Simultaneous Temperature Mapping in Fat and Water using Two Point Dixon Hybrid PRF-T1 in 3D segmented Flyback EPI

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Introduction: Accurate temperature mapping in tumor and surrounding tissue throughout a thermal therapy procedure is essential to ensure the safety and efficacy of the 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 aqueous 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 the fat signal. However, the temperature sensitivity of the spin-lattice relaxation time, T_1, has been measured for a number of fatty tissues, and was found to obey a linear relationship with the temperature [1]. In the present work, we show a sequence implementation for 3D fat and water temperature imaging based on a Two Point Dixon (2PD) fat and water separation and the Variable Flip Angle (VFA) T_1 mapping techniques [2].

Theory: A new 2PD hybrid PRF-T_1 sequence was implemented from a 3D segmented Flyback EPI sequence. The sequence was implemented by alternating two flip angles (FAs) and two TEs (TE, TE+Δ) from measurement to measurement and every other two measurements respectively. TE and (TE+Δ) represent the echo times when water and fat are in phase and out of phase. The two FAs (α_1, α_2) were computed to minimize T_1 variance as described previously [3]. The temperature maps are acquired in four measurements (**Fig 1**).

2 Point Dixon: Water and fat were separated using the extended 2PD method as follows:

$Meas.1 = (W_{\alpha 1}+F_{\alpha 1})exp(i\Phi_0)$ (1) $Meas.2 = (W_{\alpha 2}+F_{\alpha 2})exp(i\Phi_0)$ (2)

$Meas.3 = (W_{\alpha 1}-F_{\alpha 1})exp(i[\Phi_0+\Phi])$ (3) $Meas.4 = (W_{\alpha 2}-F_{\alpha 2})exp(i[\Phi_0+\Phi])$ (4)

Equations (1) and (3) can be solved by first eliminating Φ_o using:

$S_{\alpha 1} = W_{\alpha 1}+F_{\alpha 1} = |Meas.1|$ and $S'_{\alpha 1} = Meas.3*exp(-i\Phi_0) = (W_{\alpha 1}-F_{\alpha 1})exp(i\Phi)$.

Images of $((S'_{\alpha 1})^2)$ were unwrapped before extracting the phase as: $\Phi = 1/2\ \arg((S'_{\alpha 1})^2)$.

Therefore, the final water and fat images were obtained by:

$W = .5*(S_{\alpha 1}+S'_{\alpha 1}exp(i\Phi))$ $F = .5*(S_{\alpha 1} - S'_{\alpha 1}exp(i\Phi))$

Equations (2) and (4) were similarly used to obtain fat and water only images at FA α_2.

T_1 Mapping: The T_1 map was computed using the fat only images at both FAs. The signal equation of an ideally spoiled steady state gradient echo (3D Flyback EPI) sequence can be approximated as: $SI = M_o \frac{1-E_1}{1-E_1\cos\alpha}\sin\alpha$, where $E_1 = \exp(\frac{-TR}{T_1})$

Rearranging the signal equation we obtain: $\frac{SI(\alpha)}{\sin(\alpha)} = E_1\frac{SI(\alpha)}{\tan(\alpha)} + M_o(1-E_1)$

Where T_1 can be extracted as: $T_1 = -TR / \ln(E_1)$. Accurate T_1 mapping requires the determination of the actual FAs, thus $\alpha_{actual} = \arccos\left(\frac{SI(2\alpha)}{2*SI(\alpha)}\right)$.

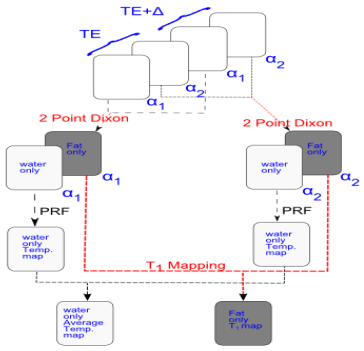

Fig 1: *Schematic diagram of the simultaneous fat and water temperature imaging using the Two Point Dixon Hybrid PRF-T_1.*

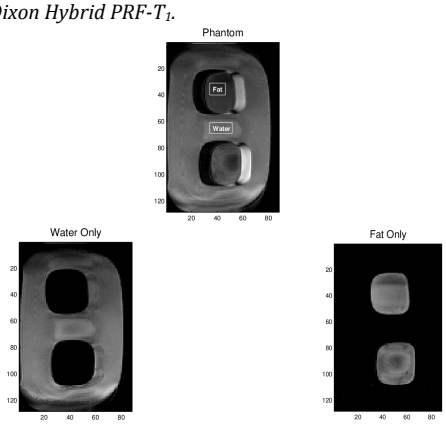

Fig 2: **a** Image of the water and vegetable oil phantom (in-phase). **b** Water-only image of the phantom. **C** Fat-only image of the phantom.

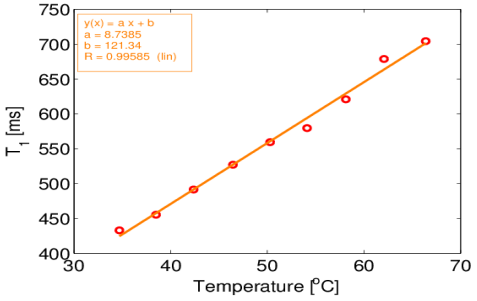

Fig 3: Plot of T_1 versus the temperature readings of the fiberoptic temperature probe over 2x2 ROI near the tip of the probe.

Methods and Results: 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 homemade phantom (**Fig 2a**) consisting of water and vegetable oil (Soybean) was used as a substitute to mixed tissue (Fat+Water). The 2PD hybrid PRF-T_1 sequence was runned throughout the cooling of one of the vegetable oil containers which was heated using a microwave oven. Images were acquired with the following parameter sets: TR/TE/TE+Δ=30/15/16.1ms, 1.6X1.6X5 mm resolution, 128X86 image matrix, echo train = 11, FAs= $12^0/59^0$, and the scan time = 4sec/measurement. To determine the correlation of T_1 with temperature, a fiberoptic temperature probe (OpSens, Inc, Quebec, Canada) was positioned in the heated vegetable oil.

Fig 2a and **2b** show the water and fat only images of the phantom. **Fig 3** is a plot of T_1 versus the fiberoptic temperature probe readings over a 2x2 ROI chosen near the tip of the probe. During the cooling T_1 decreased linearly with Temperature ($dT_1/dT = 8.7ms/^0C$).

Although, the proposed technique for simultaneous temperature mapping in fat and water is not currently practical for clinical application due to the long acquisition time (16 sec for one complete temperature map), it shows the capability of determining temperature in mixed tissue (fat+water) over a 3D volume. To reduce the acquisition time, Temporally Constrained Reconstruction (TCR) [4] is being implemented on the 2PD hybrid PRF-T_1 sequence. The TCR can reduce the acquisition time by 4 or more without sacrificing accuracy of the temperature maps. Results from TCR+2PD hybrid PRF-T_1 will be presented in future work.

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References:

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