IDEAL at 7T in Mice Using Asymmetric Spin Echo and Gradient Echo Acquisitions

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Abstract

An asymmetric spin echo (aSE) technique was developed to produce uniform, robust fat-water separation in mice at 7T using Iterative Decomposition of Water and Fat with Echo Asymmetry and Least-squares estimation method (IDEAL). The aSE technique had superior image quality as compared to gradient echo IDEAL estimation. Both the spin echo and gradient echo IDEAL techniques resulted in more accurate fat-water separation than chemical shift selective imaging. A vectorized IDEAL reconstruction was used to speed up the estimation by using multiple CPUs and graphics cards.

Introduction

We are developing quantitative MRI techniques to quantify fat depots (e.g., visceral, subcutaneous, hepatic, muscular) to determine the role of genetic, environmental, and therapeutic factors on lipid accumulation, metabolism, and disease states. We have shown previously that conventional clinical scanners can provide sufficient image quality for rats and larger animals [1]. High field MRI scanners (7T-11T) are needed to produce the high resolution images that provide the basis for accurate delineation between visceral and subcutaneous lipid compartments in mice. Unfortunately, B_0 inhomogeneities on these preclinical scanners result in inconsistent fat/water suppression from conventional spectrally selective saturation pulses (i.e., CHESS). We evaluated IDEAL [2] at 7T using either multiple spin echo or gradient echo acquisitions. Gradient echo acquisitions are problematic at 7T because the minimum echo time (~3 ms) contains enough T2* decay to produce severe susceptibility-induced signal loss. We compared the asymmetric spin echo acquisition as an alternative with an arbitrarily short amount of T2* decay but a longer effective echo time. IDEAL results have only been reported using gradient echo acquisitions at 7T previously [3-5], and the purpose of this study was to evaluate the merits of the asymmetric spin echo at 7T.

Methods

An asymmetric spin echo acquisition (aSE) was implemented for imaging mice on a 7T/30cm Bruker Biospec scanner. A short delay (79-790μs) was inserted between the 180° refocusing pulse and the readout gradient in a conventional spin echo sequence to introduce fat-water phase variation for IDEAL estimation of separate fat and water images [6]. Assuming a fat-water frequency difference of 1051 Hz at 7T, delays of 79μs, 396μs, and 790μs were used to produce expected fat-water phases of pi/6, 5pi/6, and 3pi/2 radians, respectively. This combination is the shortest possible set of three echo times for optimal IDEAL estimation [6]. We reconstructed the fat and water estimates using vectorized IDEAL. Briefly, we improved the speed of IDEAL reconstruction by vectorizing the matrix multiplications, allowing implementation on multiple CPUs and graphics cards. In contrast to previous IDEAL per-pixel algorithms, vectorized IDEAL estimates fat and water components in all pixels of the image simultaneously to reduce the reconstruction time from 4 minutes to under 1 minute. aSE images (TR/TE=1188/18ms), FLASH images (TR=218 ms, TE = 2.78, 3.10, and 3.41 ms, corresponding to the same expected fat-water phase as the aSE acquistion), and CHESS images (TR 1170 ms, TE = 17.9 ms) were acquired of a C57BL/6 mouse with respiratory gating and the same geometry (400x160 matrix, 10cm x 4 cm FOV, 17 slices).

Results

CHESS imaging had disappointing contrast because fat saturation resulted in adipose tissue of the same intensity as surrounding muscles, and water saturation was inaccurate in the head and hindlimbs of the mouse (Fig 3c, upper arrow). Gradient echo acquisitions produced more uniform fat-water separation with IDEAL, especially near the head and hindlimbs (Fig 2c vs Fig 3c, upper arrows). However, magnetic susceptibility artifacts appeared at all air-tissue interfaces, including the ears, lungs, subcutaneous fat, and also around the rectal temperature probe (Fig 2a, lower spine). None of these susceptibility artifacts appeared in the aSE images, and SNR and tissue contrast were improved in the aSE images as expected (Fig 1). The muscle-adipose tissue contrast was also better in the aSE-IDEAL fat estimate than in the FLASH-IDEAL fat estimate (Fig 1c vs. Fig 2c, lower arrows). The aSE-IDEAL water estimate retained the T2 contrast of the input aSE images, which made it easier to identify individual tissues than in the FLASH-IDEAL water estimate (Fig 1a vs Fig 2a).

Discussion

We have developed an improved fat/water reconstruction for high field MRI scanners using the IDEAL framework. IDEAL techniques have many advantages over CHESS imaging at 7T (e.g. insensitivity to B_0 inhomogeneity). Susceptibility losses due to interfaces with air, bone, and intestinal contents may cause an underestimation of subcutaneous and visceral adipose tissue volumes when using FLASH-IDEAL. Field inhomogeneity and susceptibility artifacts will only be exacerbated at higher field strengths making the aSE-IDEAL preferable for quantifying fat depots in mice.

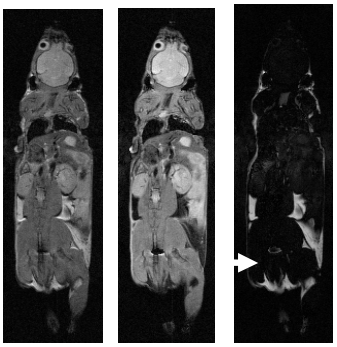

Fig 1. Input aSE (a), estimated water image (b), and estimated fat image (c) show fewer magnetic susceptibility artifacts and improved contrast.

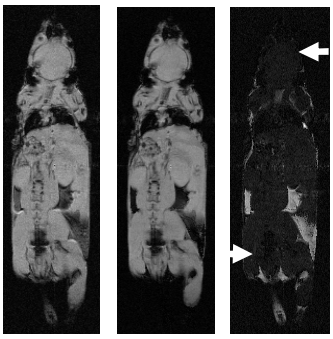

Fig 2. Input FLASH (a), estimated water image (b), and estimated fat image (c) show large magnetic susceptibility artifacts and poor contrast but good fat-water separation.

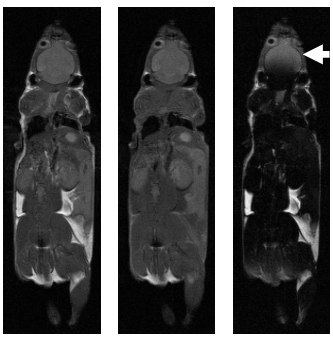

Fig 3. Reference RARE image (a), CHESS fat-saturation (b) and water-saturation (c) RARE show the failure of conventional suppression techniques at 7T.

References and Acknowledgements

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