k-Space Water-Fat Decomposition with Chemical Shift Correction and T_2* Decay Compensation for Ultrashort TE Imaging

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INTRODUCTION

Ultrashort TE (UTE) techniques have previously been used to image tissues with very short T_2* values, such as bone, tendon and menisci [1]. UTE with spectroscopic imaging (UTESI) acquires images at progressively increasing TEs and can generate spectroscopic images to evaluate short T_2 spectrum, bulk susceptibility effect, water/fat separation, etc [2]. However, off-resonance artifacts in non-Cartesian UTE imaging from off-resonance spins and blurring from rapid T_2* decay during readout have not been addressed in previous UTE applications. Chemical shift based water/fat separation methods, such as IDEAL [3] including T_2* correction method [4] and decomposition of water and fat in *k*-space [5] have been reported in literature. In this work, we present a *k*-space decomposition method that corrects for non-Cartesian chemical shift related artifacts and compensates for short T_2* decay during readout.

THEORY

Two effects can be observed in UTE experiments due to the presence of short T_2*. 1) T_2* decay between echo images. 2) T_2* decay during readout. The first effect will cause signal loss with increasing TE [4], and the second is equivalent to a low-pass filter in *k*-space, resulting in significant blurring in image space. We begin with the T_2*-IDEAL model, which is expressed as Eq.1. T_2* can be divided into two components, i.e. $1/T_{2,m}{}^*(\vec r) = 1/T_{2,m} + 1/T_{2,sys}(\vec r)$, where $T_{2,sys}$ accounts for B_0 inhomogeneity, temperature and other system-related effects, and we assume it is a function of location **r**. Therefore, Eq. 2, which is the total signal from a voxel containing *M* separate chemical species can be derived. Defining the *complex field map* as $\tilde\psi(\vec r) = \psi(r) + i/(2\pi T_{2,sys})$ and *complex frequency* as $\Delta\tilde f_m = \Delta f_m + i/(2\pi T_{2,m})$, we have the image space signal model shown as Eq. 3. Here $\rho_m(\vec r)$ is the image for a chemical species with a complex frequency, whose real part is the traditional chemical shift *Δf* and whose imaginary part includes T_2* decay. Similar to Ref.[4], we can write Eq. 4 by demodulating the complex field map in image space and rewrite the signal model in *k*-space, taking into account the relative time between the acquisition of sample point ***k*** and the center of *k*-space. After applying least-square estimation method in *k*-space [5], *k*-space matrices of water and fat are estimated and after 2D-Fourier transform provide the final separated water and fat images.

$$s_n(\vec r) = \left(\sum_{m=1}^{M} \rho_m(\vec r) e^{i2\pi\Delta f_m t_n} \cdot e^{-t_n/T_{2,m}^*}\right) e^{i2\pi\psi(r)t_n} \quad (1)$$

$$s_n(\vec r) = \left(\sum_{m=1}^{M} \rho_m(\vec r) e^{i2\pi\Delta f_m t_n} \cdot e^{-t_n/T_{2,m}}\right) e^{i2\pi\psi(\vec r)t_n} \cdot e^{-t_n/T_{2,sys}(\vec r)} \quad (2)$$

$$s_n(\vec r) = \left(\sum_{m=1}^{M} \rho_m(\vec r) e^{i2\pi\Delta\tilde f_m t_n}\right) e^{i2\pi\tilde\psi(\vec r)t_n} \quad (3)$$

$$\hat s_n(\tau_{k,n}, \vec k) = \sum_{m=1}^{M} \rho_m(\vec k) e^{i2\pi\Delta\tilde f_m (t_n + \tau_{k,n})} \quad (4)$$

MATERIALS AND METHODS

The proposed method was applied to water/fat separation of the Achilles tendon using a 2D UTE technique for a healthy volunteer at 3T. For each echo image, 512 half projections were acquired and each half projection contained 284 sampled points. In the reconstruction, half projections that were 180 degree apart were combined into a full projection prior to standard filtered back-projection (FBP) reconstruction. The proposed decomposition method was then applied to the reconstructed echo images using a short T_2 value of 1.5ms for fat (please see discussion below for the choice of T_2). Other imaging parameters included FOV = 10cm, slice thickness = 3.0mm, TR = 80ms, BW = ±62.50 kHz. Images were acquired at TE = 8μs, 400μs, 800μs, 1200μs, 2000μs, 3000μs. Total scan time was 8.5min.

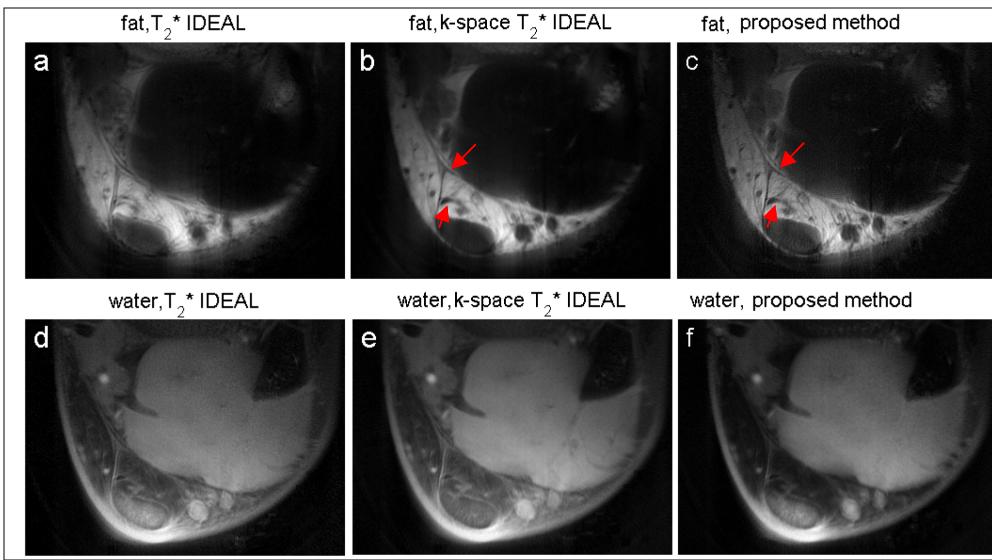

Figure 1. Comparison of different decomposition methods. (a) T_2* IDEAL; (b) k-space T_2* IDEAL, which is a combination of Ref. [4] and [5]; (c) fat image is more sharpened in the proposed method, as arrows show. (d-f) water images using these three methods

RESULTS

The results of the proposed method are shown in Fig. 1, and are compared to previously reported methods [4,5]. With T_2* correction alone, considerable blurring remains in the fat image due to the finite readout time (about 2ms) and phase evolution of fat during the readout (Fig. 1a). The T_2* *k*-space IDEAL method greatly improves the blurring from off-resonance fat and the non-Cartesian trajectory, but because T_2* of tendon is so short, significant blurring caused by T_2* during the readout remains (Fig. 1b). The proposed method with the concept of *complex frequency* takes into account this intrinsic decay and can further sharpen the species image (Fig. 1c), as the arrows show. The water images from all three methods are shown in Fig. 1(d-f).

DISCUSSION AND CONCLUSIONS

A *k*-space decomposition method with chemical shift and T_2* correction was proposed and its feasibility demonstrated using the UTE technique. The proposed method takes into account the T_2* decay between echo images, corrects for the chemical shift artifacts caused by non-Cartesian sampling and compensates for the T_2* decay during readout. Currently, the T_2* value of 1.5 ms is used to compensate the T_2* decay of fat during the readout, which was determined empirically (value that produced the least blurring between 1ms to10ms without over-compensation) and will be optimized in future work. Another fact is that fat has a complex spectrum with multiple peaks [6], which would simulate accelerated T_2* decay through effective line-width broadening. A more complete model, including multiple peaks of fat will also be investigated. Other future work may also include incorporating under-sampling and novel reconstruction methods, such as complex HYPR LR [7], to speed up the acquisition.

REFERENCES

[1] Pauly et al., US Patent 5,025,216, 1991 **[2]** Du et al., MRM 2007; 58:1001-1009 **[3]** Reeder et al., MRM 2005; 54:636-644 **[4]** Yu et al., JMRI 2007; 26:1153-1161 **[5]** Brodsky et al., MRM 2008; 59:1151-1164 **[6]** Yu et al., MRM 2008; 60:1122-1134 **[7]** Wang et al., ISMRM 2008, Toronto, abstract #3148