Water/Fat Separation of Short T_2* Tissue using Multi-echo Ultra-short Echo Time (UTE) Imaging and IDEAL

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INTRODUCTION

Tissues with short T_2 or T_2* values, such as menisci and tendons, cannot be directly visualized by conventional MRI techniques due to the rapid T_2 or T_2* decay. Novel MR sequences have been developed for the imaging of these tissues, e.g. ultrashort echo time (UTE) imaging which can achieve TE as short as 8 us (1,2). In conventional UTE imaging, fat suppression is typically required to improve conspicuity of many tissues. However, conventional chemical-shift based fat saturation is problematic for UTE due to the fact that the broad spectral width of short T_2* water protons may overlap with that of fat. As a result, the fat saturation pulse may inadvertently saturate the signal from short T_2 tissues either directly, or as a result of magnetization transfer. In addition, fat has many peaks, some of which are very close to the water peak, and spectrally selective saturation pulse cannot suppress the signal from all fat protons. In this work, we demonstrate the feasibility of combining a 2D multi-slice multi-echo UTE sequence with a chemical shift based water/fat separation method, specifically IDEAL (3), to obtain high contrast short T_2 images without any preparation pulse. Unlike past work described in Ref. (4), the multi-echo mechanism significantly reduces the scan times.

THEORY

The proposed water/fat separation method, shown in Fig. 1, combines several IDEAL variants that have been reported previously, including T_2* correction (5), decomposition in *k*-space (6), multi-frequency fat spectral modeling (7) and region growing for field map estimation (8). It can be summarized in the following steps.

1. Perform the image space IDEAL algorithm with T_2* estimation and multi-peak fat spectral model on the reconstructed echo images $s_n(r)$ to generate a B_0 inhomogeneity map $\psi(r)$ and $R*_2(r)$ map. The T_2* modeling (5) improves the fitting of measured data to signal model, and region growing scheme (8) is needed to avoid water-fat swapping.
2. Use the B_0 inhomogeneity map and the $R*_2(r)$ map to process the complex echo images to obtain demodulated echo sources, i.e. $\hat{s}_n(r)$.
3. Perform Fourier transform (if Cartesian acquisition) or non-Cartesian sampling operator on the demodulated echo images, generating a *k*-space representation of these images, $\hat{s}_n(k)$.
4. Decompose water and fat signal in *k*-space to obtain $\rho_w(k)$ and $\rho_f(k)$, using a least-square approach and the actual readout time $\tau_{\vec{k},n}$. This *k*-space formulation (6) corrects the chemical-shift-induced artifacts for radial sampling.
5. Perform inverse Fourier transform or non-Cartesian reconstruction method to generate image-space water and fat images.

Throughout this algorithm, multi-frequency modeling of the fat spectrum (7) with known fat peak locations and relative amplitudes (9) is used to reduce the residual fat signal in the water image.

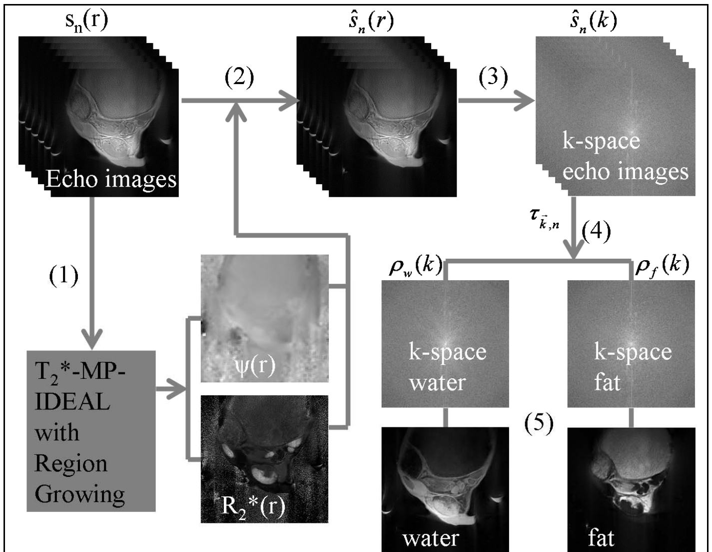

Figure 1. Schematic diagram of proposed water/fat decomposition method for UTE IDEAL. Step (1)-(5) correspond to the text in the Theory section.

MATERIALS AND METHODS

A time efficient 2D multi-slice multi-echo UTE sequence (10) was developed and implemented on a 3T scanner (Signa HDx, GE Healthcare, Waukesha, WI, USA). The minimal echo spacing (ΔTE) for the desired resolution is larger than 2π phase difference between water and the main fat peak, and thus a total of 6 echo images were acquired in three separate TRs. Imaging parameters included: TE = 12us/3.4ms (1^{st} pass), 0.8ms/4.2ms (2^{nd} pass) and 1.6ms/5ms (3^{rd} pass), BW=±125kHz, FOV=15cm, 384 readout, TR = 200ms, FA=45^{O}, NEX=2, 16 slices with slice thickness =2mm, 512 half projections, scan time = 10.5 min. In the reconstruction, half projections that were 180 degree apart were combined into a full projection prior to standard filtered back-projection (FBP) reconstruction to generate echo source images. In the 3rd step of the proposed method, demodulated echo image, $\hat{s}_n(r)$, were re-projected (i.e. Radon transformed) and Fourier transformed to produce its radial *k*-space representation, $\hat{s}_n(k)$.

RESULTS

Water images from the Achilles tendon of a cadaveric specimen are shown in Fig. 2(b-d). A fat-saturated image, obtained by using a fat-selective saturation pulse followed by spoiling gradient, is also shown (Fig. 2a) for comparison. All UTE IDEAL water images show superior image contrast (short arrow) and better depiction of the fine structures (long arrow) than the fat-sat image. An important benefit of the UTE IDEAL method is that the T_2* correction process also generate an estimated R_2* ($1/T_2$*) map, shown in Fig. 2e, which is not available from the fat-sat approach.

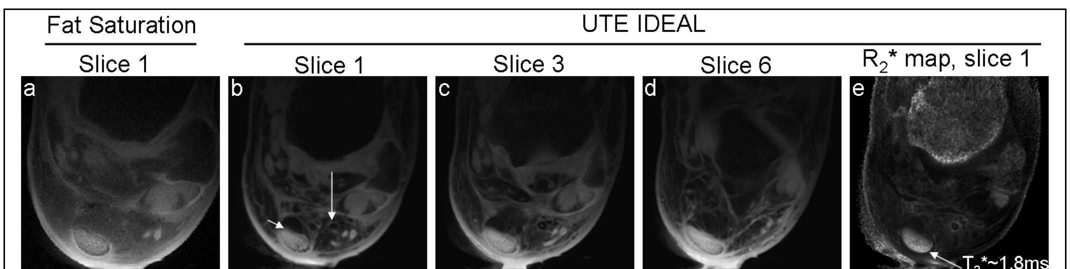

Figure 2. Tendon water images (b-c) from a 2D multi-slice multi-echo UTE IDEAL scan. A fat-saturated image (a) is also shown for comparison. In addition, UTE IDEAL can provide a R_2* map (e).

DISCUSSION AND CONCLUSIONS

In this work, we demonstrated the feasibility of obtaining high contrast short T_2* images by combining a UTE technique with the IDEAL water/fat separation method. A multi-echo UTE sequence is used to minimize the scan time. A variety of enhancements to the IDEAL algorithm are included in UTE IDEAL reconstruction. For other tissues with longer T_2*, such as meniscus, the proposed technique can also be applied more efficiently with all echoes acquired within a single pass.

ACKNOWLEDGMENTS We grateful acknowledge GE Healthcare for their assistance and support.

REFERENCES [1] Pauly et al., US Patent 5,025,216, 1991 [2] Brittain et al., ISMRM 2004, p629 [3] Reeder et al., MRM 2005; 54:636-644 [4] Wang et al., ISMRM 2009;p2800 [5] Yu et al., JMRI 2007; 26:1153-1161 [6] Brodsky et al., MRM 2008; 59:1151-1164 [7] Yu et al., MRM 2008; 60:1122-1134 [8] Yu et al., 2005;54(4):1032-1039 [9] Middleton et al., ISMRM 2009;4331 [10] Du et al., JMRI 2009; 29(2):412-421