MR Temperature Mapping in Brain: A comparison of the GRE, segmented EPI and ss EPI sequences based on the Proton-Resonance-Frequency-Method

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Introduction:

The safety and outcome of minimally invasive thermal ablation procedures, such as laserinduced thermal therapy (LITT), radio frequency ablation (RFA) and high intensity focussed ultra sound ablation (HIFU), benefit significantly from spatially resolved temperature mapping using magnetic resonance imaging (MRI). The proton resonance frequency (PRF) method is most often applied for MR temperature mapping of various organs including brain, uterus, prostate, and breast (1). Thermal therapy of the brain can be challenging due to the frequent need to treat larger tumor volumes and rapidly heating (2). In order to work within these strenuous conditions the techniques for MR temperature monitoring must include both short measuring times and high spatial precision at the same time. This study was conducted to compare the quality of temperature mapping using three sequences: a gradient echo sequence (GRE), a segmented echoplanar imaging (EPI) sequence, and a single shot EPI (ss EPI) sequence. Parameters of these sequences were then adapted to the conditions in the human brain.

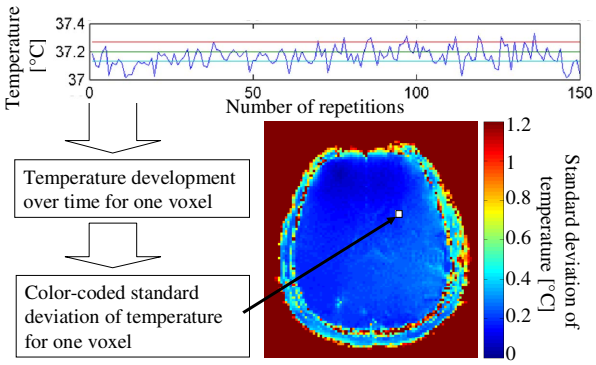

Figure 1: The temperature distribution over time was measured for each voxel of a slice. The standard deviation can be calculated by the temperature distribution of each pixel. The standard deviation over the entire slice is shown in a color-coded standard deviation map.

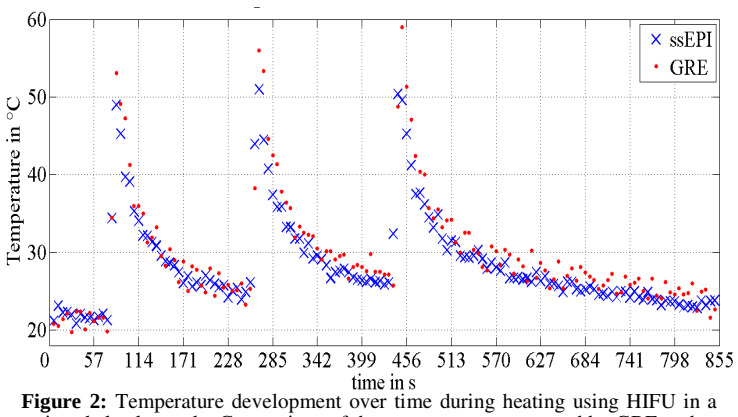

Figure 2: Temperature development over time during heating using HIFU in a swine skeletal muscle. Comparison of the temperatures measured by GRE and ss EPI sequences in a 1.5 Tesla system (MAGNETOM Avanto, Siemens Medical Solutions).

Methods:

Repetitive MR temperature mapping within the brain was performed on six healthy volunteers using comparable acquisition parameters for the GRE, segmented EPI and ss EPI sequences (see Table 1). Measurements were taken over 12 minutes on a 1.5 Tesla system (MAGNETOM Avanto, Siemens Medical Solutions) and on a 3 Tesla system (MAGNETOM Trio, Siemens Medical Solutions).

The standard deviation (SD) of the derived temperatures was calculated for each single picture element over the 12 min time period. The resulting standard deviation map indicates fluctuations of measured temperatures (Figure 1).

In order to temperature accuracy of the ss EPI, the sequence was compared to the GRE sequence (gold standard for PRF) during the heating of swine skeletal muscle three times using HIFU (80 watt; 10 seconds) (Figure 2). Temperature measurements with the two sequences were performed sequentially in different locations within the meat sample.

Table 1: Measurement parameters for the GRE, segmented EPI and ss EPI sequences with a voxel size of 2 x 2 x 2mm, a field of view of 256 mm and a geometrical matrix size of 128.

	TR [ms]	TE [ms]	α [°]	BW [Hz/Px]	GRAPPA factor	Average	Number of slices	Slice thickness [mm]	Recurrences in 12min	TA for 1 Slice [ms]
GRE	157	17	25	160	3	1	7	2	100	1100
Seg. EPI	254	17	90	500	-	1	7	2	230	455
Ss EPI	2550	30	90	752	2	4	7	2	300	378

TR = repetition time; TE = echo time; α = flip angle; TA = acquisition time; BW = bandwidth

Results:

Temperature standard deviation (SD) was less than 1°C in all brain areas for all sequences tested. Average SD across all measurements for the GRE /seg EPI / ss EPI at 3 Tesla was 0.2°C / 0.4°C / 0.4°C respectively (Table 2). At 1.5 Tesla the averaged temperature precision of GRE /seg EPI / ss EPI was 0.7 / 0.8 / 0.4°C respectively (Figure 3).

The temperature measurements using the ss EPI was achieved rapidly (9 acquisitions per second). This is approximately 11 times faster than the respective GRE sequence (1 acquisition per second).

Regional differences of temperature accuracy across transverse slices were observed, and were similar for all subjects and sequence studies. This could be explained by physiological effects such as brain and fluid pulsations.

Figure 2 demonstrates a strong correlation between temperature measurements with the GRE and ss EPI sequences. On average there is a temperature difference between the two sequences of ~ 2°C. This deviation may be due to different positions within the skeletal muscle and activation delay of HIFU heating.

Conclusion:

The ss EPI sequence was both the fastest and most accurate sequence for temperature mapping in the human brain when compared to segmented EPI and GRE. The segmented EPI and GRE pulse sequences are both less susceptible to motion artefacts , but as the vast majority of brain interventions are performed using a stereotactic frame (which nearly eliminates patient motion) the ss EPI sequence may be the 'sequence of choice' for MR temperature mapping of the brain during thermal therapy procedures.

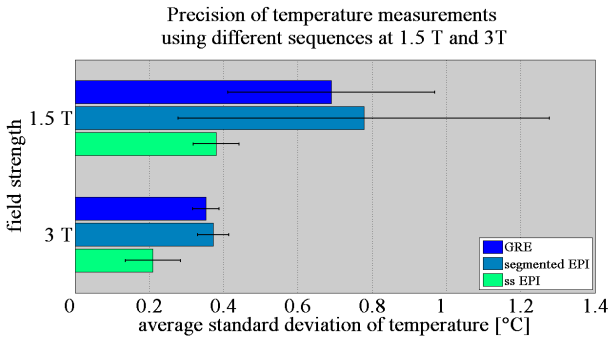

Figure 3: Summary of the averaged standard deviations for the entire head comparing pulse sequences and magnetic field strengths over several temperature measurements over ~12 minutes (sequences: GRE, segmented EPI, ss EPI; MR-systems: 3 Tesla and 1,5 Tesla) including fluctuations across different measurements.

References:

(1) Vigen KK et al. JMRI 2006; 23:578–584. (2)Mack MG, Vogl TJ.MRICNA 2002:10(4). 707-13.