A trans-rectal focused ultrasound probe for MR-guided ablation of the prostate

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Introduction:

Currently, the standard approach for MR imaging of the prostate employs trans-rectal probes that permit a small surface coil to be placed close to the prostate gland (1). The incorporation of small MR tracking coils (2) into such a probe allows the probe to be localized in real-time and to permit direct manipulation of the scan plane.

High Intensity Focused Ultrasound (HIFU) has been demonstrated as a viable method to deliver thermal ablation therapy deep into tissue structures without damage to surrounding tissues (3). Since little interaction exists between HIFU and MR, the use of HIFU for tissue ablation in an MR scanner is relatively straightforward. A significant challenge, however, is the ability to move the focal spot with a transducer that is small enough to be incorporated into a rectal probe.

We have incorporated an eight-element focused ultrasound transducer, three tracking coils and a high-quality MR imaging coil into a trans-rectal probe to create a device capable of generating high quality MRI images, fast real-time self-localization, high intensity focused ultrasound ablation and MR temperature monitoring.

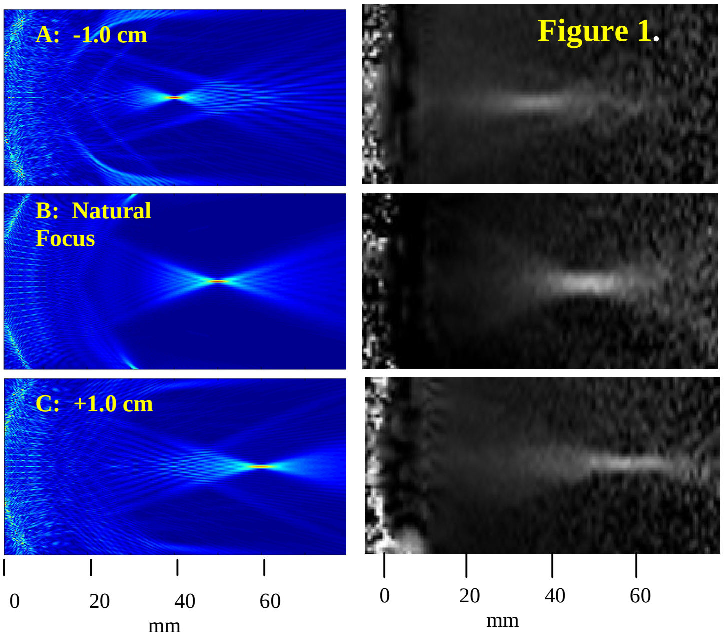
Figure 1.

Methods:

An eight-element high-powered transducer was constructed using PZT-4 Lead Zirconia Titanate. The element is 40mm long, 17mm wide, 0.5mm thick and has a 50mm radius of curvature. The transducer is impedance matched to its drive circuitry at 2.7 MHz and is operated at that frequency. The calculated acoustic field pattern at three focal depths is shown in Figure 1 (left column). This pattern is in excellent agreement with acoustic pressure maps made in a water tank (not shown).

A two-turn receive-only surface coil was built around the transducer. Interactions between the conductive transducer electrode surface and the surface coil were minimized by silver plating the transducer.

Three MR Tracking coils were placed in the housing behind the transducer (arrows in Figure 2). An MR-tracking pulse sequence was used to track the location of these three coils within the imaging volume and to control the imaging plane in real-time. The plane orthogonal to the three coils that contains the focal spot of the transducer (red triangle) was easily determined with the active MR tracking coils, and used to align the scan plane for thermal imaging.

The device was connected to a 1.5 Tesla MR scanner and was controlled using custom software and pulse sequences. The effect of the ultrasound transducer on the signal-to-noise ratio of the surface coil was evaluated. Ablations in an agar-gel phantom were performed to verify performance of the focused ultrasound transducer. Full control over the focal spot depth was demonstrated using phase-difference MR thermal imaging (Figure 1, right column).

Discussion:

MR imaging experiments verified the probe's ability to a) obtain high SNR images, b) locate itself (and hence the focal spot), c) manipulate the depth of the focal spot and d) obtain temperature-sensitive images. MR thermal imaging experiments showed excellent agreement with theoretical predictions. Through physical manipulation of the probe and electronic manipulation of the focal spot depth, almost full coverage of the human prostate gland is possible.

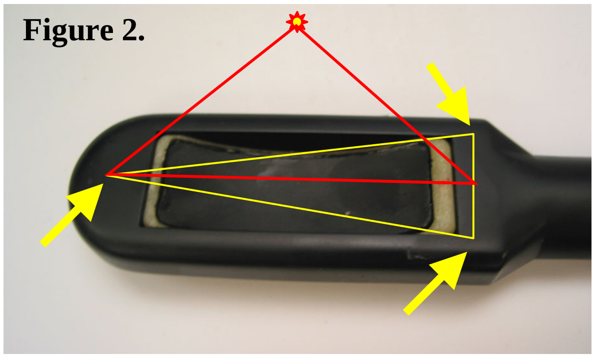
Figure 2.

Conclusions:

Although the device that we have built is intended for use in phantoms and animals, future versions of the device will be designed for clinical use. If the full potential of the device is realized, then one day MR-guided focused ultrasound ablation of prostate cancer and benign prostate hypertrophy (BPH) will be routine. Such an approach has the potential to be quicker and have lower morbidity than current practices.

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