Real-Time Balanced Steady State Free Precession Imaging with Through-Plane Flow

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Introduction: The production of MR scanner hardware with better gradient performance has enabled a range of balanced steady state free precession (bSSFP) imaging sequences with fast repetition times (TR) such as TrueFISP, FIESTA, balanced FFE, etc. These steady state imaging methods are now being utilized in a variety of clinical applications some of which require special sequence customization. Our work combines the bSSFP-based fast anatomical real-time imaging with modifications described by Markl et al [1] yielding additional through-plane flow information. This flow data comes with a minor reduction in the speed of anatomic imaging depending on the required velocity encoding (VENC).

Methods: In the work by Markl, the slice select gradients are inverted for alternate images in a segmented acquisition scheme for phase contrast (PC) through-plane velocity encoding. Two methods were proposed for adjusting the velocity encoding sensitivity (VENC) of the sequence. In the first method, the plateau of the slice select gradient is lengthened and the corresponding refocusing and prefocusing gradients are adjusted accordingly while keeping the RF pulse duration constant. In the second method, RF bandwidth and associated slice select gradient amplitude is changed. A combination of both methods was also proposed.

In our study, we implemented this idea in a non-segmented, real-time acquisition scheme. The RF bandwidth, amplitude and plateau of the slice select gradient and the associated refocusing and prefocusing slice gradients were kept unchanged. However, additional overlapping bipolar gradients were added, starting just at the beginning of the ramp down time (or similarly at the start of ramp up time) of slice select gradient, taking advantage of the ability of the scanner to play the superposition of two gradients on the same axis simultaneously. The purpose of this additional gradient was to change the first moment without changing the net area (i.e. zeroth moment) under the gradients in slice select direction, permitting the VENC to be adjusted without changing the TR, which may be desirable in interactive imaging. To image large velocities, we increased the VENC by assigning the bipolar gradient the opposite polarity as the slice select and refocusing gradients. Flipping the bipolar gradient to give it the same polarity as the slice select and refocusing gradients decreases the VENC for imaging lower velocities.

Through plane images were acquired from a custom in house flow phantom using a 1.5 T MR system (Sonata, Siemens Medical Solutions, Erlangen, Germany) and a real-time, through-plane flow-encoded, SSFP sequence with FOV Read = 200 mm, Slice Thickness = 5 mm., TR = 5.18 ms, TE = 2.59 ms, Base Resolution = 192. Attainable VENC values ranged between 214 cm/s and 49 cm/s for a range of TR values 3.64 ms and 5.12 ms. If TR is kept at 3.64 ms and a bipolar gradient is added as explained above VENC decreases to 141 cm/s. Without the use of the bipolar gradients, achieving a VENC of 56 cm/s would have required an increase in TR to 5.9 ms. Detailed analysis of attainable VENC values, depending on different imaging parameters (ST, RF bandwidth), were performed during the course of this work. A standard cine phase contrast (PC) sequence with FOV Read = 200 mm, Slice Thickness = 5 mm, TR = 68 ms, TE = 8.7 ms, Base Resolution = 192 and VENC= 150 cm/s, was used as a “gold-standard” to acquire flow information from the same slices to validate our flow results. The standard PC sequence is analyzed by standard workstation flow analysis software (Argus, Siemens). Real-time generated flow data were analyzed using a custom reconstruction program from saved raw data. On-line implementation of the algorithm with color overlay and adjustable VENC is in progress.

Results: In Figure 1, a phase image from a standard cine PC sequence is shown and flow values are calculated for the three tubes outlined in circles. The flow velocity in each tube is 36.3 cm/s, -34.5 cm/s, 36.6 cm/s, from left to right. In Figure 2, velocities are calculated for the three tubes outlined in circles from our modified real-time sequence with a VENC of 60 cm/s. The flow velocity in each tube is 34 cm/s, -33.6 cm/s, 34 cm/s, from left to right.

Discussion: This study suggests that adding a bipolar gradient, starting just at the beginning of the ramp down time (or similarly at the start of ramp up time) of slice select gradient, to change the first moment without changing the net area under the gradients in slice select direction allows us to adjust the VENC either slightly or without changing the TR.

Adjusting the VENC without changing the TR or the RF bandwidth and associated slice select amplitude is the main goal of this study. Keeping the TR as small as possible is very important for real-time imaging. Furthermore, an increase in RF bandwidth is generally associated with an increase in SAR.

Unlike the cine PC images demonstrated in [1], the real-time sequence shown here does not use cardiac triggering. For some TR values acquisition time may be bigger than a cardiac cycle. In order to reduce this effect complex difference method can be used rather than the phase difference in the reconstruction program for cardiac applications.

References: [1] Markl, M. et al. *Magn Reson Med,* 2005:**54**:138-145

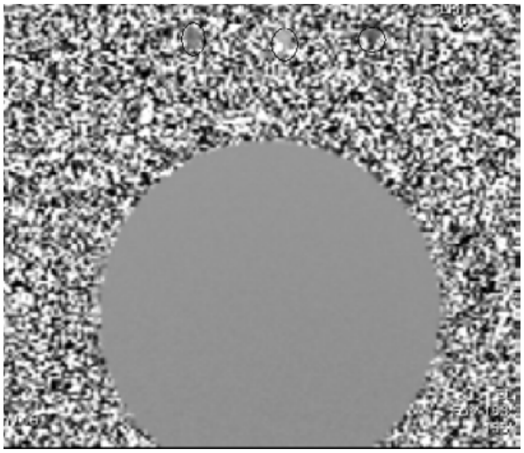

Figure 1. Phase image of flow Phantom with cine PC sequence

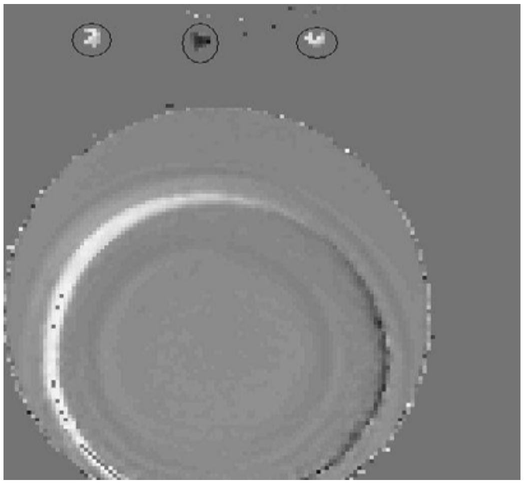

Figure 2. Phase image of flow phantom acquired using real-time SSFP. The phase image was masked based on a magnitude thresh-hold.