Contrast Detection and Timing for MR Angiography with Self-Navigated DC Signal Detection

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Introduction: Contrast bolus timing is critical to achieving high quality MR angiography. The central regions of *k*-space must be acquired during the desired phase of contrast wash-in. This is typically achieved using "fluoro-triggering" methods [1], the use of a timing bolus, or dynamic acquisitions [2]. Recently, Brau and Brittain described a method of self-navigated motion detection for abdominal imaging [3,4]. Unlike self-navigation approaches that acquire profiles through the object [5], this generalized approach measures signal at the center of *k*-space, providing a measure of the DC signal from the image itself every TR. This signal has been shown to provide cardiac and respiratory waveforms that closely correlate with physiologic motion [3,4]. In this work, we extend the generalized approach to measure DC signal change caused by the passage of a contrast agent. Monitoring the contrast uptake in addition to physiologic motion may facilitate the use of self-navigated prospective phase encode ordering and/or retrospective view ordering for self-navigated contrast timing.

Theory: In the work by Brau and Brittain, a small number of samples were acquired immediately after excitation and slice-select refocusing but before *k*-space encoding [3,4]. In this way, signal from the center of *k*-space corresponding to the DC component of spatial frequencies of the object, is measured every TR. We hypothesize that the arrival of contrast agents may be detectable in the DC signal of T_1 weighted images acquired with ultra-fast MRA pulse sequences.

The Vastly undersampled Isotropic Projection Reconstruction (VIPR) method is a 3D projection reconstruction method well suited for both MRA [6], and also for DC self-navigated approaches, as VIPR naturally samples the center of *k*-space every TR. Because the central region of *k*-space is heavily over-sampled, the VIPR reconstruction can be modified to selectively weight the center of k-space over a narrow time range using a "tornado" filter [6,7]. The detection of contrast arrival with DC signal measurements could facilitate retrospective reconstruction of VIPR images at optimal phases of contrast enhancement. Measurement of DC signal during contrast arrival is not limited to VIPR sequences, and can easily be generalized to other imaging sequences [3,4].

Materials and Methods: After obtaining IRB approval and informed consent, imaging was performed on a 1.5T GE Signa TwinSpeed MR Scanner in a volunteer using a four half-echo VIPR gradient echo sequence with an eight-channel phased array cardiac coil centered over the thorax and upper abdomen. Imaging parameters included: FOV=44cm, 256x256x256 matrix, TR/TE=4.5/0.3ms, BW=±125kHz, and 31,000 half projections for a total scan time of 35s and 1.7 x 1.7 x 1.7 mm^3 spatial resolution. 40cc gadodiamide (Omniscan, GE Healthcare, London, UK) was injected intravenously at 4.0cc/s followed by a saline bolus and VIPR images were acquired during a breath-hold. Image data were reconstructed off-line using Matlab (Mathworks, Natick, MA) in order to measure the DC signal sampled each TR immediately prior to the readout gradient and to reconstruct images at different time points and using a tornado filter with 2s low spatial frequency temporal window.

Results: Figure 1 plots the magnitude of the DC signal from one coil measured every TR during image acquisition, filtered with a ±3Hz low pass filter. The total increase in DC signal from baseline is approximately 25% as a result of the contrast bolus. Prior to the initial peak, no contrast was seen in an axial image through the heart (fig 1, left). During the initial peak, however, contrast is seen primarily in the right heart (fig 1, center), and the peak arterial phase when contrast is seen in the descending aorta occurs during the second upslope. Coronal MIP images corresponding to the same time points in fig 1 are shown in fig 2a-c. A 1Hz ripple on the waveform shown in Fig 1 was observed. Although this ripple might represent cardiac pulsation, no correlation with an EKG signal was made, and therefore a cardiac origin for this observation was not confirmed.

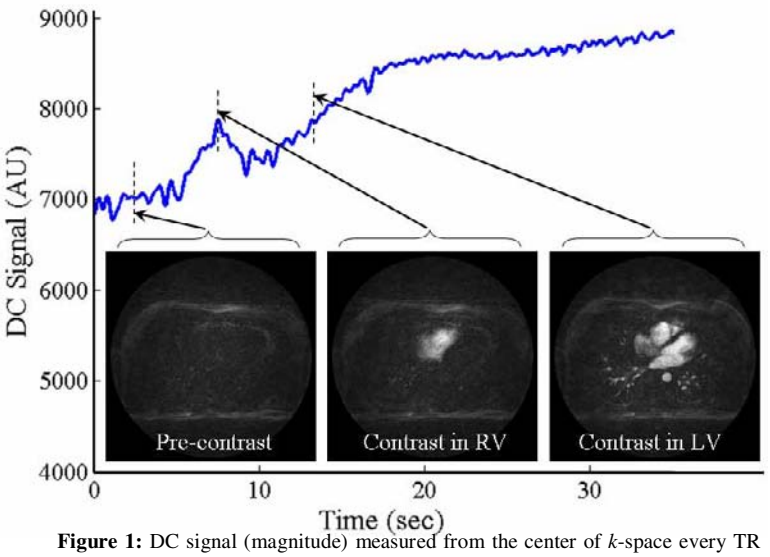

Figure 1: DC signal (magnitude) measured from the center of *k*-space every TR during a breath-hold and injection of contrast. Axial images through the heart were retrospectively reconstructed using a tornado filter with a 2s temporal window. Three time points are shown. The first peak corresponds to the arrival of contrast in the right heart. Note the signal scale – high baseline signal is from fat, which is partially suppressed in the final VIPR reconstructed images.

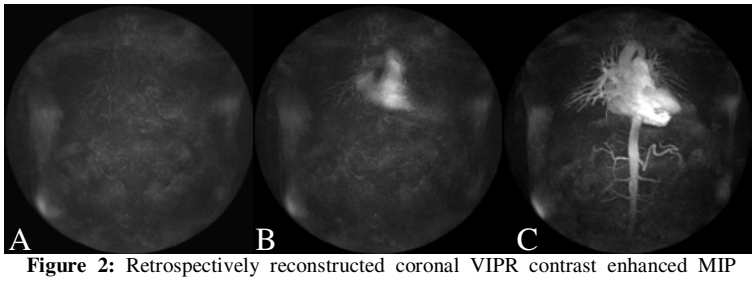

Figure 2: Retrospectively reconstructed coronal VIPR contrast enhanced MIP images at the same time points are the same as the axial images shown in figure 1. Tornado filter was centered on A) pre-contrast phase, B) first peak during contrast arrival to the right ventricle, and C) during the systemic arterial phase.

Discussion: Measurement of DC signal during contrast wash-in may provide a viable alternative to fluoro-triggering/timing boluses for clinical MRA and may be a natural addition to many dynamic MRA methods. The approach described in the work differs from the work of Carroll et al that sums the signal from regions of k-space signal acquired as part of a time-resolved acquisition, obtaining signal measurement once per second.

Using the DC signal as a guide, angiographic VIPR images were retrospectively reconstructed at different time frames corresponding to the arrival of contrast as measured by the DC self-navigated signal. Although VIPR is well suited to this approach for retrospective image reconstruction and timing, this approach could also be applied to Cartesian acquisitions for prospective view ordering during the arrival of contrast, although measurement of the DC signal may add as much as 0.3-0.5ms per TR [3,4].

Although this work only examined the magnitude of the DC signal, the phase may contain important information that will be examined in future studies. Finally, if the 1Hz ripple can be confirmed to be caused by cardiac pulsation, future work on use of self-navigated MRA with cardiac view ordering will be pursued.

Conclusion: Self-navigated DC signal measurement during contrast injection may offer improved contrast timing in angiographic and dynamic contrast enhanced imaging, augmenting the utility of timing boluses and/or fluoro-triggering.

References: 1. Prince et al, Radiology 1997 203(1):109-14, 2. Korosec et al, MRM 1996 36(3):345-51, 3. Brau and Brittain, ISMRM 2005, pg 508, 4. Brau and Brittain, MRM 2005, in press, 5. Larson et al, MRM 2004; 51(1): 93-102, 6. Barger et al, MRM 2002 48(2):297-305, 7. Du et at, JMRI, 2004 20 :894-900 8. Carroll et al MRM 2004 44:817-20