Hierarchical IDEAL – robust water-fat separation at high field by multiresolution field map estimation

J. Tsao[1]**, and Y. Jiang**[1]

[1]Global Imaging Group, Novartis Institutes for BioMedical Research, Cambridge, MA, United States

Introduction

In recent years, IDEAL (iterative decomposition of water and fat with echo asymmetry and least-squares estimation) [1] has gained considerable popularity as a practical method for acquiring high-quality fat and water images. At the core of IDEAL is a field-map estimation process, which is needed to properly assign signal components to the water and fat images. IDEAL holds particular advantages for high-field applications (e.g. 4.7T and 7T) in terms of power deposition and insensitivity to B_1 inhomogeneity, since it does not require additional radiofrequency pulses. However, the worsened B_0 inhomogeneity at high fields can be challenging for the field-map estimation, particularly for a large field of view.

Previously, to improve the robustness of this estimation, a region-growing technique [2] was developed to take advantage of the smoothness or continuity among neighboring pixels. There are potential limitations with this approach, such as the reliance on the connectivity of the signal regions, the dependence on the initial seed pixel, and the potential for error propagation. In this work, we present a robust method that is based on a hierarchical approach for field-map estimation and a new least-squares calculation.

Theory

For water and fat separation, images are acquired at 3 equally spaced asymmetric echo times (TE's) [3]. Applying an inverse Fourier transform across these images yields 3 spectroscopic images. In the idealized case without B_0 inhomogeneity and with the carrier frequency set on the water resonance, one spectroscopic image contains the water component, another contains the fat component, and the third is essentially a blank image, representing the lack of another dominant chemical species besides water and fat. In practice, these signal planes are blended in an unknown but deterministic manner as a result of an inhomogeneous B_0 field. The purpose of the field-map estimation is to unmix these signal planes in order to separate the fat and water components.

Even with the optimized TE's [3], the water-fat separation encounters an inherent ambiguity when the image contains only either water or fat, since it is not possible to assign the signals to water or to fat without additional assumptions. In that case, we heuristically assign it to the water component. In all other cases, there is a unique solution although there may be multiple local optima [2]. In practice, we observed that even with a relatively poor shim at 7T, one can observe sufficiently distinct water and fat peaks from an unlocalized NMR spectrum. Motivated by this observation, our approach is to apply a hierarchical approach (Fig. 1). It starts by estimating the overall B_0 inhomogeneity from the full field of view, which is likely to contain both water and fat to eliminate the assignment ambiguity. Then, the field of view is subdivided successively into overlapping regions to refine the field map. At each hierarchical level, the image signals are summed spatially and inverse Fourier transformed across TEs to form a 3-point NMR spectrum. To determine the B_0 inhomogeneity, we propose the following approach. The 3-point spectrum is shifted spectrally to locate a blank peak, which corresponds to the spectral frequency that is neither water nor fat. By minimizing the signal energy in this blank peak, the calculation implicitly maximizes the signal energy assigned to the water and fat components, and this is equivalent to minimizing the least-squares fitting error described in [1]. The calculated spectral shift corresponds to the B_0 inhomogeneity for the region. Then, the process proceeds to the sub-regions using the current estimated B_0 inhomogeneity as a starting point. At the finest level (determined by a user-defined minimum region size), the estimated B_0 inhomogeneity is aggregated with that from neighboring sub-regions to build up the full field map.

Methods

An IDEAL fast-spin-echo sequence was implemented on a Bruker 7T BioSpec system (Bruker BioSpin, Ettlingen, Germany). At 7T, the 3 optimized echo times are shifted from the spin-echo center by -0.080, 0.240, and 0.559 ms, respectively, thereby prolonging the echo spacing slightly by 0.559x2 = 1.118ms. The 3 echo times were acquired in separate interleaved fast-spin-echo trains. The reconstruction was performed using custom software in Matlab (The Mathworks, Natick, MA) that interacted with the scanner software.

Results

Fig. 2 shows representative results from an axial view of a rabbit at the abdominal region, with a field of view of 16.5cm x 13.5cm. The water and fat images were separated cleanly using the estimated B_0 field map on the right. The water image reveals the presence of a slight edema on one side (see asterisk). To date, the method has been applied successfully to several hundred image slices.

Discussion

In this work, we propose a hierarchical approach for robust field-map estimation that is motivated by practical observations. First, even with a relatively poor shim, the water and fat peaks in an unlocalized NMR spectrum often appear somewhat distinct, thus providing a good starting point for signal separation. Second, the entire field of view is more likely to contain both water and fat, thereby eliminating the assignment ambiguity. By using a hierarchical approach, the estimation process is robust against local minima and it naturally bypasses potential problems associated with a region-growing approach such as connectivity and seed-point selection. Finally, the image sub-regions at each level are collapsed into one-dimensional 3-point spectra for field-map estimation, thus allowing for efficient computation.

Acknowledgments The authors would like to thank Drs. Scott B. Reeder and Angel R. Pineda for helpful discussions.

References [1] Reeder SB, et al. MRM, 51(1): 35 – 45. 2003. [2] Yu H, et al. MRM, 54(4): 1032 – 1039. 2005. [3] Pineda AR, et al. MRM, 54(3): 625 – 635. 2005.

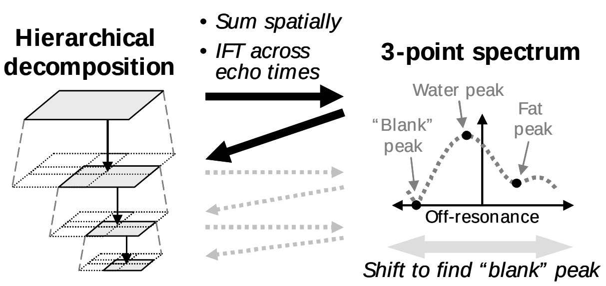

Fig.1 Schematic of hierarchical IDEAL

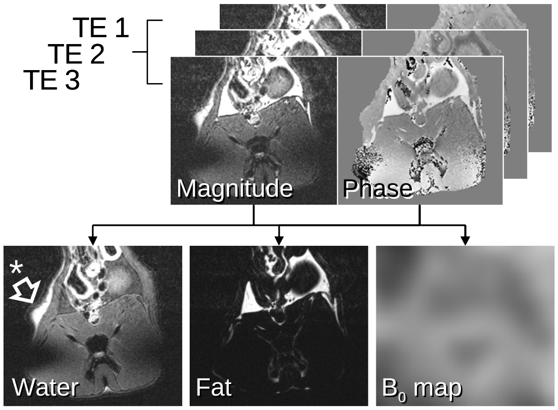

Fig. 2. Typical results from hierarchical IDEAL