The Optimization of Magnetic Resonance Temperature Imaging Sequences

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Purpose

In this paper, we design the optimal gradient echo pulse parameters to achieve maximal temperature sensitivity of MR signal based on measured T1, T2 and proton density data at different temperatures for various tissues *in vitro*.

Key word: MR, T1, T2 proton density.

1. Introduction

MR temperature imaging has shown its feasibility in hyperthermia temperature monitoring for optimal therapy effects. It is unique in that non-invasive deep tissue temperature distributions could be possible with properly designed MR sequences. Its weakness is in its sensitivity to detect minute temperature changes in a reasonable duration of time for medical diagnosis. In this paper, we design the MR pulse sequences to optimize the temperature sensitivity with the T1, T2, proton density measured at different temperatures.

2. Material and method

Experiments was conducted in a GE SIGNA 1.5 tesla MR Imager. Different tissues, including brain, muscle and fat was wrapped by a heating water bag of which water temperature was controlled by a temperature servo. Heated water is circulating in tubes and was pumped during the experiments. RTD PT1000 sensors and Yokogawa 7563 electronic thermometer was used with a multiplexer for real-timed and multi-channeled temperature monitoring. Acquired data is then transmitted into PC for further analysis.

T1,T2 and PD was measured using two different TRs, double spin echo imaging sequences with TEs as 30ms and 60ms for muscle, 40ms and 80ms for fat and brain. In order to obtain optimal T1 values, TRs are set to be 3sec and 0.8T1 according to different tissues. We then plot these measured T1, T2 and PD for all these tissues as a function of temperature and fit them to a linear equation of temperature for further sequence optimization.

GE and SE siganl are calculated as a function of temperature and TR, TE. Sensitivity of these signal to temperature(dS/dT) can be derived and expressed as a function of TR · TE and temperature T. By setting T equal to 37.5°C, which is about the temperature of human body, one can find the optimal MR imaging parameter TR, TE with computer program for different tissues.

3. Result

T1, T2,PD data The relationship of various tissues's parameters are as follows :

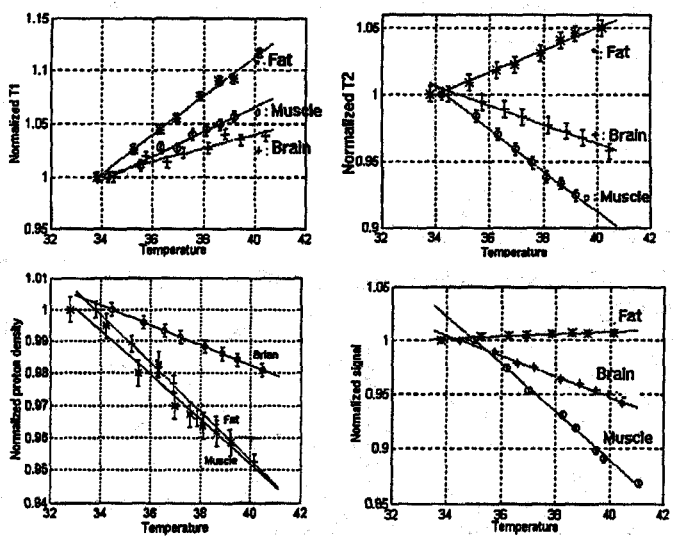

Fig.1. T1, T2, PD and spin echo signal vs. Temperature

	muscle	fat	brain
(dT1/T1)/T	1.15%	1.82%	0.63%
(dT2/T2)/T	-0.87%	0.84%	-0.7%
(dPD/PD)/T	-0.67%	-0.75%	-0.32%
(dS/S)/T*	-2.2%	0.11%	-0.95%

Table.1 *TR/TE=(3000/20)ms for muscle, (3000/40)ms for fat, (3000/40)ms for brain.

The errorbar in Fig(1) is derived from noise in image calculated in error propagation algorithm to T1、T2 and PD.

TR/TE optimization T1(T), T2(T), PD(T) could be fitted from Fig.1 :

$T_1(T) = 641.42 + 12.13 \cdot T$
$T_2(T) = 58.67 - 0.594 \cdot T$ for muscle
$PD(T) = 1.2293 - 0.0069 \cdot T$

$T_1(T) = 125.56 + 5.914 \cdot T$
$T_2(T) = 33.46 + 0.394 \cdot T$ for fat
$PD(T) = 1.2553 - 0.0075 \cdot T$

$T_1(T) = 806.11 + 6.48 \cdot T$
$T_2(T) = 96.07 - 0.538 \cdot T$ for brain
$PD(T) = 1.1192 - 0.0032 \cdot T$

One can optimize the pulse sequence with the relationship above and calculate the signal for spin echo and gradient echo

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as a fuunction of T, TE and TR. To find the optimal TR/TE, we derive dS/dT=F(T,TR,TE) and adjust TR, TE to make $|dS/dT|$ largest at the temperature of 37.5°C.

As shown in Fig.2, the results are listed in Table.2, 3, and 4.

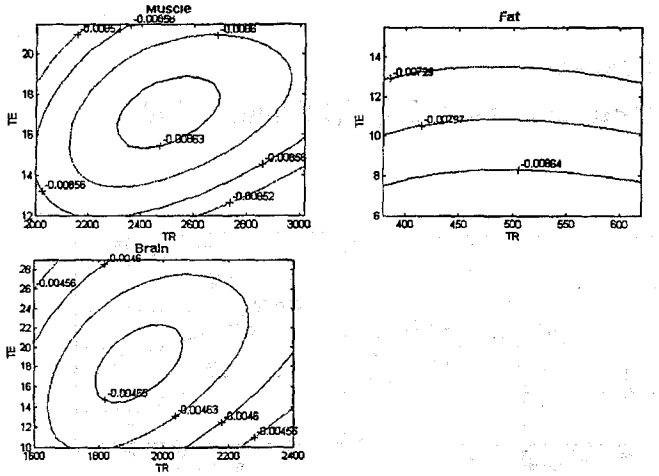

Fig.2-1 Contour plot of muscle, fat and brain of optimization for spin echo

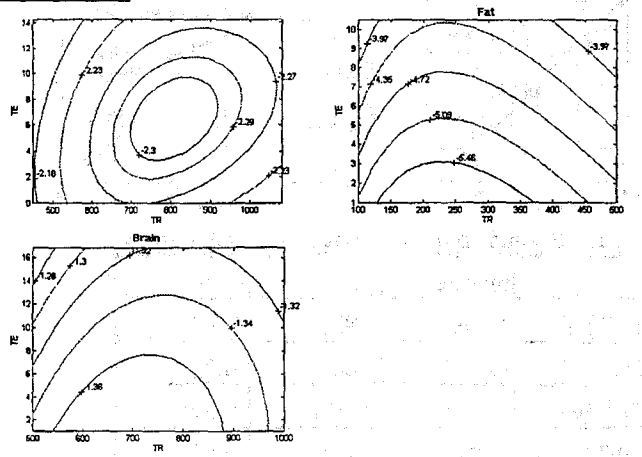

Fig.2-2 Contour plot of muscle, fat and brain of optimization for spin echo with time consideration.

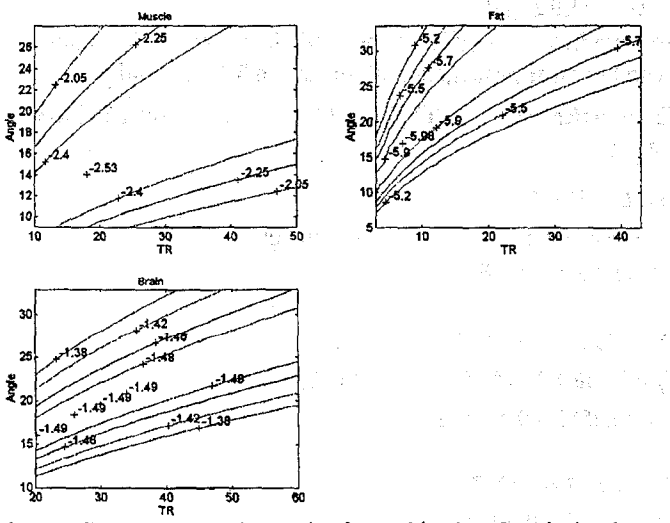

Fig.2-3 Contour plot of muscle, fat and brain of optimization for gradient echo with time consideration.

	muscle	fat	brain
SE(TR/TE)	2500/17	470/10	1940/19
dS/dT	-20.10	-17.63	-8.23

Table.2. dS/dT for spin echo Noise level is about 3.

It takes 4 min to get a 128*256 image with TR=2500ms which is time-consuming in clinical use. To include the time-effectiveness and related change in signal-to noise, we optimize (dS/dT)/sqrt(time) instead of dS/dT to have a compromise between sensitivity and scanning time[2].

	muscle	fat	brain
SE(TR/TE)	800/11	230/11	750/11
dS/dT	-15.15	-14.18	-6.53

Table.3. dS/dT for spin echo sequence with time consideration

	muscle	fat	brain
GE(TR/TE/Angle)	18/8/16	8/3/19	31/4/19
dS/dT	-2.87	-3.63	-1.47

Table.4. dS/dT for gradient echo sequence with time consideration

All these sensitivity has been checked right by MR experiment. This justfy the effectiveness of this optimizatiuon procedure.

4. Discussion

MR Signal Sensitivity vs. T1, T2, PD sensitivity To increase temperature sensitivity is our main purpose. From table 1., one can expect with the combined temperature sensitivity of all three parameters T1, T2 and PD for muscle and brain, MR signal sensitivity will be higher. One typical value has been shown in the table. However, for fat tissue, T1 and T2 sensitivity to temperature will cancel out in MR signal. This implies that MR signal strength of muscle and brain are more sensitive to temperature than anyone of the three parameters, while fat is more sensitive to T1 or T1-weighted imaging as the temperature image choice.

Time Considerations From table 4, we can extimate the imaging time to have a image of 1°C sensitivity . In order to distiguish the signal difference from noise, one has to consider on the value $\Delta S/N$. For minimal $\Delta S/N$ to conceive the signal change, In Rose model suggests values higher than 3. In this situation, it takes about 29sec for muscle, 7sec for fat and 142sec for brain which make the noise of the image one-third of the signal difference per centigrade. The ROI is about 2cm square. To increase the sensitivity by 2 one has to pay four times time in hyperthermia, this is all rightt, but it is far from the diagnostic requirements to have real-timed temperature monitoring for better spatial resolution.

5. Conclusion

We have measure T1, T2, PD sensitivity to temperature and optimize MR signal TE/TR parameters for MR temperature imaging. To even faster the process, we are now working on MR temperature optimization using phase imaging with the same process. With the higher inherent sensitivity of chemical shift parameter, we expect to get better MR temperature imaging sensitivity in a shorter duration of time.

6. Reference :

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