory cycle is selected and used for phase correction. Thus the sequence is acquired in real-time but the temporal resolution is effectively doubled.

Methods – Real-time flow-encoded and flow-compensated data was acquired using a uniform density, undersampled spiral readout [3], with SENSE reconstruction [4]. Data was acquired in 3 blocks of approximately 2 seconds each, as seen in Figure 1. Each flow-encoded frame was matched to a flow-compensated frame by minimizing the global difference between magnitude images. The phase of the matched frames was then subtracted to produce the final hybrid phase contrast frame.

Validation was performed on 10 healthy volunteers, during free-breathing. The hybrid sequence (matrix 128x128, FOV 400-500mm, 1.6/9.8ms TE/TR, 8 spiral interleaves, SENSE 4, temporal resolution 19.6ms, scan time 6s) was validated against a standard gated sequence (temporal resolution 27.0ms, scan time 2.5mins) and an in-house real-time spiral sequence with interleaved flow-encoded and compensated readouts (temporal resolution 39.2ms, scan time 6s). To ascertain the accuracy of the hybrid matching, the real-time interleaved spiral data set was split into 3 sections. Phase contrast data was then reconstructed using the using the hybrid schema above and compared to the normal reconstruction. Stroke volumes (SV) were compared between the methods using Bland Altman analysis and the Wilcoxon rank sum test.

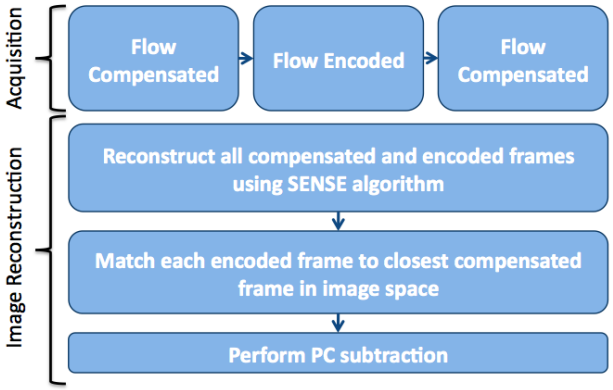
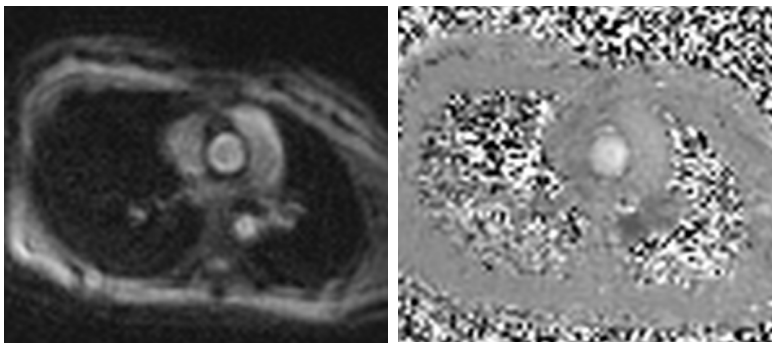


Figure 1: Pipeline of data acquisition and image reconstruction

Results – There was good agreement between the hybrid sequence (mean SV 91.69±24.85mls), the standard gated sequence (mean SV 91.5±24.4ml, p=0.85) and the real-time interleaved spiral sequence (mean SV 91.0±24.6ml, p=0.28). Bland Altman analysis found a bias between the hybrid and the gated sequence of 0.07ml (limits of -3.07 to +3.21ml) and between the hybrid and real-time interleaved spiral sequence of -0.87ml (limits of -4.48 to +2.74). The accuracy of matching was good, with very little difference between real-time interleaved PC and the same raw data reconstructed using the hybrid schema (0.1±1.5ml).

a) Hybrid: Magnitude **b) Hybrid: Phase** **c)**



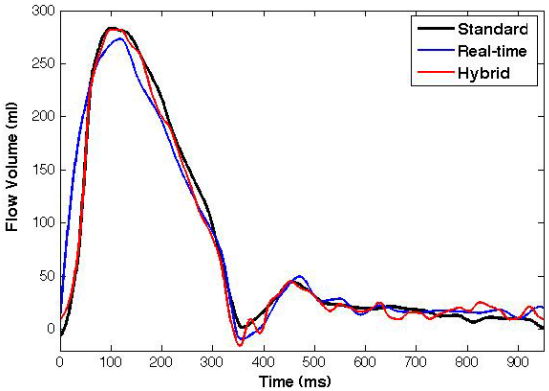


Figure 2: Magnitude (a) and phase (b) images from the hybrid sequence. c) Flow curves from one volunteer.

Conclusion – Real-time imaging is desirable because it does not require cardiac gating and can be acquired during free breathing. However, real-time PC imaging has a low temporal resolution because interleaved flow-encoded and compensated readouts must be acquired. We have developed a hybrid sequence in which encoded and compensated readouts are acquired in separate blocks and subsequently matched. Thus this scan can be acquired without cardiac gating during free breathing, and has twice the temporal resolution of standard real-time interleaved PC imaging. We have shown this technique to be accurate in comparison to both reference gated and real-time interleaved flow sequences. Furthermore we have demonstrated the effectiveness of matching flow-encoded and compensated readouts from separate cardiac cycles.

The proposed sequence allows us to acquire high temporal resolution flow data during free-breathing in a matter of seconds. This will be particularly useful when imaging small children and may in the future alleviate the need for general anesthetic. Spatial resolution could also be increased allowing flow assessment in smaller vessels. We believe this sequence will enable accurate, quick and simple assessment of patients with cardiovascular disease.

References: [1] Man, MRM 2009. 42(4);704. [2] Nielsen, MRM 2009. 61(5);1096. [3] Nezafat, IEEE 2004. 1;1914. [4] Pruessmann, MRM 2001. 46(4); 638.