

Assessment of Tissue Damage using PRF-T1 Technique

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1 Introduction:

One of the main reasons focused ultrasound surgery has not been used widely in the clinical setting has been the difficulty to assess the extent of biological tissue damage due to hyperthermia. Denaturation of macromolecules within the tissues is believed to be the major factor contributing to the damage of tissues upon hyperthermia. Water in biological tissues is mostly bound to macromolecules such as: protein, fibers, membranes, and ions. As a result, the values of the relaxation time (T_1) of the tissue water, which are related to the translational and rotational rates of water, represent the intrinsic probes for investigating the structural changes in the tissues at high temperature. It has been also shown that methods based on the temperature dependency of the water proton resonance frequency (PRF) shift has the best ability to quantify temperature rises in soft tissues [1]. Therefore, the goal of the present study is to investigate whether the hybrid technique (PRF- T_1), can be used to quantify the threshold of tissue damage.

2 Theory:

A new hybrid PRF- T_1 sequence based on the variable flip angle (FA) DESPOT₁ method [2] was implemented from the standard 3D segmented EPI sequence by alternating two FAs from measurement to measurement. The two FAs were computed to minimize T_1 variance as described previously [3]. The complete temperature maps are acquired in either one or two measurements for PRF and T_1 methods respectively. The PRF temperature mapping method is described by: $\Delta\phi = \gamma * \alpha * B_0 * TE * \Delta T$.

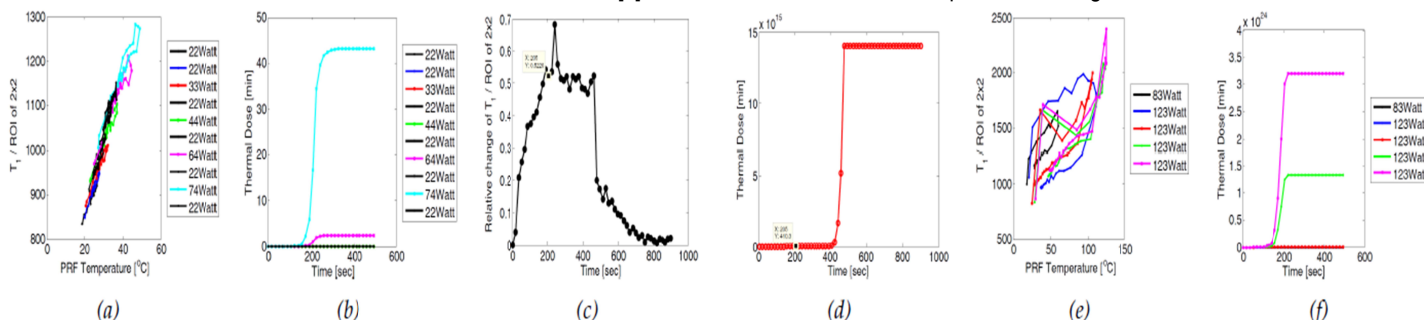
The T_1 map computed using the signals of both FAs, is based on the signal equation of an ideally spoiled steady state gradient echo (3D segmented EPI) sequence, which can be approximated as: $SI = M_0 \frac{1 - \exp(-\frac{TR}{T_1})}{1 - \cos(\alpha) \exp(-\frac{TR}{T_1})} \sin(\alpha) \exp(-\frac{TE}{T_2^*})$.

The above equation can be linearized as: $\frac{SI}{\sin(\alpha)} = \frac{SI}{\tan(\alpha)} \exp(-\frac{TR}{T_1}) - SI \left(1 - \exp(-\frac{TR}{T_1})\right) \exp(-\frac{TE}{T_2^*})$, where T_1 is extracted as: $T_1 = -\frac{TR}{\text{slope}}$.

In practice, RF excitation is not uniform, and results in an imperfect slice profile and a spatial variation of the FA across the imaged object. 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 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: $\alpha_{actual} = \cos^{-1} \left[\frac{SI(2\alpha)}{2 * SI(\alpha)} \right]$.

3 Methods:

All MR imaging was performed using an in-house built 4-channel RF receive coil on the Siemens TIM Trio 3T MRI scanner (Siemens Medical Solutions, Erlangen, Germany). A conventional inversion recovery (IR) spin echo pulse sequence (TR/TE = 4100/17 ms, 2X2X2 mm resolution, 128X64 image matrix, echo train = 11, TI = [50 200 400 800 2000 2500]) was used for T_1 mapping of the chicken breast before and after the heating with HIFU. Two scans were performed using our hybrid PRF- T_1 sequence with two pairs of nominal FAs (α_1 , $2\alpha_1$) and (α_2 , $2\alpha_2$) where α_1 and α_2 were calculated to be 8° and 42° respectively for TR = 40 ms and TE = 7 ms. The hybrid PRF- T_1 sequence was run throughout the HIFU heating and the cooling of the chicken breast with the same parameter sets as the inversion recovery sequence except: TR/TE = 40/7 ms; flip angles 8° and 42° ; bandwidth = 752 Hz/pixel; 8.3 sec/measurement. To validate our new method, the thermal dose [4] measurement was also used to predict the coagulated tissue volumes.



4 Results and Conclusion

Figure (a) shows the plot of T_1 versus the absolute temperature for a series of heating and cooling at the following acoustic power: 22 watt, 22 watt, 33 watt, 22 watt, 44 watt, 22 watt, 64, watt, 22 watt, 74 watt, and 22 watt. Figure (b) is the plot of the corresponding thermal dose for all the measurements. Figure (c) shows the plot of the relative change of T_1 versus time when the equivalent thermal dose shown in figure (d) exceeds the critical value of 240 CEM. Figure (e) and (f) represent the plots of T_1 versus the absolute temperature, and the corresponding thermal dose versus time when tissue damage already occurred (Thermal dose \gg 240 CEM).

Although, the proposed PRF- T_1 technique for tissue damage assessment is in an early experimental stage, the results obtained are very encouraging. Figure (a) has shown that before tissue damage occurs, T_1 is reversible with temperature. And when tissue damage occurs (figure (e)), this T_1 reversibility is severely altered. Therefore, PRF- T_1 technique has the potential to probe the structural changes in the tissues at high temperature. Future work will involve in vivo experiments to validate these presented results.

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References

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