Imaging of short T2 and ultra-short T2 tissues using R2* map

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Introduction: Ultrashort echo time (UTE) imaging techniques have potential clinical applications for imaging of short T2 species (1). To increase contrast of short T2 species, it is usually necessary to suppress signal from long T2 tissues. Two common methods used to suppress long T2 tissues are RF pulse preparation (2,3) and image subtraction (1,4). In this work, we investigated imaging of short T2 species using a R2* map, which creates image contrast between long and short T2 species different to that provided by current long T2 suppression methods. We demonstrated our methods with both Cartesian and radial acquisition.

Methods: The main technique we used to image short T2 tissue is T2* IDEAL (5-7). In T2* IDEAL, images are reconstructed at a few different TEs and the reconstruction can provide a water image, a fat image, and a R2* map (5). The R2* map provides excellent contrast between tissues with short and long T2* value, therefore, can be used directly to examine short T2 tissues. By minimizing the TE of early echoes, a Cartesian acquisition can be used to image tissues with relatively short T2. To retrieve signal from tissues with ultra-short T2, we implemented T2* IDEAL with radial k-space sampling. For radial acquisition, the variation of the field map within the off-resonance PSF of fat usually can be ignored. Consequently, we can first perform gridding (8) and then apply T2* IDEAL reconstruction on a Cartesian grid. With the acquired R2* map, we can also synthesize images based on the equation given in reference (3) to achieve contrast similar to images acquired with long T2 suppression using RF pulse preparation. Long T2 suppression using RF pulse preparation is sensitive to off-resonance effects, whereas it is not a problem here.

To perform T2* IDEAL for radial acquisition, we typically acquire four echoes, which prolongs scan time. To achieve R2* contrast with reduced scan time, we can collect data sets at two TEs with water and fat in phase and then calculate the subtraction of the logarithm of the magnitude images.

The in vivo data sets are acquired from a 1.5T GE scanner (GE Healthcare, Waukesha, WI) with both Cartesian and radial acquisition. Investigational version of T2* IDEAL with 3D-SPGR Cartesian acquisition is used with imaging parameters: 19×14cm FOV, TR 20ms, BW±111kHz, TE_1=1.6ms, ΔTE = 1.36ms, 256×224 matrix, 48 slices, 2.5mm slice thickness, 6 echoes collected with total scan time 5.35min. The imaging parameters for radial acquisition include: 19×19cm FOV, TR 110ms, BW±125kHz, 0.37mm in-plane resolution, 1609 rays, 512×512 matrix, 5 slices, 5mm slice thickness, four echoes acquired with total scan time 22min, TE=[0.1 1.2 2.6 4.6] ms. For the radial trajectory used here, the FWHM of off-resonance PSF of fat is less than 2 pixels.

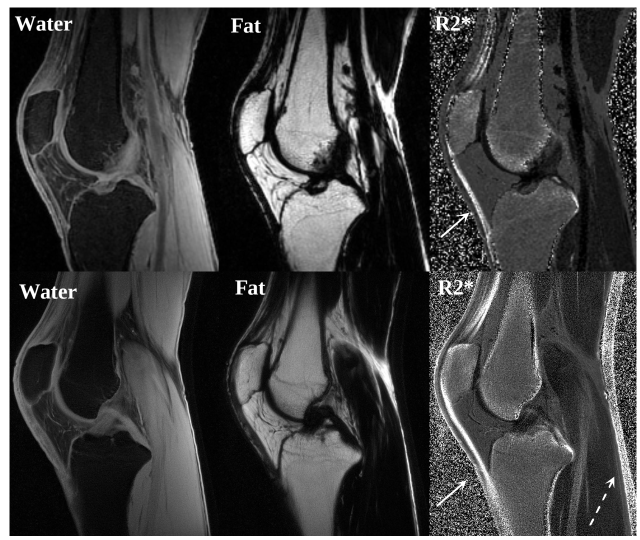

Figure 1: Top and bottom rows are images from T2* IDEAL using Cartesian and radial acquisition, respectively. Solid line indicates patellar tendon. Dashed line indicates foam pad.

Results: Figure 1 shows knee images after T2* IDEAL reconstruction. Water and fat are successfully separated after T2* IDEAL reconstruction. The patellar tendon is clearly depicted in the R2* map. The foam pad can also be seen in the R2* map from radial acquisition. Figure 2 shows the images from the same radial acquisition date set using direct subtraction, subtraction of logarithmic images, and synthetic image. Compared to direct subtraction, the subtraction of logarithmic images creates higher contrast between tissues with short and long T2. The synthetic image creates image contrast similar to long T2 suppression using RF preparation.

Discussion: If we express the magnitude image acquired at echo time TE as $M(\mathbf{r})\exp\{-\mathrm{TE}/T_2^*(\mathbf{r})\}$, it can be shown that direct subtraction of images at two echoes can result in contrast loss between long and short T2 tissues for certain spatial variation of $M(\mathbf{r})$, whereas the contrast in R2* map will not be affected by $M(\mathbf{r})$. Long T2 suppression using RF pulse preparation is susceptible to off-resonance, whereas T2* IDEAL is insensitive to off-resonance. T2* IDEAL also does not require an additional RF pulse for fat suppression. A drawback of using a fat suppression RF pulse is that it can reduce the signal from short T2 tissues due to its broad spectrum.

For tissues with ultra-short T2, it becomes difficult to separate fat and water as signal decays away before there is adequate water-fat phase shifts. Methods to effectively address this problem are currently under investigation.

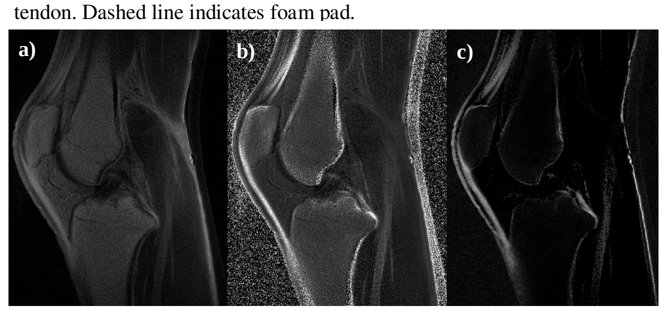

Figure 2: a) Direct subtraction of two echoes collected using radial sampling when water and fat are in phase. b) Subtraction of logarithmic magnitude images of the same two echoes. c) Synthetic image created using acquired R2* map and known magnetization with contrast similar to long T2 suppression using RF pulse preparation.

Conclusion: We demonstrated that the R2* map has high contrast between tissues with long and short T2 and therefore can be used for UTE imaging. Furthermore, the use of T2* IDEAL for this purpose allows decomposition of water and fat images, providing additional diagnostic utility from a single scan. The use of Cartesian T2* IDEAL also provides capability of a full 3D multi-echo acquisition with a greatly reduced scan time compared to conventional 3D UTE imaging methods.

Reference: 1. Gatehouse et al, Clin Radiol 2003; 58:1-19 2. Pauly et al, SMRI 1992; 330 3. Larson et al, MRM 2006; 56: 94-103 4. Rahmer et al, MAGMA 2007; 20:83-92 5. Yu et al, JMRI 2007; 26:1153-1161 6. Yu et al, ISMRM 2007; 3353 7. Yu et al, MRM 2008; 60:1122 8. Jackson et al, IEEE TMI; 1991; 10:473-478 4.