Proton resonance frequency MRI shows focal spot shifts due to interfaces during MR-HIFU treatment

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Introduction: As more anatomical regions are added to the list of potential treatment areas for magnetic resonance guided high intensity focused ultrasound (MR-HIFU), it becomes imperative that full information is available to improve treatment planning and create safety guidelines. Heating at tissue interfaces (e.g. muscle/bone, bowel/air) is a serious clinical concern that has often been addressed by recommending a 4 cm safety margin. This heating is a result of differences in the acoustic properties of the materials: the speed of sound in bone and air, 3500 m/sec and 344 m/sec, respectively, varies significantly from that of water: 1540 m/sec. The differences in speed of sound cause an impedance mismatch at interfaces. The purpose of this study was to characterize changes in focal spot location and shape for sonications targeted close to tissue interfaces.

Methods: The effects of four different tissue interfaces on the HIFU heating pattern were investigated by using a thermal phantom (v_{sound} = 1536 m/sec, attn coeff = 0.5 dB/cm at 1.2 MHz and 23ºC). The Philips MR-HIFU clinical platform was used for sonications and MR guidance. Images were acquired using a 3D T2-weighted sequence (TR/TE = 1000/80 msec, voxel size = 1.09 mm) for treatment planning. Dynamic temperature monitoring based on changes in proton resonance frequency was performed using 2D EPI with reconstructed voxel size of 1.25 mm in-plane, and temporal resolution of 2.9 sec. A thermal phantom, approximately 8 cm tall, was coupled to the treatment table's mylar membrane using distilled water, and volumetric sonications (4 mm treatment cell diameter) were defined at each of three positions: 4 cm, 2 cm, and 1 cm below the interface. Each treatment cell location was sonicated for 20 sec at 50 watts, 1.195 MHz. Sonications were performed for four interface materials: air, acrylic (to model bone), rubber, and a non-absorbing gel pad used in clinical uterine fibroid trials to mimic water for acoustically coupling the patient to the transducer. Data were processed and analyzed using software written in IDL.

Results: Heating patterns are displayed as color maps in Figure 1. The slices shown were acquired just prior to the end of the 20 sec sonication. Depth from interface to treatment cell varies from left to right at 4, 2, 1 cm respectively. The materials are as labeled. The Table reports how much the center of the focal spot shifted towards the interface. The air, acrylic and rubber interfaces all cause the heating focus to shift further towards the interface as the treatment cell is placed closer to the interface. Figure 2 shows a preclinical example of a rabbit's leg where a tissue region was left exposed to air and a blister resulted.

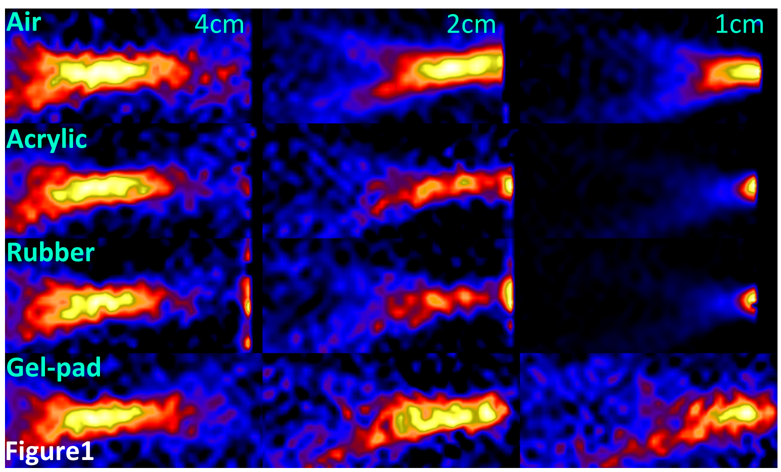

Figure1


Figure 2

Focal from interface	Distance shifted toward interface (mm)			
	Air	Bone	Rubber	Gel
1 cm	2.7	3.1	2.1	1.1
2 cm	1.8	1.4	1.1	0.7
4 cm	0.0	0.0	0.0	0.0

Discussion: The heating patterns illustrate how the lesion shape shifts closer to the interface at the sonication positions closest to the interface. Heating outside of the prescribed treatment cell at or near the interface is seen for both acrylic and rubber interfaces at distances of 2 cm or less. Reflections from bone and air interfaces, while significant, are not exceptionally different from the rubber interface. In fact, rubber more closely resembles acrylic than it does air. This difference can be attributed to the ability of both acrylic and air to absorb more energy than air, resulting in more heat at the interface, and less of a reflected tail. Rubber, which is sometimes used as an absorber, is shown here to work poorly as a shield from skin burns on the distal side of the subject. A water-mimicking gel pad is the best material for maintaining cell treatment shape, which is unsurprising.