Pre-clinical testing of a phased array ultrasound system for MRI-guided noninvasive surgery of the brain

K. Hynynen¹, G. Clement⁴, N. McDannold¹, R. King¹, P. J. White¹, F. A. Jolesz², S. Vitek², E. Zadicario²
¹Harvard Medical School/Brigham and Women's Hospital, Boston, MA, United States, ²InSightec, Haifa, Tirat Carmel, Israel

Abstract:

A prototype system designed for MRI-guided noninvasive thermal brain surgery was tested in preparation for clinical trials. The system consisted of a 0.75 MHz 500-element ultrasound array and had a complete driving system with software that allowed a CT scan of the skull to be registered on the MR image. The CT-derived geometry and density information were used to calculate a compensation factor for the bone-induced ultrasound wave distortions. This approach was tested in a phantom with ex vivo human skulls. Using MRI targeting and temperature measurements, the technique was used to produce sharp focal temperature elevations in the brain phantom.

Introduction:

Recently a technique was developed for focusing ultrasound through the human skull using bone data from CT scans of the head (1). With precise monitoring, this technique could potentially provide a completely noninvasive method for treating tumors and other brain disorders (2). In this study, a complete system designed for clinical focused ultrasound surgery was tested to establish the practical feasibility of the approach.

Methods:

The ultrasound system (InSightec) consisted of a hemispherical ultrasound array with 500 equal area elements and radius of curvature of 15 cm. The array was driven with 500 separate RF lines with independent amplitude and phase control. The array was connected to a three dimensional manual positioning device that allowed the array to be aimed in the target volume. The array was filled with degassed water that could be circulated through a temperature controller. Ex vivo human skulls filled with a phantom material that simulated both the ultrasound and the MRI properties of the brain was fixed with a holder simulating a patient’s head in front of the array. The holder was sealed to the transducer array with a plastic membrane, which allowed for a water layer between the skull and the array. The whole sonication set up was placed in a standard 1.5 T MRI scanner (GE Signa). At the beginning of the experiment, three sets of orthogonal FSE T2-weighted scans were obtained to localize the skull, the transducer array and the target volume in the brain phantom (figure 1).

The algorithm for focusing through the skull utilized derived information of the skull geometry and its localization (1). Data for the algorithm was obtained from a digitized profile of the skull obtained using CT images. Each skull was imaged with a Siemens SOMATOM CT Scanner (FOV = 20 cm, slice thickness = 1 mm). The CT and MRI images were co-registered by selecting three landmarks from each image set. An overlay display allowed visual inspection to evaluate the accuracy of the registration.

Experiments were performed by sonicating locations within the skull in the brain phantom while imaging the temperature elevation with the MRI. Temperature images were acquired in one plane from phase-difference images of a fast spoiled gradient echo sequence (3) (TR/TE = 39.3/19.3 ms, flip angle = 30°, bandwidth = 3.57 kHz, FOV = 32 cm, slice thickness = 3 mm, matrix size = 256x128, scan time = 5.3 s). A temperature sensitivity of −0.010 ppm/°C was used. A time series of temperature maps were produced.

Results:

Temperature rises were recorded inside three skulls both with, and without using the model correction. The model is observed to correct for aberration caused by the skull and to produce a sharp temperature elevation in the phantom (figure 2). The focal spot location was on average 3.2+/-1.5 mm away from the targeted location. This is small enough to allow the focus to be localized with the MRI with pre-treatment low power sonications.

Discussion:

This preliminary study demonstrated that the prototype clinical system can be used to sonicate in experimental conditions that simulate clinical treatments.

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References


Figure 1: Temperature images showing the focal heating obtained through a human skull in an MRI/ultrasound phantom. Left: axial, Right: sagittal.

Figure 2: T2-weighted images of a human skull and an MRI/ultrasound phantom placed in the clinical ultrasound device. Left: coronal, Right: sagittal.