MR-compatible small animal ultrasound hyperthermia system including matrix array transducers between 500 kHz and 2 MHz

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Background, Motivation and Objective

The mild elevation of the body temperature to approximately 42-43°C is known as hyperthermia. Focused ultrasound hyperthermia has the advantage of a high resolution, so that even very small volumes within the body can be heated without affecting surrounding tissue. This locally confined and reversible temperature increase does not cause permanent damage to tissue and has shown to be beneficious in a range of therapeutic applications. For instance, it enhances the local metabolic activity and improves drug delivery. Furthermore, it has been proven that mild hyperthermia improves the efficacy of subsequent radiation therapy. Although the effect was shown in different applications, it still is unclear which acoustic settings lead to an optimal therapeutic effect. In order to allow a systematic assessment of the influence of ultrasound of different parameters (burst length, exposure time, frequency, amplitude) on the resulting biological effect, we developed a hyperthermia system for small animal experiments. Since MR or PET-MR systems often are used to control the effects, our electronics and the US arrays are MR-compatible.

Statement of Contribution/Methods

The system consist of a multichannel electronics platform derived from an ultrasound imaging research system (DiPhAS, Fraunhofer IBMT). The device allows pulses with up to +/- 75 V and durations up to 50 µs at a PRF of up to 1 kHz. It is equipped with different matrix array transducers (11 x 11 elements, foot print of 1 cm x 1 cm) at frequencies of 500 kHz, 1 MHz, 1,5 MHz and 2 MHz. The arrays were designed in a flat shaped for integration in a small animal PET/MR system. This has been achieved by processing the piezoceramic material directly on the PCB used for array contacting. Copper shielding was used for improved EMC (electromagnetic compatibility).

Results/Discussion

We verified the steering capabilities of the arrays by measurement of the sound field in a water tank with a calibrated hydrophone (RP 50, RP Acoustics). A focus of approximately 1,3 mm / 6 mm (lateral and axial FWHM respectively) could be generated at arbitrary positions in the medium with an I_{SPTA} up to 5 W /cm². The size and the location of the focus were in good agreement with preliminary sound field simulations (performed with SCALP, sound field simulation tool by IBMT), with deviations below 300 µm for the sound field position. In a next step, we verified the feasibility of generating locally confined hyperthermia. Tissue mimicking phantoms based on PVCP were produced for this purpose. Local hotspots with a temperature increase by 10 °C with < 1 min could be demonstrated in the material. In a next step, experiments on ex-vivo tissue samples will be performed. The capability of our system for mild hyperthermia has been demonstrated, however, for generating a higher temperature increase and potentially being usable for ablation, the system will be improved by integrating multichannel amplifier electronics allowing duty cycles up to 100%.