MR-ARFI for Characterizing transcranial FUS in the Rat Model

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Target Audience

This abstract is targeted to scientists, clinicians, and engineers who use transcranial focused ultrasound (FUS).

Purpose

Transcranial focused ultrasound (FUS) in a mouse model at low frequencies (< 1MHz) has previously ignored the effect of the skull[1]. However, quantitative neurostimulation or BBB studies of larger animal models with smaller focal spots, such as the rat model with a focused 2.3 MHz ultrasound beam, may not be able to ignore the effect of the skull on the focal spot characteristics. The purpose of this work was use MR-Acoustic Radiation Force Imaging (MR-ARFI) for quantifying the focal spot characteristics as a 2.3 MHz focused beam is steered to various locations in the brain.

Methods

Two rats were sonicated transcranially and electronically steering to five different locations laterally and at three different focal depths. Ultrasound was generated using the MR-compatible ExAblate 2100 2.3 MHz system (Insightec, Haifa, Israel) containing a 2980-element 2D phased array originally designed for prostate treatment. The experimental setup was placed inside the bore of a 3T MR system (GE, Waukesha, WI). An MR-ARFI sequence[2] shown in Figure 1 was used to acquire images encoded with the radiation force displacement. Images for analysis were generated by subtracting images taken with the gradients as shown and inverted. A custom rectangular surface coil was built to optimize image quality and avoid interference with the ultrasound beam path. The coil was placed on top of the rat head below the transducer, seen in Figure 2. Other imaging parameters included 8 cm FOV and 3 mm slice thickness.

Results

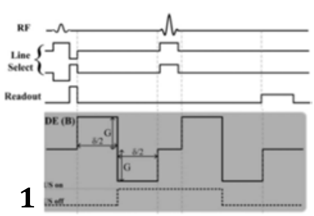
Figure 3 shows MR-ARFI of sonications electronically steered to five L/R locations, spaced by 1 mm. Figure 4 shows the L/R intensity profiles through the voxel of maximum displacement. Figure 5 shows coronal MR-ARFI of sonications at three different focal depths without lateral electronic steering. Figure 6 shows a three-line average profile through the focal region.

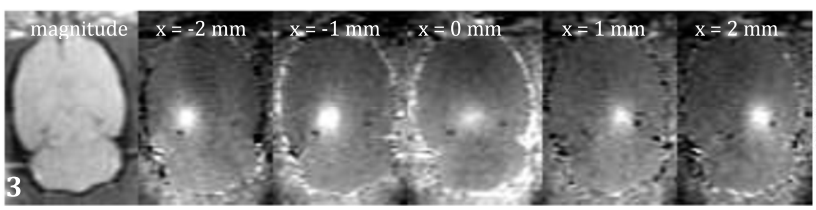
Discussion

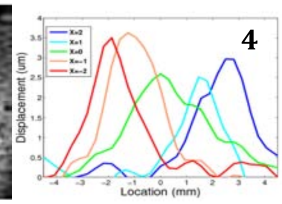
Focal spot intensity and size vary greatly with small changes in steering. Shifting the target spot laterally significantly changes the focal intensity and shape, most likely due to the varying bone thickness across the skull. We also observe that the lateral location of peak tissue displacement does not correspond exactly to the input electronic steering, suggesting that accurate targeting requires an iterative process. In Figure 3, we see a decrease in focal spot intensity and varying extent in the axial direction with decreasing focal depth. When the focal depth is closest to the top of the skull, most displacement occurs in the top portion of the skull. In contrast, when the focal spot is closest to the base of the skull, there is significant displacement throughout the entire depth of the skull. The variability in focal spot extent must be accounted for when targeting.

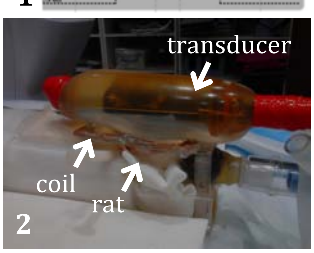
Conclusion

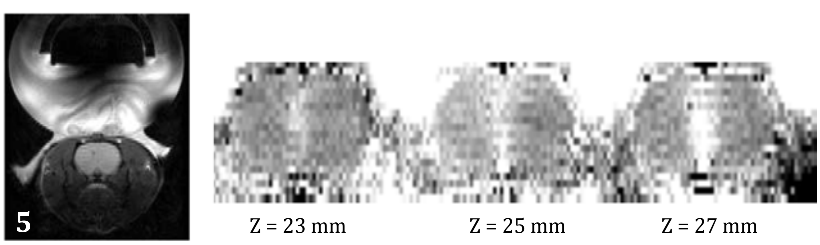
MR guidance of transcranial FUS using MR-ARFI allows for precise targeting of specific brain regions and visualization of the focal region. The target location itself can strongly affect focal intensity and size; assuming constant intensity and spot size can result in ultrasound dose error. MR-ARFI enables more accurate quantification of ultrasound physical effects for ultrasound neuromodulation and other transcranial FUS applications.

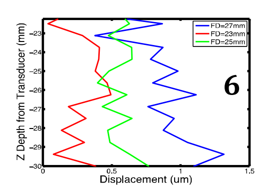












[1] King et. al. "Effective Parameters for Ultrasound-Induced In Vivo Neurostimulation." *Ultrasound in Medicine & Biology*. 39.2 (2013): 312-331.

[2] Chen et. al. "Optimization of encoding gradients for MR-ARFI." *Magnetic Resonance in Medicine* 63.4 (2010): 1050-1058.