Accelerated IDEAL Water-Fat Separation Techniques for Single- and Multi-Coil Applications

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Introduction: The 3-point IDEAL (**I**terative **D**ixon water-fat separation with **E**cho **A**symmetry and **L**east-squares estimation) method [1] offers superior water-fat separation compared to conventional fat suppression techniques [2,3]. However, the three-fold scan time increase imposed by IDEAL restricts its clinical use, particularly in time-limited applications such as breath-hold and dynamic imaging. The purpose of this work was to accelerate IDEAL acquisition in order to extend the benefits of robust water-fat separation to a broader range of clinical applications. Although parallel imaging has previously been combined with Dixon techniques [4,5], the modification proposed here allows acceleration factors beyond what can be achieved with parallel imaging alone and also works for single-coil applications.

The original IDEAL method uses an iterative least-squares algorithm to estimate field inhomogeneity from three high-resolution source images acquired with variable echo time increments. The field map is then demodulated from the source images, from which water and fat images are decomposed, each having SNR equivalent to a 3-NEX acquisition [1,3]. In the modified IDEAL approach presented here, the field map is assumed to vary slowly across the object. This assumption permits an accelerated acquisition scheme whereby one of the three source images is acquired with low spatial resolution. For single-coil applications, this technique facilitates a scan time acceleration of 1.4X. For multi-coil applications, this technique can be combined with R=2 parallel imaging to achieve an effective acceleration of 2.7X. Additionally, the low-resolution, fully encoded echo acts as a coil sensitivity map to ensure accurate calibration in motion sensitive applications such as abdominal imaging [5].

Methods: Imaging was performed on six healthy volunteers on a 1.5T scanner (Signa TwinSpeed, GE Healthcare, Milwaukee, WI). A spoiled gradient echo (SPGR) sequence was modified to acquire three IDEAL echoes with variable spatial resolution in k_y. The 1st echo was acquired with low-resolution (32x256), followed by full-resolution 2nd and 3rd echoes (256x256). A low-resolution field map was estimated from low-pass filtered versions of the three source images. After field map demodulation, water and fat images were decomposed from the two full-resolution source images. For multi-coil applications, the 2nd and 3rd echoes were accelerated using parallel imaging (R=2). The low-resolution, fully encoded 1st echo served as the coil sensitivity map needed to unwrap the 2nd and 3rd aliased images using ASSET (Array Spatial Sensitivity Encoding Technique), resulting in two full-resolution, full-FOV, combined-coil complex images. The low-resolution echo was also reconstructed using ASSET (R=1) to create combined-coil complex data needed for field map estimation. The field map was then estimated from the three low-pass filtered source images, after which field demodulation and water-fat decomposition were performed on the two full-resolution, unwrapped images. All source images were reconstructed on-line, and subsequent water-fat separation was also performed on-line with a robust field map estimation algorithm [6].

Results: Representative water and fat images acquired with accelerated IDEAL-SPGR using a single-channel quadrature knee coil are shown in Fig. 1 (bottom). Unaccelerated 3-point IDEAL images are shown for comparison (top). Fig. 2 shows water and fat images acquired with self-calibrated, accelerated IDEAL+ASSET (R=2) SPGR during a breath-hold using an 8-channel torso coil (bottom). IDEAL+ASSET (R=2) images are shown for comparison (top). In both examples, robust water-fat separation is preserved using the accelerated technique, with an expected SNR loss that does not significantly degrade image quality owing to the high SNR of IDEAL-calculated water and fat images. Table 1 summarizes the acceleration factors possible with each of the discussed techniques relative to unaccelerated 3-point IDEAL, based on a 256x256 reconstructed matrix size.

Figure 1. Water (left) and fat (right) images calculated from unaccelerated (top) vs. 1.4X accelerated IDEAL SPGR using a single-channel quad knee coil. TE=4.36 ms/ 5.95 ms/ 7.54 ms, TR=70 ms, BW=62 kHz, sl=4 mm, FOV=16 cm, α=20°. Good water-fat separation and SNR are preserved with accelerated IDEAL.

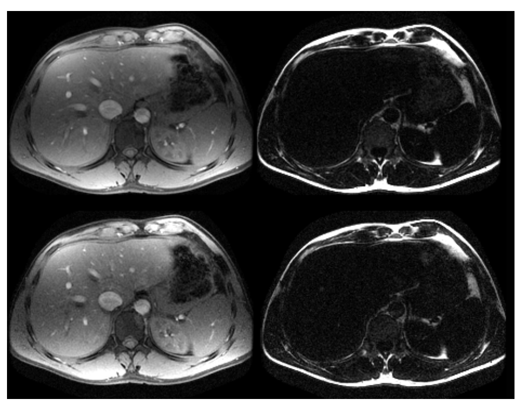

Figure 2. Water (left) and fat (right) images calculated from IDEAL + ASSET (R=2) (top) vs. self-calibrated, accelerated IDEAL + ASSET (R=2) acquired with breath-held SPGR using an 8-channel torso coil. TE=4.36 ms/ 5.95 ms/ 7.54 ms, TR=20 ms, BW=32 kHz, sl=8 mm, FOV = 38 cm, α=20°. Accelerated IDEAL + ASSET is faster than IDEAL + ASSET (2.7X vs. 2X) with comparable image quality.

Technique	Echo 1 k_y lines	Echo 2 k_y lines	Echo 3 k_y lines	Total	Acceleration	Scan Time Equivalence
IDEAL	256	256	256	768	-	3 point
Accelerated IDEAL	32	256	256	544	1.4X	2+ point
IDEAL+ASSET (R=2)	128	128	128	384	2X	1.5 point
Accelerated IDEAL+ASSET (R=2)	32	128	128	288	2.7X*	1+ point
Fat Saturation	256	-	-	256	2.7X†	1+ point

Table 1. Scan time comparison of water-fat separation techniques. *Does not include time savings offered by self-calibration. †Fat saturation pulses increase scan time by 10-20%.

Discussion: By presupposing the limited spectral content of the B_0 field – an assumption frequently made in spiral fMRI and other field-sensitive applications – we can accelerate IDEAL acquisition for single- and multi-coil applications. Accelerated IDEAL techniques preserve excellent water-fat separation with minimal impact on image quality. Integrating parallel imaging with accelerated IDEAL achieves scan times comparable to fat saturation while offering more robust chemical species separation. Self-calibration minimizes motion errors and further reduces scan time by obviating the need for an external calibration scan. Net accelerations greater than 2.7X should be possible with ASSET factors greater than R=2.

References: [1] Reeder S, et al. Magn Res Med 51:35-45 (2004). [2] Dixon W, Radiology 153:189-194, 1984. [3] Glover G, et al. Magn Res Med 18:371-383, 1991. [4] Ma J, et al. 12th Proc ISMRM, 2004, #1069. [5] McKenzie C, et al. 12th Proc ISMRM, 2004, #917. [6] Yu H, et al. 12th Proc ISMRM, 2004, #345.