Velocity Navigator Triggering for Motion Compensated PRF Thermometry

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Introduction

MR-guidance is increasingly used for thermo-therapies such as radio frequency, laser (LITT) or focused ultrasound ablation, because MR allows for non-invasive temperature measurements. In the most commonly applied proton resonance frequency (PRF) shift thermometry, temperature differences are calculated based on phase variations with respect to a reference baseline. Since there is a temporal delay between the current and the reference image acquisition this method is very sensitive to motion. Artifacts are caused by tissue displacement and susceptibility changes. In the treatment of abdominal organs such as liver or kidney, breathing motion causes the largest tissue displacement. Therefore, respiratory gated sequences have been proposed to reduce motion-induced temperature artifacts. Trigger signals were generated based on breathing belts [1], air way pressure [2], diaphragm position determination [3], and projection navigator echoes [4]. In this abstract, a novel navigator technique for triggering MR thermometry image acquisition is presented, which is based on velocity encoded and non-velocity encoded navigator signal acquisition.

Materials and Methods

All experiments were carried out on a clinical 1.5 T whole body MR system (Magnetom Symphony, Siemens, Erlangen, Germany). The trigger algorithm was implemented directly on the image reconstruction system of the scanner.

Pulse Sequence: A segmented EPI sequence (parameters: TR/TE = 25/15 ms, α = 15°, FOV: 350×263 mm, matrix: 128×96, slice thickness: 5 mm, EPI factor: 11, acquisition time per slice: 225 ms) was modified for triggered temperature mapping (Fig. 1). A navigator ADC without spatial encoding was inserted before the start of the readout train and the phase encoding gradients. Since the echo times of thermometry sequences are relatively long, the additional navigator gradients did not lead to a lengthening of TR. Until a trigger event was generated to start the acquisition of a complete slice (cf. below), the first segment was acquired repeatedly to maintain magnetization steady state. Every second navigator was velocity-encoded by a bipolar gradient with a velocity sensitivity of VENC = 0.3 m/s. Velocity encoding can be applied in readout, phase encoding and slice selection direction. After a trigger event, velocity encoding was switched off during acquisition of one complete image.

Trigger Algorithm: Each navigator ADC measured eight complex values within 20 µs, which were averaged. The initial 400 repetitions (acquisition time: 10 s) were used as training data. The phase of the values without velocity encoding was unwrapped over time, and minimum and maximum phase as well as the mean value c_m were calculated (Fig. 2). Subsequently, c_m was subtracted from every acquired navigator value before calculating the corresponding phase angle to reduce signal influences from static tissues on the navigator value. Velocity values were calculated by using the current velocity encoded navigator value and its non-velocity encoded predecessor (temporal distance: 1 × TR = 25 ms). A trigger event was generated if the estimated velocity value was less than 0.002 m/s, and the phase angle of the non-encoded navigator value exceeded a certain threshold (80% of maximum phase angle). Trigger events were sent back from the image reconstruction computer to the gradient hardware using the standard real-time feedback mechanism.

Online Thermometry: Temperature data was evaluated immediately after image reconstruction on a separate workstation. Images were directly transmitted from the image reconstruction system via a TCP/IP connection. *TAM* [5] was used for online thermometry and thermal dosimetry.

Experiments: Two agarose gel phantoms (500 ml, 3 % agar, 1:800 Gd-DTPA) were used for an initial experiment without heating. One phantom was periodically moved by an actuator built in-house with an amplitude of 80 mm and a frequency of 0.27 Hz. The second phantom was placed nearby at a fixed position.

In a second experiment a thermal lesion was induced in a moving piece of *ex vivo* beef (Fig. 4, same motion cycle parameter set) using a water-cooled LITT applicator (Somatex, Teltow, Germany). The Nd:YAG laser (mediLas 4060 N, Dornier MedTech, Wessling, Germany) operated at a wavelength of 1.06 µm (30 W, 1:30 min).

Results and Discussion

In the non-heated phantom experiment, a displacement of the magnitude images of less than one pixel (< 2.7 mm) was found. Figure 3 shows the phase variation and the velocity over five periods of motion. The time integral of the velocity over one period was not zero due to measurement imprecision. However, zero-crossings occurred at the expected positions. A temperature standard deviation of ± 0.7 K/± 1.3 K was observed in the non-heated fixed/moving phantom. Figure 4 presents a temperature map and a thermal dose map of the LITT experiment. A maximum temperature rise of about 45 K was measured.

With the proposed navigator technique, additional devices like breathing belts [1] and air way pressure measurement equipment [2] are dispensable. Compared to Vigen *et al.* [3] temporal resolution of this method is improved. The navigator signal is updated every 50 ms and the temperature image every breathing cycle. In contrast to de Zwart *et al.* [4] the navigator signal is not spatially encoded, but velocity encoded. Since motion and variations of background phase are the major sources of temperature errors, the proposed method allows for exact triggering of MR thermometry image acquisition by directly analyzing both sources of errors.

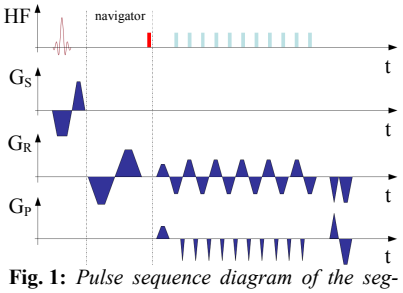

Fig. 1: *Pulse sequence diagram of the segmented EPI sequence including velocity encoded navigator acquisition.*

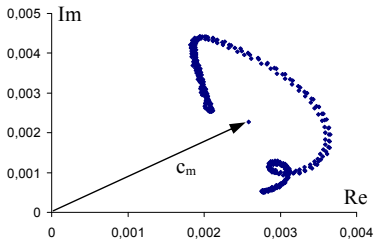

Fig. 2: *Variation of complex navigator values over time and mean value c_m.*

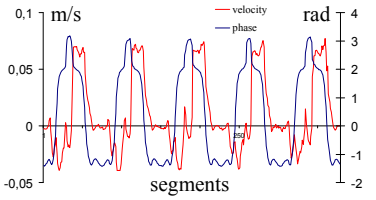

Fig. 3: *Plot of non-velocity encoded navigator phase (blue) and estimated velocity (red).*

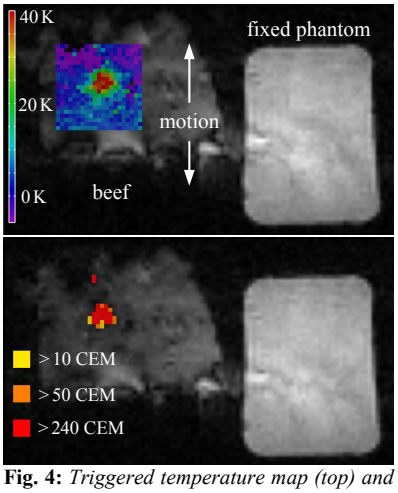

Fig. 4: *Triggered temperature map (top) and dose map (bottom) overlaid with the corresponding magnitude image. Thermal dose was quantified using the approach of cumulative equivalent minutes* [6].

References

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