Echo-shifted Proton Resonance Frequency Temperature Mapping

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Introduction

Magnetic resonance temperature measurements are an established method to monitor local temperature changes during thermal therapies such as high intensity focused ultrasound (HIFU). In particular, the change of the local proton resonance frequency (PRF) with temperature can be measured using gradient echo techniques. To detect the small frequency changes phase images are acquired using long echo times between 10 and 30 ms, which results in long repetition times of 20 to 40 ms. With these parameters the temporal resolution of the image acquisition is limited to several seconds per slice and the acquisition of temperature information in multiple slices can be challenging.

In long-TE gradient echo pulse sequences the time between rf excitation and data readout is only partly used for the encoding gradients. In this work we propose a new slice-interleaved temperature measurement pulse sequence where several parallel slices are excited consecutively followed by a series of data readouts to acquire the individual gradient echoes. Compared to conventional gradient echo techniques this method is significantly more time-efficient and allows for measuring temperatures in a whole volume around the target tissue.

Materials and Methods

The slice-interleaved temperature measurement technique was implemented on a clinical 1.5 T whole body MR system (Siemens Symphony, Erlangen, Germany) with a G_{max} = 30 mT/m gradient system. A schematic of the pulse sequence, which is similar to the echo-shifted techniques [1,2], is shown in Fig. 1. Initially, a number of parallel slices (typically, 3 to 7) are excited using evenly-spaced slice-selective rf pulses without refocusing of the slice selection gradient. After the last rf pulse, a rewinder gradient is applied in slice selection direction which refocuses the transverse magnetization in the first slice and the first gradient echo is acquired (ACQ 1). Next, rewinder gradients refocus the remaining slices followed by the acquisition of the other gradient echoes (here: ACQ 2 and ACQ 3).

The pulse sequence was tested on an isolated porcine kidney in a temperature-stabilized water bath. Local temperature changes were induced with either an LITT applicator (5 min irradiation, 30 W, Ni:YAG laser, λ = 1064 nm, Dornier, Germany) or a home-built HIFU applicator (20 s sonication time, 67 W acoustic power). Three slices were positioned at the expected target point using the following typical parameters: TE = 16.2 ms, TR = 33 ms, BW = 200 Hz/pixel, α = 20°, Matrix = 204x256, TA/3 slices = 6.7 s. Images were acquired before, during and after heating. Pre-heating complex image data were averaged to form a reference data set. Temperature maps were generated from the phase difference between reference and time-resolved images using a temperature sensitivity of 0.64 Hz/K.

Results and Discussion

The slice-interleaved temperature measurement allowed for shortening the acquisition time by 46% over a conventional gradient echo pulse sequence with the same number of slices and TE. No artifacts were seen from incomplete signal spoiling in the adjacent slices. In Fig. 2 a temperature map during sonication is shown together with a temperature-time curve near the LITT fiber. During laser irradiation an exponential temperature increase with an amplitude of ΔT = 35.8 K and a time-constant of 74 s was seen, which is in excellent agreement with fiber-optic temperature measurements.

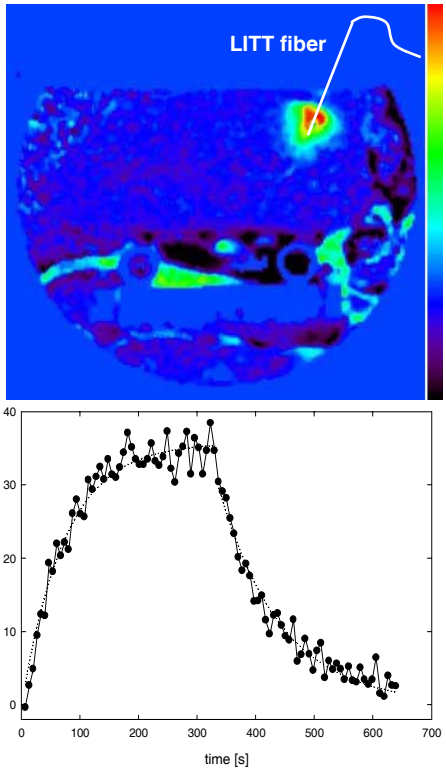

Fig. 2: Top: Temperature map of the central slice during sonication. Here, red corresponds to ΔT = 40 K. Bottom: The temperature time curve near the laser fiber showns an exponential temperature increase during sonication.

References

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[2] Loenneker T, Hennel F, Hennig J. Magn Reson Med 35: 870-4 (1996).

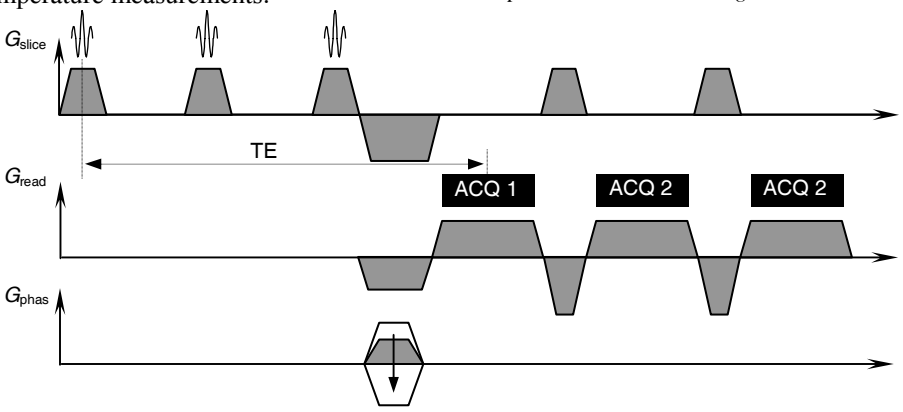

Fig 1: Timing diagram of the slice-interleaved gradient echo pulse sequence. After the excitation of 3 parallel slices the gradient echoes of the individual slices are sampled consecutively (ACQ 1 – ACQ 3). Separation of the signals is achieved by de- and refocusing in slice selection direction yielding the same echo time TE for all slices.