DESIGN AND DEVELOPMENT OF A PROTOTYPE ENDOCAVITARY PROBE FOR HIGH INTENSITY FOCUSED ULTRASOUND DELIVERY WITH MAGNETIC RESONANCE IMAGING THERMOMETRY AND GUIDANCE

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INTRODUCTION MR techniques, which demonstrate changes associated with High Intensity Focussed Ultrasound tissue ablation may be useful for intraprocedural guidance and exposure determination. Endocavitary MR imaging is a well-established, routine diagnostic investigation in prostate cancer. The purpose of this study was to develop an endocavitary probe comprising an MR compatible HIFU transducer integrated with an MR receiver coil for MR guided thermal ablation.

MATERIALS AND METHODS ***Probe design:*** This was based on a previously described solid endorectal MR receiver coil (1, Fig. 1). Cable connections for HIFU transducer and receiver coil and irrigation tubes passed through the handle. ***MR compatibility of HIFU transducers:*** MR characteristics of a piezoceramic material routinely used in HIFU transducers were compared with a piezocomposite. Piezoceramic contains nickel, which is ferromagnetic but permits the transducer to handle the high levels of electrical excitation and mechanical stress required to produce high ultrasound intensities. The same is true for the bismuth sulphate paste used to bond the silver flake coating necessary for electrical connection to the ceramic tile. The silver coating may also induce eddy currents and lead to image artefact. The silvered surface of the ceramic therefore was divided into 4 equal-sized electrically isolated elements. Imaging was carried out on a 1.5 T Siemens Vision. GRE sequences (TR=800 ms, TE=26 ms, FA 30^0) and T_1-W and phase temperature-sensitive Sliding Window Dual-echo GRE (SW-dGRE) sequences, (TR=35ms, TE's=9.1ms, 31.8 ms) were used (2). Multi-slice images transverse and coronal to the transducer element were obtained and magnitude and phase reconstructions done. ***HIFU transducer beam characteristic:*** HIFU transducers were calibrated using complex impedance measurement, pressure distribution plotting and acoustic power measurement. The real component of the complex electrical impedance of the piezocomposite transducer (1.46 MHz) was ~33 Ω. For these "truncated circle" shaped transducers (43mm diameter x 21mm) the focal region was ellipsoidal ~10.2 x 3.0 x 1.4mm (-6dB beam width). Acoustic power output was determined in degassed water. Free field spatial peak intensities were obtained above the 1500W/cm^2 needed for tissue ablation (3). ***Cooling System:*** Transducer cooling was investigated. The probe containing a water-filled plastic tubing was placed in a water bath maintained at 70^{o}C. A thermocouple on the front of the transducer verified temperature equilibration. The probe was then transferred to a water bath at 37^{o}C and circulation of cooled water (12^{o}C) through the plastic tubing begun. Temperature measurements were obtained at 5s intervals for 350s. Cooling rates between 10 and 100 ml/min in 10ml/min increments were investigated. ***MR Receiver Coil:*** MR receive only coils were constructed (6.5 X 2.5 cm rectangular design) and located in a probe housing outside and above the edge of the ultrasound transducer (Fig. 1) to minimize ultrasound field disturbance. The special housing permitted endocavitary insertion. A purpose-built MR phantom was used to measure signal to noise ratio (SNR) at a point where the HIFU focus would be expected (4cm from the transducer surface). ***Ex-vivo temperature measurements:*** Temperature sensitive SW-dGRE sequences were used to obtain baseline T1 measurements and a T1-W image and phase data provided thermal measurements every 1.4 seconds during HIFU heating and cooling. Subtherapeutic "siting" shots were investigated in which high intensity (2400 W cm^{-2}) short duration (<1.5s) exposures were used to obtain temperature rises of <5^{o}C. Such shots would be used to establish the position of the focus in tissue prior to an ablative exposure. Lesion formation was also monitored using high intensity exposures (1750 W cm^{-2}) for longer duration (6s).

RESULTS ***Transducer MR compatibility:*** A dramatic reduction in the magnitude of the rf eddy currents was achieved by quartering the conducting area of the piezoceramic transducer. SNR on T1-W images at the 4cm focal plane of the transducer was 40% greater using the quartered transducer. (95.9 vs. 68.1). With the SW-dGRE sequence the improvement was 32.6%. MR compatibility (phase variations) of the piezocomposite was significantly better than the piezoceramic. ***Cooling system:*** Up to 11^{o}C cooling in 10s could be achieved, optimal flow rate 50 ml/min. *In vivo* the 150 ml water reservoir would not exceed body temperature; furthermore the duration of HIFU exposure (<10s) would not lead to temperatures as high as 70^{o}C. Therefore this cooling technique should prevent significant HIFU source heating during use *in vivo*. ***MR receiver coil performance:*** SNR for the endocavitary coils at the focal point (4cm) of the HIFU transducer were 3 times greater than those for the body array coil (endocavitary coil SNR=637; body array SNR=205). The reduction in Q factor seen with the piezocomposite transducer did not translate to a measurable reduction in SNR. ***Ex Vivo heating experiments:*** The ability to produce phase images capable of detecting small (<5˚C temperature rises) was demonstrated (Fig 2). Implementation of local shimming in the volume of the image slice produced phase images with greater phase uniformity. Thus this approach is recommended for future use.

Figure 1 HIFU probe with MR receive only coil mounted around it in a casing designed for endocavitary insertion

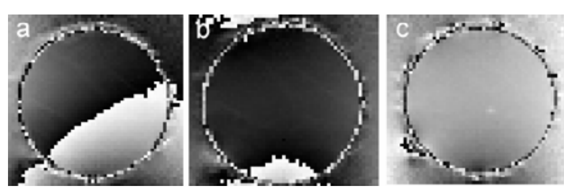

Figure 2 *Ex vivo heating experiments with MR monitoring:* Phase images without shimming (a), with shimming (b), with shimming and during HIFU exposure (c) using a Sliding Window Dual-echo Gradient Echo sequence, (TR=35ms, TE's=9.1ms, 31.8ms). There is marked improvement in homogeneity in b compared to a. In c the area of elevated temperature appears as a small white spot slightly off centre within the sample. The ring is the Perspex holder used to contain the *ex-vivo* liver sample.

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