Towards reliable calibrated transducers for MR-guided focused ultrasound

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Introduction and Motivation

High Intensity Focused Ultrasound (HIFU) guided by MR thermometry is a promising tumor therapy in organs such as liver, uterus and prostate [1]. Although the technique is already clinical routine the calibrated measurement of high intensity ultrasound fields still needs closer examination. We present an approach towards finding a traceable calibration for MR guided focused ultrasound (MRgFUS) using a reference heating element. Furthermore we examined the focal zone of a commercial MR compatible transducer with MR thermometry at 3 tesla. This was done either for a fixed position or during translational movement of the transducer.

Materials and Methods

The coaxial reference heating element consists of an outer conductor divided into two segments separated by a 2cm long PTFE-tube. This assembly is coated by an epoxy/graphite mixture and due its high resistivity the coating on the PTFE section is the dominant heating source. The coaxial design reduces B_0-field distortions during heating. The element was placed in a PMMA cylinder filled with a solution of hydroxy ethyl cellulose (HEC). The phantom was tested in a 3T MR scanner (Verio, Siemens Healthcare, Erlangen, Germany) using a DC power supply which delivered 1 W for heating of the element. Temperature difference maps were calculated from the MR data using the PRF shift method [2] and a gradient echo pulse sequence (TR/TE= 15ms/4ms, 1mm x 1mm in plane resolution). Reference temperatures were measured by a fluoroptic sensor (Luxtron, LUMASENSE, Santa Clara, CA, USA) which was inserted vertically into the phantom.

In a second experiment we examined the focal zone of a commercial MR compatible HIFU transducer (H-108MRA, Sonic Concepts, Bothell, Washington, USA, active diameter 60 mm, focal length 50 mm, fundamental frequency f_0=2.45 MHz, electro acoustic efficiency η=0.545) using MR-thermometry. A cylindrical phantom (d=100 mm, h= 100 mm, prepared following the recipe given in [3]) was placed in a water filled Perspex box. The HIFU transducer was installed in the water, 2 cm above the phantom and was powered with 15W (acoustic) at a frequency of 2.45 MHz. Using the same gradient echo pulse sequence the focal zone was localized and from phase-difference images maps of the temperature increase were calculated. The transducer could be moved by a stepper motor attached via a 2-m long leverage (Fig.1). The controller unit of the motor was kept outside the RF cage to avoid artifacts. After sonication was started the transducer was moved at a speed of 2 mm/s along the gel phantom and MR data were acquired concurrently. This was done for variable acoustic powers with a maximum of 50W.

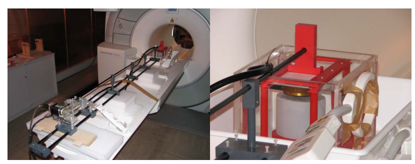

Fig.1: experimental setup

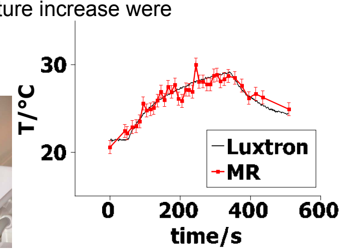

Fig.2: Heating curve measured by MR-thermometry (1 voxel) and fluoroptic sensor

Results

The resistive heating element produced a narrow temperature distribution with a high temperature gradient. The results of MR-thermometry were validated with the fluoroptic sensor. Apart from a linear drift correction of the MR data no further adjustments were needed to achieve quantitative agreement in the single voxel containing the sensor's tip (Fig.2). However, due to chemical reactions with the HEC solution, the resistivity of the heating element degraded substantially during consecutive runs.

Fig.3 (panels b-d) shows the distribution of the induced temperature change in the centre of the focal zone for static ultra-sound heating. In panels b) and c) the acoustic heating was still on while in d) the transducer had been shut off already. The broadening of the temperature profile with time due to thermal diffusion is clearly observed. In a second experiment the temperature distribution was measured during slow translational movement of the transducer. Motion artifacts appeared only on the edge of the phantom and did not occur in the zone of interest. An expected broadening of the heated area in the phantom was observed and due to the movement the temperature changes were smaller than for static sonication.

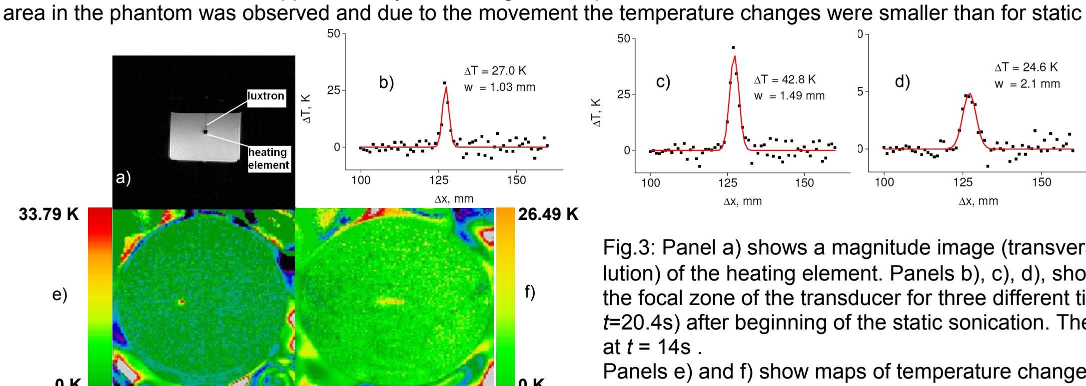

Fig.3: Panel a) shows a magnitude image (transversal cut, 1mmx1mm resolution) of the heating element. Panels b), c), d), show profiles of ΔT in the focal zone of the transducer for three different times (*t*=7.4s, *t*=13.4s, *t*=20.4s) after beginning of the static sonication. The transducer was turned off at *t* = 14s .
Panels e) and f) show maps of temperature change for static (e) and dynamic sonication (f).

Conclusions

We introduced a first approach towards a traceable calibration for the online monitoring of HIFU using a reference heating element. Concerning the structure and selection of material the element is still to be improved to make the measurements reproducible. With the help of the leverage we showed the feasibility of measuring high resolution temperature maps in the focal zone of a HIFU transducer using MR-thermometry.

References

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