Simultaneous Estimation of T2, T2-dagger and Lipid Content in Bone With a Novel Iterative Algorithm

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Introduction: The detection of bone pathologies such as osteoporosis degeneration and metastases is an important medical imaging task. Bone marrow is a challenging region of the body for MR imaging due to the presence of two chemical species, both fatty yellow bone marrow and red bone marrow, as well as micro-trabeculae which cause significant intra-voxel de-phasing (characterized by the time constant $T2^{\dagger}$). Our goal is to obtain an estimate of $T2^{\dagger}$ to evaluate the bone architecture, as well as an estimate of the relative lipid concentration and T2 of the water component for the characterization of lesions.

Recently a technique based on the acquisition of multiple gradient echoes within a spin-echo period (GRASE) [1] has been developed which provides good lipid-water separation when post-processed with an iterative algorithm (IDEAL) [2]. The original IDEAL algorithm ignores relaxation, and was later extended to include some relaxation effects and the influence of multiple lipid resonances [3, 4]. Here we present a new algorithm, based on IDEAL, which extends previous work to include estimation of $T2^{\dagger}$, the water-component T2 and a non-parametric lipid model which accounts for multiple lipid resonances, as well as T2 relaxation and J-coupling effects.

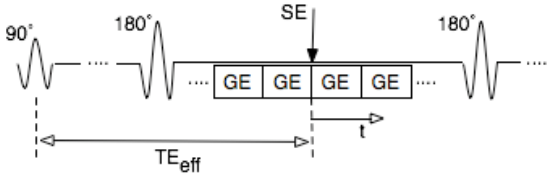

Figure 1: GRASE acquisition and timing

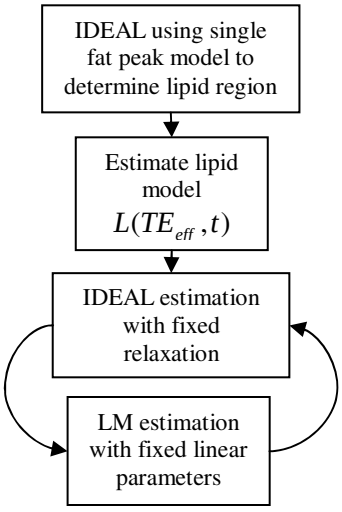

Figure 2: Iterative Algorithm

Methods: In the GRASE acquisition, 8 gradient echoes are collected per spin echo. The gradient echo data sets are reconstructed to create a series of 8 images with varying phase shifts between water and lipid. The signal also is a function of T2 and $T2^{\dagger}$ relaxation. The signal model for a given pixel in the reconstructed images is given by:

$$s(t) = (\rho_w e^{-(TEeff+t)/T2w} + \rho_l L(TE_{eff},t))e^{i\varphi t}e^{-|t|/T2\dagger}$$

where TE_{eff} is the effective TE (chosen according to the desired image contrast as in any regular spin-echo sequence) and t is time relative to the spin-echo refocusing point (Fig. 1). ρ_w and ρ_l are the water and lipid concentrations, $T2_w$ is the T2 of the water component, $T2^{\dagger}$ represents intra-voxel de-phasing, φ is the field inhomogeneity and $L(TE_{eff},t)$ is a function representing the multiple resonances, T2 effects and J-coupling of the lipid component. $L(TE_{eff},t)$ is determined from the subcutaneous lipid region of the images and then treated as known a priori in the bone and other regions of the body. Once the lipid model is determined, an iterative procedure is performed to estimate the other parameters as shown in Fig. 2. We alternately hold the non-linear parameters fixed and estimate the linear parameters and the field map using a modified IDEAL algorithm, and then hold the linear parameters fixed, and estimate T2 and $T2^{\dagger}$ using the Levenberg-Marquardt algorithm (LM). These alternating estimation steps are continued until the parameter estimates converge.

Results and Discussion: Cartesian GRASE data from the pelvis and spine were acquired from a healthy volunteer on a 1.5T GE scanner. The acquisition parameters were water/lipid echo shifts = $\pm n\pi/2$, n = 1,3,5,7, BW = ±64 kHz, ETL=4, matrix size=256x192, TR = 3s, NEX = 1 for the pelvis and NEX = 2 for the spine, slice thickness = 5 mm for the pelvis and 4 mm for the spine. Resulting parameter maps are shown in Fig. 3. A good lipid-water separation is obtained throughout the FOV with an estimated lipid fraction of 49±7% for the vertebrae, 57±8% for pelvic bone, and 81±10% for the intertrochanteric femur. The $R2^{\dagger}$ ($1/T2^{\dagger}$) map clearly shows the influence of the bone structure, with little $T2^{\dagger}$ effect detected in non-osseous tissue. The $T2^{\dagger}$ of the vertebrae and pelvic bone was similar, 21±4 ms, and 21±5 ms respectively. $T2^{\dagger}$ of the femur was longer, 41±19 ms. The T2 of the red bone marrow was 37±13 ms, while for muscle and intervertebral discs it was 32±3 ms & 107±34 ms respectively. Pixels containing little or no water are masked out of the $T2_w$ map.

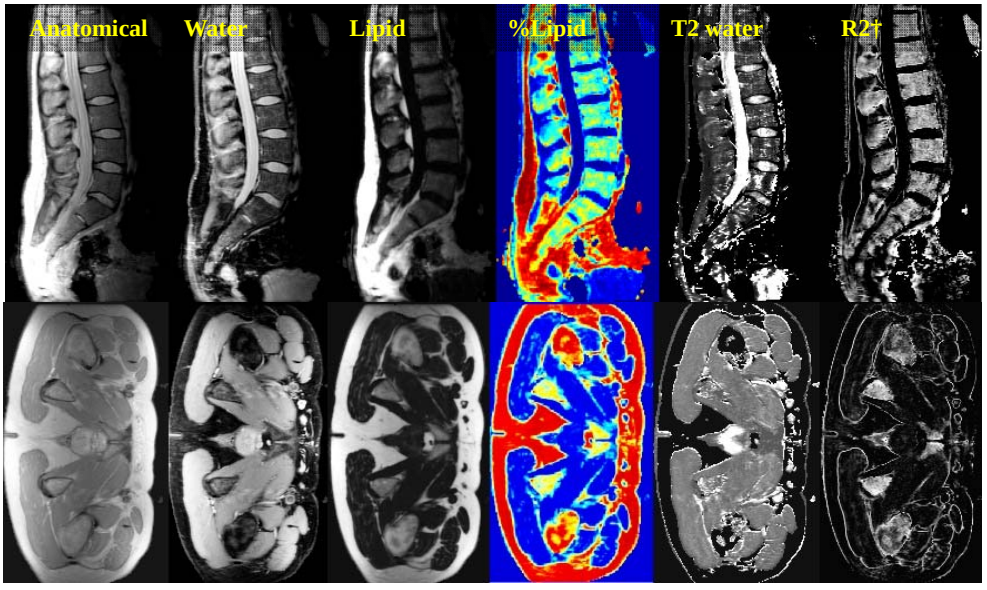

Figure 3: Sagittal spinal and axial pelvic anatomical images and parameter maps

Conclusions: This work introduces a new post-processing technique which increases the amount of information obtainable from a GRASE acquisition. By including a non-parametric fat model which incorporates the multi-peak nature of lipid, and estimating the T2 of the water component, this technique has advantages over previously published methods for bone imaging.

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References: (1) Li et al. MRM, 2007; 57, 1047. (2) Reeder et al. MRM, 2005; 54, 636. (3) Graff et al. ISMRM, 2007; 5872. (4) Yu et al. MRM 2008; 60, 1122.