A fast simultaneous water/fat decomposition and T1, T2 quantification method using dual TR bSSFP

Dongyeob Han[1], Min-Oh Kim[1], Dosik Hwang[1], and Dong-Hyun Kim[1]
[1]*Yonsei University, Seoul, Korea*

Target audience Researchers interested in water/fat separation and T1, T2 quantification.

Purpose In body imaging such as knee or liver, fat signal needs to be quantified for applications such as bone marrow diseases[1] or hepatic steatosis[2]. However, water/fat (w/f) separation in body imaging is problematic due to the artifact from chemical shift. Often, the fat signal is separated based on techniques originating from the Dixon method[3]. Herein, a fast dual TR bSSFP acquisition method for simultaneous w/f decomposition with T1, T2 quantification is proposed.

Methods Figure 1 shows the proposed bSSFP TR and flip angle pattern. An inversion preparation pulse is applied. The dual TR were set to at 4.6 ms and 6.9 ms which leads to in-phase and out-phase effect between water and fat at 3T. For the first 150 TRs where zero-crossing occurs due to inversion RF pulse, the TR was set to be in-phase to increase SNR. Afterwards, the in-phase TR (4.6ms) and out-phase TR (6.9ms) were applied alternatively (Fig. 1a). During the acquisition, a varying flip angle pattern (Fig. 1b) was used to enhance the signal evolution uniqueness[4]. A total of 500 images were acquired with highly under sampled 2D radial acquisition (8 arms, reduction factor 16) while rotating the radial spokes for each TR.

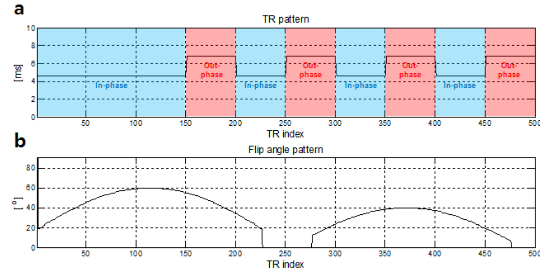

Figure 1. Proposed TR pattern (**a**) and varying flip angle pattern (**b**).

In vivo (knee) and phantom data were collected in 3T scanner with 2x2 mm^2 resolution, 5mm/10mm slice thickness and 1560 Hz/Px bandwidth for a scan time 27 sec/slice. Each TR 2D radial image was reconstructed with 128x128 matrix using gridding. For the phantom experiment, to make a linearly varying w/f mixed environment, a phantom was constructed as illustrated in Fig. 2.

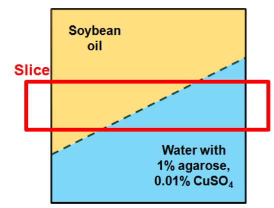

Figure 2. Illustration of constructed phantom.

A forward signal model based on the Bloch equation was used to decompose w/f components with T1, T2 quantification.

$$\mathbf{argmin}_{M_0, f, wT1, wT2, fT1, fT2, \Delta B, \varphi_0} \| \mathbf{S} - M_0 * (f * \mathbf{wS'}(wT1, wT2, \Delta B) + (1-f) * \mathbf{fS'}(fT1, fT2, \Delta B + \Delta f)) * \exp(i * \varphi_0) \|_2$$

S is the acquired signal from the proposed pulse sequence and the **wS'/fS'** are the simulated signal from Bloch equation with parameters; M_0 : total magnetization, f : water fraction, $w/fT1,2$: water and fat T1, T2 respectively, ΔB : background off-resonance, φ_0 : B1 phase, Δf : chemical shift of fat (440Hz in 3T). The minimization problem was solved using complex fitting method at each voxel.

Results Fig. 3a shows phantom results with w/f fraction map and decomposed T1, T2 map. In the w/f mixed region, constant wT1,2 and fT1,2 value were measured with linearly varying w/f fraction indicating that the proposed method successfully decomposed water and fat component. However, w/f T1, w/f T2 estimation errors occurred in the shaded region due to limited SNR of each component, which can be avoided by increasing the scan time. Fig. 3b shows the signal evolution from the forward model. Dual TR increases the orthogonality between water and fat signal for both magnitude (in-phase TR : w + f, out-phase TR : w-f) and phase (real and imaginary). In vivo (knee) results also shows w/f decomposition and estimated wT1,2 and fT1,2 values from the propose method are in good agreement with previous study[5].

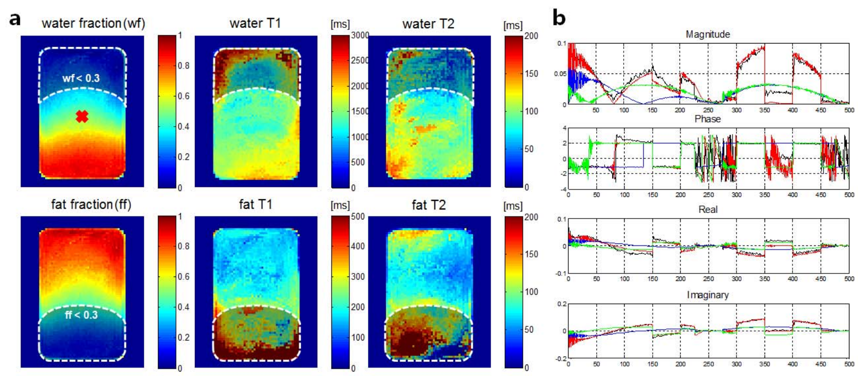

Figure 3. Phantom results. Estimated fraction, T1, T2 map for each water and fat component (**a**). The regions which have each w/f fraction below 0.3 are shaded. Acquired (black line) and fitted signal profiles (red line : water signal + fat signal, blue line : decomposed water signal, green line : decomposed fat signal) at point 'x' (**b**).

Discussion The use of dual TR seemed to avoid banding artifacts which are commonly observed in SSFP. Even though the off-resonance frequency varied from -100 to 500 Hz in in vivo knee, the banding artifact is not observed in the quantitative images.

To further improve spatial resolution especially in knee, parameter optimization would be required; the in-phase and out-phase TR would need to be prolonged due to extended k-space coverage and the number of acquired images should be increased beyond 500 images for SNR.

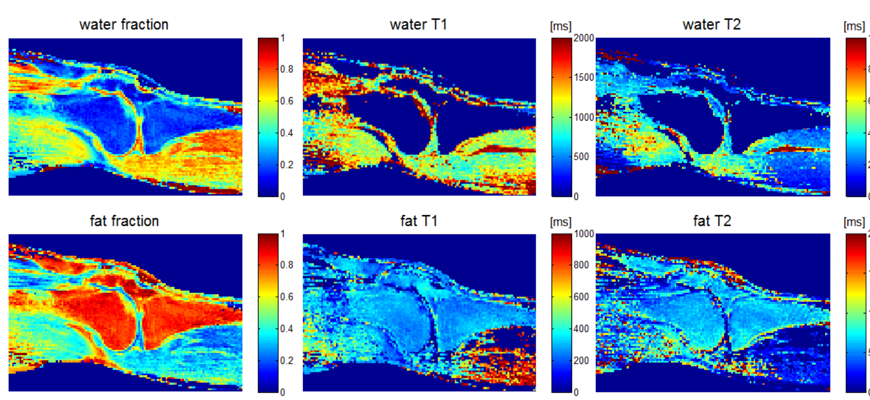

Figure 4. In vivo (knee) results. Estimated fraction, T1, T2 map for each water and fat component. w/fT1, w/fT2 values are masked out in regions where the fraction is below 0.3 due to limited SNR.

Conclusion We have presented a fast simultaneous water and fat decomposed T1, T2 quantification with dual TR bSSFP sequence. The method uses data matching with a forward model based Bloch equation simulator.

References [1] Moulopoulos LA. Blood, 1997; 90: 2127-2147, [2] McCullough AJ. J Clin Gastroenterol, 2002; 34:255-263, [3] Dixon WT. Radiology, 1987; 153:189-194, [4] Ma D. Nature, 2013; 495:187-192, [5] Bazelaire CM. Radiology, 2004; 230:652-659.

Acknowledgement This work was supported by Samsung electronics.