Improved hybrid PRF-T1 pulse sequence for accurate T1 mapping in high field (3T)

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Introduction: Accurate temperature mapping in tumor and surrounding tissue throughout the thermal therapy is essential to ensure the safety and efficacy of thermal treatment. Methods based on the temperature dependency of the water proton resonance frequency (PRF) shift have shown the best ability to quantify temperature rises in soft tissues. Unfortunately, the PRF shift with temperature does not apply to lipid protons, since there is no hydrogen bonding among the methylene protons that supply the bulk of fat signal. However, the temperature sensitivity of the spin-lattice relaxation time, T_1, has been measured for a number of fatty tissues and found to obey a linear relationship over a small temperature range [1]. We previously proposed the hybrid PRF-T_1 method to combine these two techniques to simultaneously monitor temperature in fat and soft tissues [2]. In this work, we show a sequence implementation and improve the accuracy of T_1 measurements for better temperature mapping.

Theory: A new hybrid PRF-T_1 sequence based on the variable flip angle (FA) DESPOT1 method [3] was implemented from the standard FLASH sequence by alternating two FAs from measurement to measurement. The two FAs were computed to minimize T_1 variance as described previously [4]. The complete temperature maps are acquired in either one or two measurements for PRF and T_1 methods respectively. The PRF temperature map uses the fact that temperature change is proportional to phase change:

$$\Delta\phi = \gamma \cdot \alpha \cdot Bo \cdot TE \cdot \Delta T \quad (1)$$

The T_1 map computed using the signals of both FAs, is based on the signal equation of an ideally spoiled steady state gradient echo (FLASH) sequence, which can be approximated as: $SI_{FLASH}(\alpha(r)) = \frac{M_o(1-E_1)}{(1-E_1 cos\alpha(r))} sin\alpha(r)$, where $E_1 = \exp(-\frac{TR}{T_1})$ (2)

Rearranging equation 2 gives: $\frac{SI_{FLASH}(\alpha_{nominal})}{\sin(\alpha_{actual}(r))} = E_1 \frac{SI_{FLASH}(\alpha_{nominal})}{\tan(\alpha_{actual}(r))} + M_o(1-E_1)$, where T_1 can be extracted as: $T_1(r) = -TR / \ln(E_1(r))$. (3)

In practice, RF excitation is not uniform, and results in an imperfect slice profile and a spatial variation of the FA across the phantom. This variation becomes even more important in MRI scanners operating at 3T and higher. Therefore, measurement of the actual FA is necessary to obtain accurate T_1 mapping with the variable flip angle technique. The actual FA mapping requires two images which are acquired with a pair of FAs (α,2α). Dividing the magnitude image of the two FA yields:

$$\alpha_{actual}(r) = cos^{-1}\left|\frac{SI_{FLASH}(2\alpha)}{2*SI_{FLASH}(\alpha)}\right|. \quad (4)$$

Methods: All MR imaging was performed using a 12 channel phased array receive coil on the Siemens TIM Trio 3T MRI scanner (Siemens Medical Solutions, Erlangen, Germany). A conventional inversion recovery (IR) gradient echo pulse sequence (TR/TE = 2200/17 ms, 1.6X1.6X3 mm resolution, 128X132 image matrix, echo train = 5, TI = [50 200 400 800 2000]) was used for T_1 mapping of a homogeneous liquid phantom containing cupric sulfate, and this T_1 was used as a reference. Two scans were performed using our hybrid PRF-T_1 sequence with two pairs of nominal FAs (α_1,2α_1) and (α_2,2α_2) where α_1 and α_2 were set to be 19° and 88° respectively for TR = 45 ms and $T_1 \approx 140$ ms [4]. The actual FA map of each nominal FA was acquired with TR/TE = 3000/10 ms, single slice, 1.6x1.6x3 mm resolution, 128x76 image matrix, and scan time was 7 min 36 s. Using the variable flip angle method, a T_1 map was derived from the images of the nominal FA α_1 and α_2 which were acquired with the same parameters sets except: TR/TE was 45/10 ms, and the scan time was 20 s for 4 measurements.

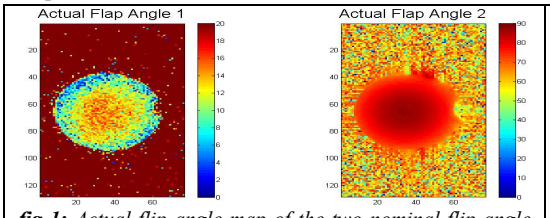

fig 1: *Actual flip angle map of the two nominal flip angle 19 ^{o} and 88 ^{o}*

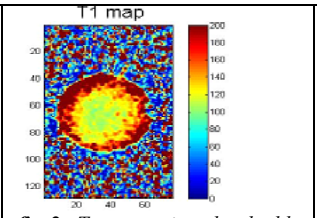

fig 2: *T_1 map using the double flip angle method*

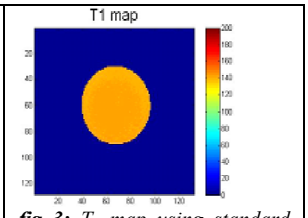

fig 3: *T_1 map using standard Inversion Recovery method.*

Results: Figure 1 shows the actual FA map of the nominal FAs α_1 and α_2. From these FA maps, the average FA across the phantom for the two nominal angles were found to be 12±2° and 84±3°. Figures 2 and 3 display the T_1 map of the phantom using double FA and the standard inversion recovery methods respectively. The mean T_1 of the phantom using the inversion recovery method was found to be 140±0.5 ms which is relatively high compared to the mean T_1 = 126±21 ms value obtained using the variable FA correction method.

Conclusion: Even though the proposed method is in an early investigation stage, we believe that this method can be used to map T_1. The accuracy of the T_1 map depends on a correct FA as well as a good spoiling of the transverse magnetization since equation 2 was derived under the assumption of a perfect spoiling of the transverse magnetization. We believed that the error in the T_1 map is caused by incomplete spoiling of the transverse magnetization. Investigation of this matter is under way, and the result will be presented in future work.

References: [1] Kullervo Hynymen et al. MRM 43:901-904(2000), [2] Todd N et al. ISMRM, 2008, Toronto, Canada, poster 1228, [3] Deoni et al. MRM 49:515-526, 2003 [4]Matthias C. Schabel et al. Phys. Med. Biol. 54 (2009) N1-N8.

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