Fast Dixon Fat/Water Separation with Cartesian Total Sampling Time Sequence

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Introduction: The misregistration of fat in MR images can seriously degrade the quality of an image and obscure important pathology. Many fat suppression methods use specialized radio-frequency (RF) excitation pulses (e.g. inversion recovery pulse sequences and chemical shift selective excitation pulses), but these methods are often limited by extended acquisition times and SAR constraints. Multi-point Dixon methods have been effective in water/fat separation without SAR limitations. [1,2] The typical Dixon implementation requires two acquisitions with different TEs, where the ΔTE equals 2.2 msec at 1.5 T. This characteristic ΔTE generates two complex data sets with 180° relative phase variation in the fat magnetization. The most important limitation of the Dixon techniques is the long acquisition time required for two separate acquisitions. In this study, the efficiency of the Dixon technique is improved by continuously sampling (a.k.a., a total sampling time (TST) acquisition) [3,4] during the entire readout gradients. Typically unsampled data from the dephase and rephase lobes are combined and used as the first Dixon data set while the traditional readout lobe data are used as the second Dixon data set. Simple algebraic manipulation of the image data results in separate water and fat images. By using three echoes of a TST dataset, it is possible not only to achieve fat-water separation in homogeneous fields but also in areas of field inhomogeneity.

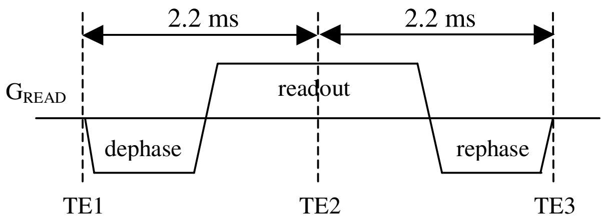

Figure 1. Partial sequence diagram depicting the read gradient. The timing between the start of the applied gradient and the echo is set to 2.2 ms as labeled by the arrows in order to accomplish Dixon fat suppression at 1.5 T. A spoiler gradient was used but not shown.

Methods: A continuously sampled rectilinear FLASH pulse sequence was modified such that the time between echoes was 2.2 ms (Figure 1). The sequence was implemented on a 1.5T Siemens Sonata MR scanner. The TEs were selected to allow 180° phase variation in the fat magnetization between each of the three TEs (TE1, TE2, and TE3). The data collected during the dephase and rephase gradient lobes are defined as the first Dixon acquisition and the data collected by the readout gradient lobe is defined as second Dixon acquisition. Imaging parameters used were TE1/TE2/TE3 = 3.4/5.6/7.8 ms, TR = 14 ms, FOV = 300, slice thickness = 5mm. A second acquisition was collected with TE2 = 7.8 ms in order to perform traditional, two-point Dixon fat suppression for comparison with the TST acquisition. The human volunteer imaging experiments were conducted in compliance with the institution's IRB; patient informed consent was obtained.

Phantom and clinical images were acquired with the TST sequence. The dephase/rephase (S_1) and readout (S_2) k-space data was gridded separately using linear interpolation from a measured trajectory. The water and fat images were calculated by adding or subtracting S_1 and S_2 and then 2DFFT to image space. Off resonance correction [5] was applied, as needed. The reconstructed images were visually inspected for artifact. The contrast-to-noise ratio (CNR) was measured in the phantom and in vivo images to quantify the level of fat suppression. Here, CNR was calculated by $CNR = (I_{water} + I_{fat})/\sigma_{background}$, where I_{water} and I_{fat} are the mean signal amplitudes of the water and fat, respectively using a hand selected region of interest and $\sigma_{background}$ is the standard deviation of the background signal.

Results: Phantom and in-vivo head images are shown in Figure 2. In the phantom images, the round object is a standard water phantom and the smaller object is a bottle of mineral oil. The fat images are not shown. Figure 2a and d show the traditional image without suppression as reference. The traditional, two-point, two-acquisition Dixon images are shown in Figure 2b and e while the continuously sampled, two-point, one-acquisition Dixon images are shown in Figure 2c and f. CNR for the water images shown were 8.6, 8.7, 30.4, and 28.0 for Figures 2b, c, e, and f, respectively. The images shown are not corrected for off-resonance. For these cases, images before and after the correction were virtually identical.

Discussion: This work successfully demonstrates Dixon fat suppression with TST data in a single acquisition. The most important improvement over traditional two-point Dixon methods is the time savings, with nearly identical suppression of fat or water. By accomplishing fat suppression in one TST acquisition, the total acquisition time is approximately halved compared to traditional two-point Dixon methods in comparable sequences. The TST method may even be more time efficient compared to dual-echo Dixon acquisitions. The 2.2msec ΔTE used here is to demonstrate the method in its simplest form; the interval is not a fixed constraint for a general implementation and therefore further reduction of total acquisition time is possible. [6] Further improvements may be necessary to improve image quality such as off-resonance correction or echo alignment.

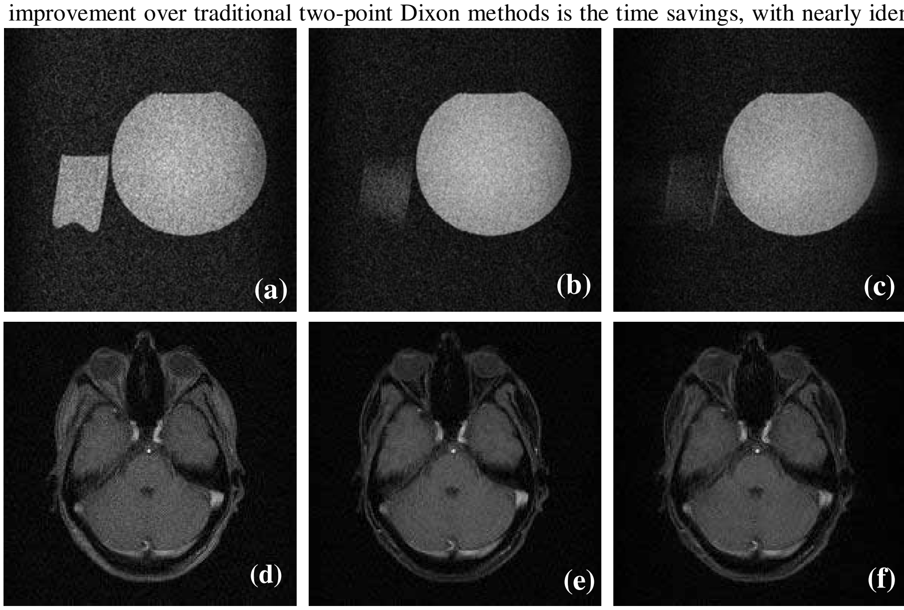

Figure 2: Phantom (a-c) and in vivo asymptomatic volunteer head images (d-f) images using traditional, two-point Dixon (b and e) and continuous sampling Dixon (c and f).

Conclusion: A TST sequence is shown to more efficiently suppress fat using a modified Dixon technique compared to traditional Dixon methods. This simple application of TST gives adequate suppression of fat in both phantoms and in vivo.

References: [1] Dixon, Radiology, 153, 189-194, 1984. [2] Glover et.al., JMRI, 1, 521-530, 1991. [3] Winkelmann et.al., IEEE TMI, 24, 254-262, 2005. [4] Bookwalter et.al., Proc. ISMRM 2005, Poster 2371. [5] Coombs et.al., MRM, 38, 884-889, 1997. [6] Reeder et.al., AJR, 180, 357-362, 2003.