Parallel Imaging Accelerated Single Acquisition Water-Fat Separation for Dynamic Imaging

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Introduction The perfect fat suppression or water-fat separation method should not only achieve robust and uniform fat suppression despite the presence of field inhomogeneities, but also introduce minimum scan time overhead. Achieving these goals has been difficult for past techniques. Fat saturated imaging is routinely used and relatively rapid, but it is sensitive to field inhomogeneities. Three-point (3pt) Dixon methods [1-3] correct for B_0 field inhomogeneity; however, they triple scan time, making 3pt techniques undesirable for applications requiring high temporal and/or spatial resolution. We recently proposed a single acquisition water-fat separation method for dynamic imaging [4] that achieves uniform separation while maintaining scan times comparable to conventional non-fat suppressed acquisitions.

Parallel imaging techniques [5, 6] utilize sensitivity differences between multiple coils to unwrap under-sampled data to full field of view (FOV) images. This allows the acquisition of fewer phase encoding lines (smaller FOV) and thus shorter scan times. In this work, the single acquisition water-fat separation method, or "1+pt" method, is refined and combined with parallel imaging to provide further scan time reduction. This method may be particularly advantageous for dynamic contrast enhanced imaging applications in regions including the breast, abdomen (breath-hold), and pelvis, as well as for angiographic imaging.

Methods To separate water and fat from a single acquisition, the echo time TE is chosen such that phase shift of fat relative to water at TE is $(1/2 + k)\pi$, where k is any integer. Signal with water (W) and fat (F) is described by: $S(TE) = (W \pm jF)\cdot e^{j2\pi\phi(TE)}$, where $\phi(TE) = \psi TE + \phi_0$ denotes additional spatially dependent phase shifts from B_0 field inhomogeneity (ψ) and other system imperfections (ϕ_0). If $\phi(TE)$ is known, water and fat can be obtained from real and imaginary channels of the $\phi(TE)$-corrected signals. To obtain $\phi(TE)$, we first perform a low resolution 3pt "calibration scan". An iterative method similar to IDEAL (**I**terative **D**ixon water-fat separation with **E**cho **A**symmetry and **L**east-squares estimation) [7] is used to estimate ψ and ϕ_0, and thus $\phi(TE)$, which is then repeatedly used in subsequent scans of the same location during a dynamic acquisition to calculate water and fat images, based on the assumption that phase is relatively stable in these situations.

Dixon methods have been successfully combined with parallel imaging techniques [8-10] based on the fact that parallel imaging reconstruction methods, such as ASSET (Array Spatial Sensitivity Encoding Technique), preserve the phase information in the unwrapped full FOV images. Similarly, the 1+pt separation algorithm can easily fit into the parallel imaging framework. To truly combine parallel imaging and 1+pt separation methods, we propose to use one calibration scan for both ASSET calibration and the 1+pt phase calibration, similar to the idea in the self calibrated parallel 3pt IDEAL method [10]. The proposed scheme is illustrated in Figure 1 with an ASSET reduction factor of 2 (R=2). The shared calibration scan acquires low-resolution images (S_1, S_2, S_3) at 3 echo times. In particular, S_1 acquired with no ASSET acceleration is also used for ASSET calibration, which enables unwrapping of the accelerated S_2 and S_3. $\phi(TE)$ is then estimated from ASSET-reconstructed images at the 3 echo times. During the dynamic portion of the study, full-resolution, accelerated images are acquired with phase $(1/2+k)\pi$. The reconstruction unwraps these images to full FOV, demodulates them by $\phi(TE)$, and finally separates them into water and fat images.

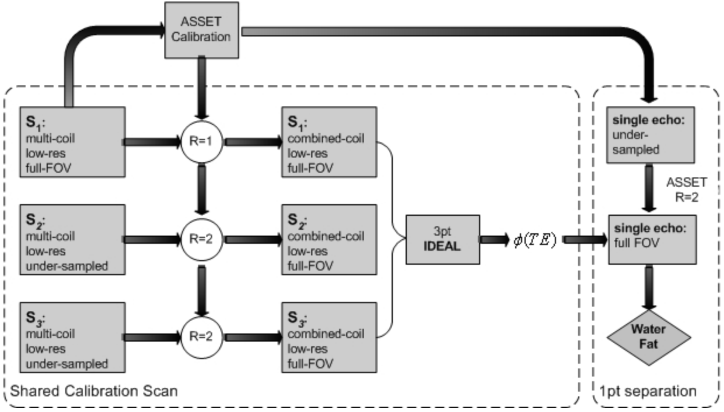

Figure 1: schematic diagram of combining ASSET with 1+pt separation method. R=2 (reduction factor) is used as the example.

Liver imaging was performed to demonstrate the feasibility of this method. A modified 3pt SPGR sequence was used in both shared calibration scan and 1pt separation scan. Echo times were [2.0, 3.6, 5.2] ms, corresponding to phase shifts of [$5\pi/6$, $3\pi/2$, $13\pi/6$], which have been shown to offer the best noise performance [11]. In the calibration scan, S_2 and S_3 were acquired with high resolution, but were filtered in k-space to match the low-resolution S_1. In the 1pt separation scan, only the signal at echo shift = $3\pi/2$ was used, simulating the single acquisition data. Two scans were obtained within different breath-holds, but transmit gain, receiver gain, center frequency and shim values were held constant. An 8-channel cardiac coil was used. Other imaging parameters included: TR = 20ms, FOV = 36cm, BW = ±83.3kHz, acquisition matrix = 256x256. All volunteer scanning was approved by our IRB and informed consent was obtained prior to imaging.

Results Fig. 2 shows 1+pt images of the abdomen of a normal volunteer. Excellent and uniform separation of water and fat was achieved. Using an acceleration factor of 2 and low-resolution shared calibration scan, the scan time is approximately half that of a conventional non-accelerated acquisition.

Discussion and Conclusion We have demonstrated the feasibility of a "1+pt" water-fat separation method that it is compatible with parallel imaging, which maintains the phase relationship necessary for IDEAL reconstruction and 1pt water-fat separation. This method provides significant scan time reductions compared to conventional fat-saturated imaging. Although both 1+pt and ASSET imaging methods require a calibration scan, they can be integrated into a single, shared calibration scan. The 1+pt method assumes that the $\phi(TE)$ is static in time, suggesting that it may be necessary to keep the pre-scan parameters constant for calibration scan and 1pt separation. In clinical dynamic imaging situations, the calibration scan can be performed intermittently to update the $\phi(TE)$ if needed. If a reduction factor of R is used for parallel imaging and $\phi(TE)$ is updated every N single acquisition frames, our scheme allows a total acceleration factor of at least RN/(N+3). The cost for faster scan times is reduced SNR, which decreases with the square root of scan time, and the g-factor [5]. Potential errors of the phase map measured in the calibration scan could result from inconsistent breath-holds, contrast passage and cardiac motion. The results in liver imaging demonstrate excellent water-fat separation. This method may be valuable for dynamic imaging to provide both high temporal resolution and uniform fat suppression.

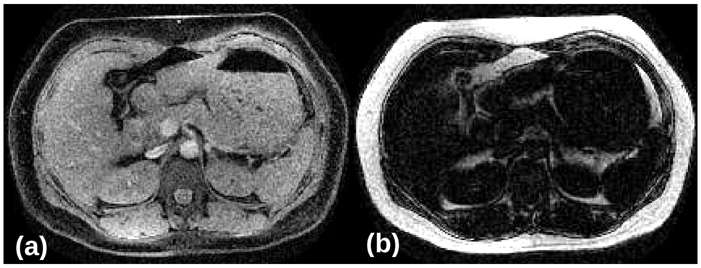

Figure 2: 1+pt separated (a) water and (b) fat. ASSET R=2 is used for the 1pt scan and S_2, S_3 of the calibration scan.

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