Measuring temperature rise during spin echo MR-ARFI acquisition

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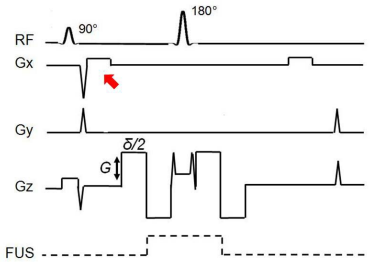

Figure 1. Diagram of modified spin echo MR-ARFI pulse sequence. Red arrow indicates an additional echo incorporated for temperature measurements.

Introduction

MR-guided Focused Ultrasound (FUS) is a promising minimally invasive treatment option for various pathologies [1-5]. During the targeting stage of the treatment, the transducer is calibrated to insure the accurate position of the focal spot based on small temperature rise sonications, and visualized with MR using PRF thermometry. MR Acoustic Radiation Force Imaging (MR-ARFI) has been recently demonstrated [6-11] as an alternative tool for focal spot localization that doesn't produce a temperature rise due to the short duration of the FUS pulses applied with a duty cycle of only 1-2 %. While the temperature rise is generally not expected when FUS is used with low duty cycle, increasing FUS power to achieve higher displacement or simply repeating acquisition many times when accessing the treatment may potentially result in a temperature rise, and it is important to monitor it as a safety precaution. In [11] the temperature was monitored during a gradient echo MR-ARFI acquisition using half sum and half difference of the phase acquired with alternating encoding gradient amplitude. However, most MR-ARFI techniques currently implemented are based on spin echo sequences and are not sensitive to temperature changes. The goal of this work was to modify a spin echo MR-ARFI pulse sequence in order to provide simultaneous temperature monitoring capabilities during MR-ARFI acquisitions.

Methods

A spin echo MR-ARFI [12] pulse sequence was modified to acquire a gradient echo after 90º RF pulse with an arbitrary echo time (Fig.1). The sequence was tested in *ex vivo* porcine brain tissue using a planar 1024 element transducer (InSightec Ltd.) focused at 72 mm. The FUS pulse was synchronized with displacement encoding gradients as shown in Figure 1. Gradient duration was set based on b-value of 32 s/mm^2 found as optimal for *in vivo* imaging in [12] with gradient amplitude set to 4 G/cm^2 and duration of each bipolar gradient lobe of 5.9ms. The duration of the FUS pulse was 18 ms. The FUS acoustic power was varied from 37W to 185W in step of 18W and at each power level a temperature map and a displacement map were acquired simultaneously.

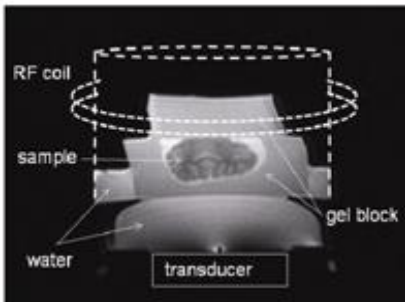

Figure 2. Experimental setup showing *ex vivo* brain inside the gel holder placed on top of the transducer membrane filled with degassed water.

Images were acquired on a 3T GE MRI scanner using a solenoid breast coil placed around the tissue sample as shown in Figure 2. Imaging was performed in coronal plane with the following parameters: FOV = 16 cm^2, matrix size = 128 x 128, BW = 15.63 kHz, TR = 1 s, GRE TE = 10 ms and SE TE = 47 ms. A reference scan was performed with FUS turned off, and its phase was used to calculate phase difference images for temperature map calculations. For each acoustic power two scans were performed with alternating polarity of the encoding gradient.

Results

The temperature and displacement images obtained for nine different acoustic power levels are shown in Figure 3. The mean temperature and mean displacement calculated in the 4 pixel region of interest (ROI) in the center of focal spot are plotted as a function of power. Both quantities linearly increase with power.

Conclusion

This study demonstrated a method for simultaneous monitoring of temperature rise during spin echo based MR - ARFI acquisitions. Temperature rise was measured in non-perfused ex vivo brain tissue for a wide range of acoustic power levels. The results show that 1 to 2 degree temperature rise is anticipated for the lowest acoustic power necessary to produce measurable displacement. This temperature rise should be negligible in perfused tissue, however, if the MR-ARFI is going to be performed repeatedly, temperature monitoring could be still beneficial. Depending on the mechanical properties of the tissue, temperature and displacement increase with power at different rates. To ensure safe scanning conditions this needs to be kept in mind when selecting optimal FUS power level.

The temperature sensitivity of the sequence can be manipulated by increasing the echo time of the gradient echo and also by using inverse centric k - space acquisition rather than sequential. The tradeoff between temperature and displacement sensitivity will be further investigated.

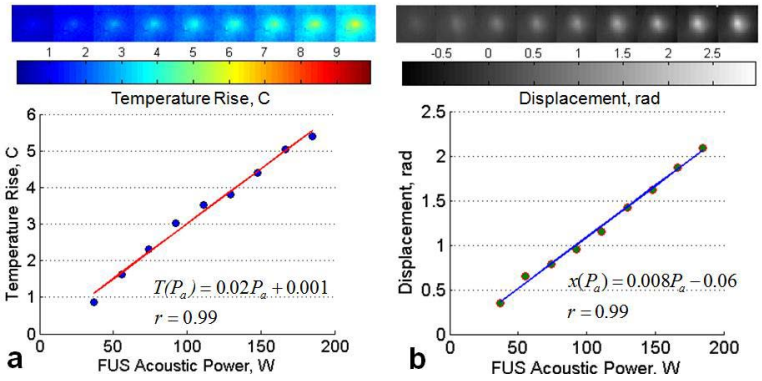

Figure 3. Top: cropped 2.6 cm^2 a) temperature rise images and b) displacement images obtained for varying acoustic power. Bottom: mean a) temperature and b) displacement calculated in the focal spot at each power level. Data and linear fits are displayed.

References:

[1] K. Hynynen et al., Radiology (219) 2001. **[2]** C. Tempany et al., Radiology (226) 2003, **[3]** D. Gianfelice et al., Radiology (227) 2003. **[4]** K. Hynynen et al., Eur J Radiol (59) 2006. **[5]** E Martin et al., Ann Neurol (66) 2009. **[6]** N.McDannold, et al., Med Phys, 35(8):3748–58, 2008.**[7]** Y. Huang et al. Med Phys (36) 2009. **[8]** J. Chen, et al, MRM (63), 2010. **[9]** B. Larrat et al, Phys.Med.Biol. (55), 2010. **[10]** Y. Herzberg et al., Med. Phys. (37), 2010. **[11]** M. Viallon et al., ISMRM 2010. **[12]** E. Kaye et al., ISMRM 2010.

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