Robust Abdominal Imaging with Motion Sensitive Sequences using Cardiac and Respiratory Double Gating

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Introduction: One of the main challenges of abdominal imaging is to avoid signal loss, artifacts, and misregistration between slices caused by cardio-respiratory induced motion. Sequences such as Diffusion Weighted imaging with echoplanar or fast spin echo acquisition (DW-SSFSE) (1,2) and Square Wave Enabling of the Echo Train (SWEET) which reduces B_1 inhomogeneity errors (3) are sensitive to cardio-respiratory motion. One approach to acquire these images without signal loss is a cardiac-gated acquisition during a breath hold (4), however patients often have difficulty holding their breath even for short intervals. Recent protocols for whole body screening with DWI, for example, require large volumes and many averages which are not amenable to breath holding. Another approach is simultaneous cardiac and respiratory retrospective gating (5), but for the relatively long repetition times (TRs) of SSFSE, this is very inefficient.

In this work, we designed a prospective gating algorithm where data are acquired only when gating information fall within appropriate limits for both cardiac and respiratory motion. With this new prospective double-gating technique, we demonstrate abdominal images acquired during free breathing without any signal loss using both SWEET and DW-SSFSE.

Methods: To achieve high-SNR abdominal images, data are acquired during periods of minimum motion, when end-diastolic cardiac phase coincides with end-expiration respiratory phase. To detect cardiac phase, we used a plethysmographic peripheral gating (PG) device and to detect respiratory motion, we used an external bellows device. The double gating algorithm works as follows: On detection of the PG signal, multiple respiratory bellows positions are measured at an interval of 10-20ms for a 400ms period between PG trigger and end-diastole. Using these N respiratory bellows positions, a velocity profile is generated. Data acquisition is then performed if the respiratory bellows position is at end expiration and the velocity profile reflects minimal motion. If these conditions are not true, the entire procedure is repeated upon detection of the next PG signal.

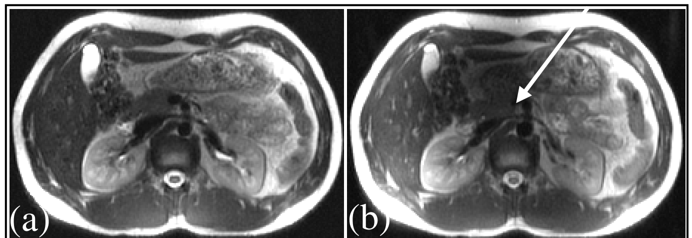

Fig. 1. Images with SWEET (a) exhibit uniform signal intensity while with standard SSFSE (b) exhibit signal loss due to B_1 inhomogeneities.

Four volunteers were scanned with the SWEET technique on a 3T scanner (Signa, GE Healthcare, Waukesha, WI) and one volunteer was scanned with the DW-SSFSE technique on a 1.5T scanner using 3 different gating strategies: a) breathhold with peripheral gating, b) free breathing with peripheral gating, and c) free breathing with double gating as described in this work. The institutional review board approved these studies and informed consent was obtained from the volunteers.

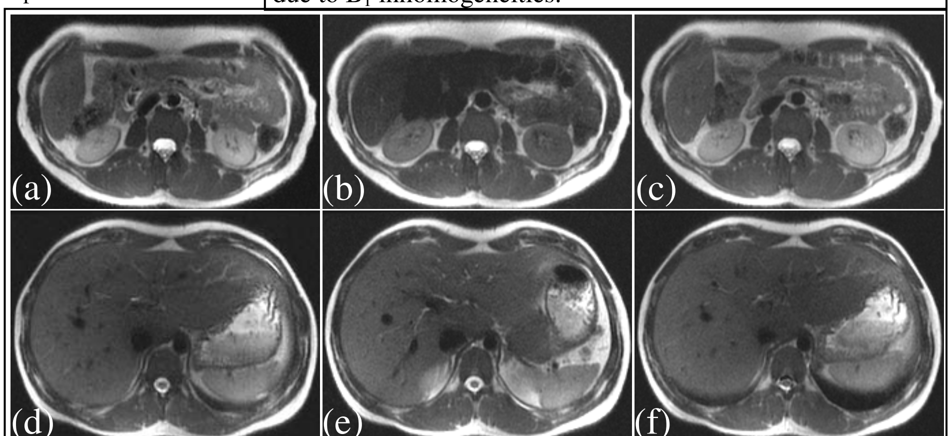

Fig. 2. Images acquired using cardiac gating alone during breath hold (a, d), cardiac gating along during free breathing (b, e), and cardiac and respiratory double gating during free breathing (c, f).

Results: SWEET exhibited uniform image quality (fig. 1a) without being sensitive to B_1 imhomogeneities compared to standard SSFSE (fig. 1b). Images acquired with peripheral gating within a perfect breath hold using SWEET (fig. 2a, 2d) exhibited good image quality without any visible signal loss, while images acquired during free breathing and only peripheral gating exhibited signal loss in some slices (fig. 2b) and good image quality in other slices (fig. 2e), depending upon the motion due to the respiratory cycle. Images acquired with free breathing and double gating exhibited good image quality without any visible signal loss in all slices (fig. 2c, 2f). DW-SSFSE images acquired with double gating exhibit better image quality (fig. 3a) when compared to images acquired during free breathing using PG alone (fig. 3b).

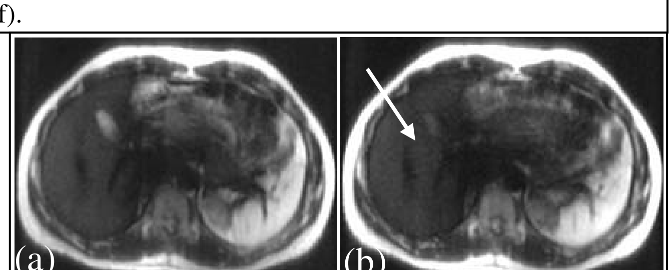

Fig. 3. DW-SSFSE images with double gating (a) and free breathing with PG (b) acquired using four signal averages.

Discussion: While the SWEET technique had previously been demonstrated to provide good image quality in the abdomen at 3T without any signal voids due to B_1 inhomogeneities, the clinical utility of this sequence was impeded by its sensitivity to motion. Similarly, diffusion weighted images of the abdomen acquired over multiple acquisitions during free breathing exhibit poor image quality. In this work, we have demonstrated a double gating strategy to overcome these limitations and to make these sequences clinically practical. The scan efficiency using double gating decreases for fewer slices but is comparable to breath hold acquisitions for larger number of slices. In the five cases that we have tested, at least one slice is acquired for every respiratory cycle. Future studies will include validation of this technique in patients.

Reference: 1) Norris DB et al, MRM 1992; 27: p.142. 2. Alsop DC, MRM 1997; 38: p.527. 3) Madhuranthakam AJ et. al., ISMRM 2007; p. 357. 3) Busse RF. ISMRM 2006; p. 2430. 4) Madhuranthakam AJ et. al. ISMRM 2007; p. 2523. 5) Larson AC et. al. MRM 2005; 53: p. 159.