Self-Navigated Detection of Motion in 3D Abdominal Imaging

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Introduction: Respiratory motion remains a primary obstacle to diagnostic MR image quality in the abdomen. While many techniques exist to reduce respiratory artifacts, most require external physiological monitoring or additional gradient and RF pulses, increasing scan time and complexity. Recently, a generalized "self-navigated" technique was demonstrated that extracted motion information directly from the DC signal measured at the k-space origin during normal imaging, requiring no additional gradient or RF pulses and minimal, if any, increase in scan time [1,2]. This previous work applied self-navigation to a 2D Cartesian gradient echo (GRE) sequence in the abdomen and demonstrated sensitivity to motion in 3 orthogonal scan planes due to a combination of through-plane and in-plane motion effects.

Here we extend the concept of self-navigation to 3D imaging to investigate whether motion-correlated DC signal modulation can be detected in 3D volumes. Initial feasibility results using a 3D Cartesian spoiled gradient echo (SPGR) sequence in volunteer abdominal studies are presented, demonstrating the ability of the self-navigated method to detect respiratory motion in volumetric acquisitions. Since abdominal 3D GRE applications generally apply a periodic spectrally-selective inversion pulse to suppress fat, the effect of fat signal recovery on the self-navigated signal is also examined.

Theory: Immediately after RF excitation and refocusing of any slab-select gradient—but prior to the onset of spatial-encoding gradients—spins in the excited volume are maximally coherent, corresponding to the DC position $k_x=k_y=k_z=0$ in k-space. The signal sampled at this instant equals the complex sum of all transverse magnetization in the excited volume. Once the spin system reaches a steady-state, the DC signal sampled from a moving object can fluctuate due to motion-induced changes in detected magnetization; thus motion information can be derived in a "self-navigated" manner [3] by repeatedly sampling the DC signal during imaging.

Methods: A standard 3D SPGR pulse sequence was modified to sample the DC signal every TR interval (Fig. 1). Data acquisition with BW=±125 kHz was enabled for 20 µs immediately after slab selection and refocusing to acquire a few points of the FID (arrow), after which spatial encoding and image data acquisition occurred. In 3D encoding, the slab-refocusing gradient and the partition-encoding gradient can be combined into a single gradient lobe. In order to acquire the self-navigated signal from the same position in 3D k-space every TR, the partition-encoding gradient was separated from the slab-refocusing gradient, as shown in Fig. 1. These adjustments increased the minimum TE by a few hundred µs, depending on the imaging parameters used.

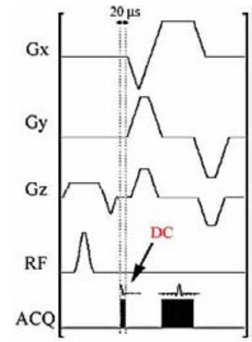

Figure 1. Self-navigated 3D GRE Cartesian pulse sequence. To capture the DC signal, data acquisition (ACQ) is turned on for 20 µs immediately after slab selection and refocusing, but prior to the application of phase-encoding gradients.

All imaging was performed on a 1.5T scanner (Signa TwinSpeed, GE Healthcare, Waukesha, WI) with the following scan parameters: TE/TR=3.5/8ms, 256x256x16, slab thickness=64mm, α=20°, BW=±31kHz. To validate the technique, phantom studies were first performed using a stationary 3-inch surface coil while periodic table motion (±10mm) was applied in the superior-inferior direction. Next, volunteer abdominal imaging was performed in three orthogonal scan planes with and without breath-holding using an 8-channel torso coil. Imaging was also performed with and without a periodic fat inversion pulse to examine the effect of the fat recovery on the self-navigated signal. The DC magnitude from the coil exhibiting the maximum signal was low-pass filtered to isolate frequencies in the expected range for respiratory motion and compared to the signal measured by the respiratory bellows.

Results: Fig. 2 compares the results from a coronal abdominal imaging study (a) without and (b) with breath-holding and no fat suppression. The data shown was collected over a 20-s sampling interval. The filtered DC signal (solid line) is shown to be correlated with the respiratory bellows signal (dashed line) during both free-breathing and breath-holding. A breath-held slice from the corresponding 3D volume from which data was acquired is shown for reference (c). Fig. 3 shows the results from an axial free-breathing study *with* fat suppression. Fig. 3a shows a 2-s snapshot of the unfiltered DC signal, which is dominated by the characteristic T1 signal recovery shape caused by repeated application of the fat inversion pulse; however, the filtered DC signal in Fig. 3b confirms an underlying low-frequency signal that closely matches the periodicity of bellows signal. A fat-suppressed, breath-held slice from the corresponding 3D volume is shown in Fig. 3c.

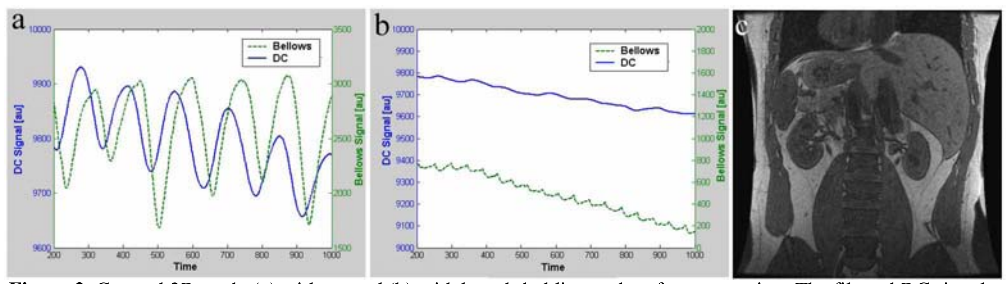

Figure 2. Coronal 3D study (a) without and (b) with breath-holding and no fat suppression. The filtered DC signal and respiratory bellows are well correlated in both cases. c) A breath-held slice from the corresponding 3D volume.

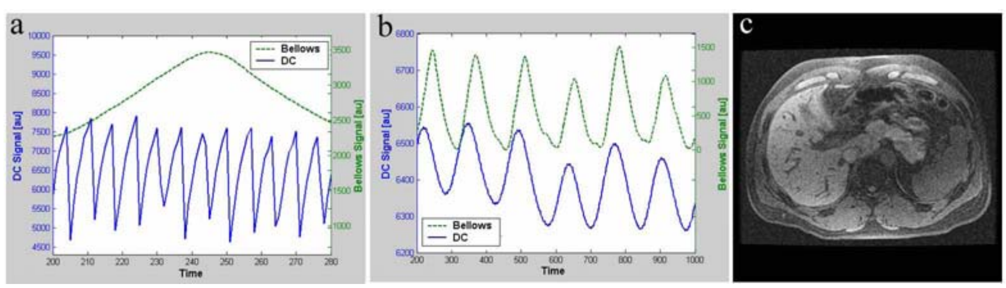

Figure 3. Axial free-breathing 3D study with fat suppression. a) The unfiltered DC signal, shown over a 2-s sampling interval, reveals oscillations caused by periodic fat inversion and recovery. b) The filtered DC signal (20-s sampling interval) closely matches the bellows signal. c) A fat-suppressed, breath-held slice from the corresponding 3D volume.

Discussion: These results demonstrate the ability of the self-navigated method to detect breathing motion in different scan planes during 3D abdominal imaging. Furthermore, the method is shown to be compatible with fat suppression inversion pulses commonly applied during 3D SPGR imaging. Based on the phantom and volunteer results, we hypothesize that DC amplitude modulation in 3D volumes is governed primarily by motion-induced spin density changes detected by a given coil rather than by spin saturation differences. Future work will examine whether the phase of the DC signal can also be used to derive additional motion information. The self-navigated method of motion detection could be used in a variety of possible applications, including synchronization of image acquisition with motion or prospective phase-encode ordering to minimize motion artifacts. Compared to other self-gating techniques that have been demonstrated for cardiac SSFP imaging [4-5], the method presented is not limited to a specific pulse sequence and can easily be extended to other sequences and applications.

References: [1] Brau et al. ISMRM 2005, 508. [2] Brau et al. MRM, in press. [3] Glover G, et al. Magn Res Med 39:361-368, 1998. [4] Larson A, et al. Magn Res Med 51:93-102, 2004. [5] Crowe M, et al. Magn Res Med 52:782-788, 2004.