Pre-Clinical Head-Mounted MRgFUS Device for Large Animals

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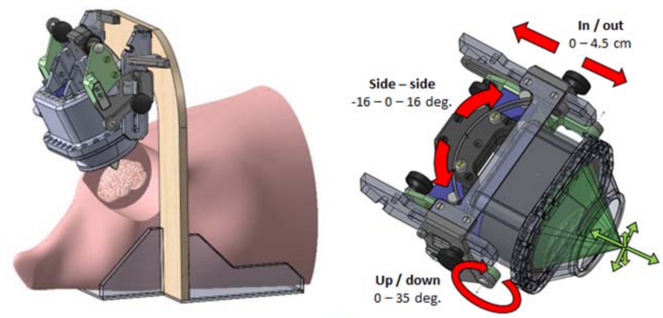
INTRODUCTION: The purpose of this work was to design, construct, and test a transcranial MRgFUS system for large animals. The primary design objective was to facilitate ultrasound coupling and transducer adjustability while maintaining the animal in a natural prone position. Although the presented experiments using the device test the feasibility of transcranial ultrasound procedures in a porcine model on a 3T MRI scanner, the device can be easily adapted for use on other large animals (and anatomy) of interest. The setup includes an over-the-head vertically-sonicating ultrasound transducer (Fig. 1a) and custom-built RF coils for visualization and real-time MR monitoring.

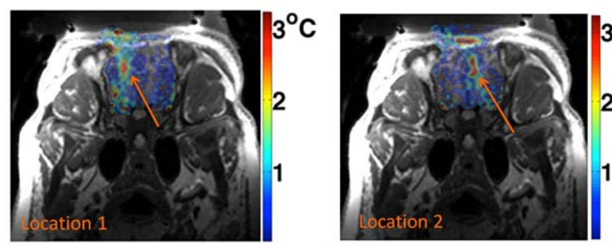
METHODS: The system houses a phased-array ultrasound transducer (f = 940 kHz, focal length = 10 cm, FWHM = 2x2x8 mm, 256 elements, Imasonics, Besancon, France). The transducer was surrounded with water within a 3D-printed waterproof container with an 11 cm wide aperture sealed with a latex membrane. Ports in the side of the transducer mount allowed for the release of any trapped air bubbles. The sealed transducer housing was coupled to the skin of the animal with ultrasonic gel (Fig. 1a). For this transcranial procedure, a craniotomy was performed on the pig to remove a 5x5 cm portion of the skull immediately atop the brain to allow unobstructed passage of the ultrasound beam. The acoustic window was surrounded by a custom-built seven-channel phased array RF coil for increased SNR. A multi-axis positioning mechanism supporting the transducer (Fig. 1b)[1], combined with phased electronic steering, allowed for a large treatment envelope of approximately 1000 cm^3 which covered the majority of the brain volume.

Two locations within the brain were targeted with low-level heating pulses to verify the position of the ultrasound focus while monitoring the sonication with MR thermometry. A 3D segmented EPI pulse sequence with gradient recalled echo read out was used for temperature monitoring (FOV=256x192x36 mm, Voxel spacing 2.0x2.0x3.0 mm zero-filled interpolated to 0.5x0.5x1.0 mm voxel spacing to mitigate partial volume effects, TR/TE=30.0/7.9 ms, ETL=9, flip angle=15°, t_{Tacq} =3.96 s, BW=1002 Hz/px, echo spacing=1.18ms) on a 3T MRI scanner (Tim Trio, Siemens Medical Solutions, Erlangen, Germany). The ultrasound was applied at 13W for 20 s in both locations.



(a) (b)

Figure 1. (a) Device setup, with animal in natural prone position. (b) Mechanical transducer adjustability for ~1000 cm^3 treatable volume.



(a) (b)

Figure 2. Targeted brain regions (arrows) exhibit heating. Images (a) and (b) show the time of peak temperature rise. Transducer is at top in both images.

RESULTS & DISCUSSION: Ultrasound heating was successfully observed and measured with 3D MR thermometry at the two targeted regions, accurately verifying ultrasound focus positioning (Fig. 2). The seven-channel RF coil phased array provided high SNR over the entire brain and top of the skull, enabling accurate temperature measurements, high resolution anatomical images, and the use of high readout bandwidth which minimizes off-resonance effects. Some near-field heating, equivalent to the heating seen at the focal spot, is observed at location 2 in the tissues between the transducer and the brain potentially due to air bubbles present below the skin.

CONCLUSIONS: An MR-guided FUS system for large animal applications has been developed and evaluated. The vertically-sonicating transducer placed on top of the animal head allows the animal to be maintained in a natural prone position, minimizing animal stress. The phased array RF coil setup ensures high SNR over the entire region of interest, and electronic steering in combination with the novel 3D mechanical positioning system enables a large treatment envelope covering the majority of the intra-cranial volume. In addition, this system is designed to be modular, so that different transducers with varied operating frequencies and aperture sizes could be evaluated in large animals.

REFERENCES: 1. Payne, et al., Med Phys, 2012. 39(3): p. 1552-60.

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