Using a Double Echo Steady State (DESS) Sequence to Monitor Thermal Treatments

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Purpose: In MR-guided thermal ablation (1), changes in temperature, along with an estimate of baseline temperature, are used to compute thermal dose maps and treatment efficacy (2). Following treatment, actual lesion size is estimated from diffusion weighted imaging, contrast enhanced, or in some cases T1-weighted images (2–4). Previous studies have looked at monitoring the apparent diffusion coefficient (ADC) (5), or temperature and ADC (6), in order to study the progression of the ADC signal to assess when tissue viability is lost. In this work, a double echo steady state (DESS) sequence was implemented and investigated as a potential solution for simultaneous monitoring of temperature and tissue viability. DESS offers rapid imaging with multiple contrasts present in the two echoes (7). Our aim was to use the phase of the first echo to compute temperature, in order to measure how the signal strength of the second echo should change with temperature, and to use the difference between predicted changes and actual changes to indicate structural changes in the tissue.

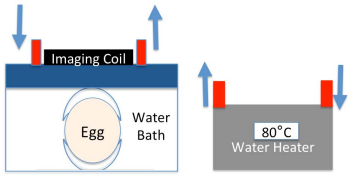

Figure 1. Experimental Setup. An egg in a water bath was placed inside of a 3T GE Signa scanner. Water temperature was controlled with a heater with a built in thermostat and feedback controller outside of the MR suite. A surface coil was used for acquisition.

Methods: An egg white model was used to empirically derive T1/T2/ADC dependences on temperature provided in Table 1. Using these values, an extended phase graph (EPG) model was used to simulate the signal changes of our second echo with temperature (8). Individual contributions of T1, T2, and ADC changes with temperature were simulated, as well as the overall signal change (Fig. 2). For validation, eggs (n=4) were placed inside of a watertight container and monitored as 80°C water was circulated to cook them for 5 or 20 mins (Fig. 1). Changes in temperature were computed using PRF thermometry of the first echo. The imaging parameters for our DESS sequence are as follows (Flip angle=15°, TE1/TE2=6/28ms, TR=17ms). Representative data from both heatings were binned and averaged for small temperature ranges in order to compare their agreement with the simulation for temperature changes smaller than 23°C. Immediately after monitoring stopped, eggs were inspected for coagulation (Fig. 3).

Table 1. T1, T2, ADC Temperature Dependence

	Sequence	TE/TR (ms)	Equation	N
T1	IR-SE, TIs=50, 400, 1100, 2500ms	10/2550	T1(ms) = 50 ΔT+640 R^2=0.81	10
T2	SE, TEs=20, 40 , 80, 160, 320ms	…/2000	T2(ms) = - 0.56 ΔT+208 R^2=0.21	8
ADC	ssEPI/ SE, b= 0, 50, 100, 200, 400,800 s/mm2	54/4000	ADC(mm^2/s) = 6e-5 ΔT +4e-4 R^2=0.95	12

Parameters were monitored at 25°C, 30°C, 35°C, 40°C, 45°C, 50°C, 55°C

Results: Simulation of the second echo indicates significant signal drop with temperature is associated with changes in diffusion. Changes in T1 are simulated to have a strong but smaller contribution to signal loss. In experimental data for the 5 min and 20 min heating, we found strong coefficients of determination (R^2=0.965, R^2=0.971) until a temperature rise of 23°C. Visual inspection shows 20 min heating solidified the egg white, while the 5 min heat turned the egg white from translucent to opaque without solidification.

Discussion: Although many contrast mechanisms contribute to the signal drop, all work synergistically in the same direction, hence increasing the sensitivity of our signal to changes in temperature. Structural changes that affect diffusion, T1, or T2 will all affect this relationship. We believe deviations from the predicted curve for the case where the egg is cooked are associated with irreversible changes that are analogous to loss of tissue of viability in an *in vivo* situation, and hence would be useful for monitoring tissue viability during thermal treatments.

Conclusion: Monitoring treatments with DESS could allow for strategies to monitor tissue viability changes during treatment. If a consistent relationship between signal intensity and temperature, like that observed in egg white phantom, is present for other tissues, then signal dependence on temperature can be removed to highlight changes in tissue structure associated with loss of tissue viability.

References:

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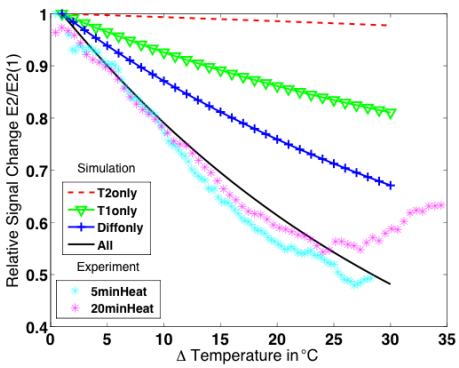

Figure 2. Extended Phase Graph (EPG) Simulations for Relative Changes of the Second Echo (E2). Simulations including only T2 (red), T1 (green), and Diffusion (blue) changes with temperature are plotted in order to assess their individual contribution to the signal change. A simulation with all parameters changing (black) was also performed and shows good agreement with experimental sample points for binned data from our 5min (cyan) and 20 min (magenta) heats.

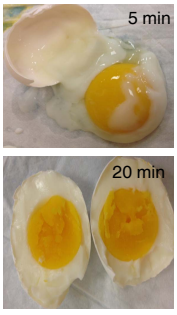

Figure 3. Visual Inspection. The 5 min heat was sufficient to opacify but not solidify the egg white while the 20 min was enough to solidify the egg white.