Targeted treatment of localized regions within the prostate gland using MRI-guided transurethral ultrasound therapy

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INTRODUCTION

Due to the widespread use of PSA screening and biopsy, an increasing number of men are being diagnosed with low-grade localized prostate cancer. This presents a dilemma for both patients and clinicians due to the significant complications associated with conventional therapies. A minimally-invasive therapy for localized prostate cancer capable of treating targeted volumes within the gland could be an important option for this population. A promising method for the treatment of localized prostate cancer is MRI-guided transurethral ultrasound therapy [1,2], in which a rotating applicator delivers high intensity ultrasound energy to the prostate from the urethra to generate a targeted region of thermal damage in the gland. Magnetic resonance imaging (MRI) is used to measure the spatial temperature distribution in the prostate and surrounding tissues non-invasively during treatment. Accurate measurement of the spatial heating pattern during heating can be used to deliver a precisely shaped energy pattern to a target volume of tissue [3, 4]. Although the advantages of using MR thermometry for active feedback and control are clear, a major barrier in adapting this technology is the difficulty of integrating the heating technology with an MR imaging system without significant interference between both systems. We have recently developed a unique system for MRI-guided transurethral prostate thermal therapy that incorporates real-time active temperature feedback to generate precise volumes of tissue coagulation. The goal of this study was to evaluate the capability to generate a targeted region of thermal damage within the prostate gland using this system.

METHODS

MRI-compatible treatment system: The system described in this paper generates heating within the prostate gland from a transurethral heating applicator incorporating planar ultrasound transducers. Coverage of the entire prostate gland is achieved by rotating the applicator, accomplished with an MRI-compatible positioning system. The system is designed to operate within a standard clinical 1.5T MR imager (Figure 1), which we have determined previously is capable of measuring the temperature distribution during heating with sufficient temporal and spatial resolution for use as active feedback [5].

Heating Experiments in vivo: Transurethral ultrasound therapy was performed in a canine prostate model (n=5). Heating applicators were inserted into the prostatic urethra through a perineal urethrostomy, and a cooling device was placed in the rectum to cool the rectal wall during treatment. A region of the prostate was selected based on previously-acquired MR images and subsequently treated with active MR temperature feedback throughout the therapy. The temperature distribution was measured using the Proton Resonant Frequency Shift (PRF) method of thermometry, and the measurements were used to adjust the output from the transurethral heating applicators to achieve a temperature of 55°C (sufficient for thermal coagulation) along the target treatment boundary. All images were acquired in a single plane transverse to the heating applicator in the plane of rotation. A gradient echo imaging sequence with a temporal resolution of 5 seconds (FSPGR, TE/TR=10/38.5ms, θ=30°, 128x128, slice=10mm) was used to make the temperature measurements. A single transducer was used in these experiments; hence, control over the shape of the heating pattern was only achieved in the plane of rotation. Animals were sacrificed immediately after treatment, and the prostates and rectal tissue were harvested. Detailed histology of the treated region was performed to compare with the imaging measurements.

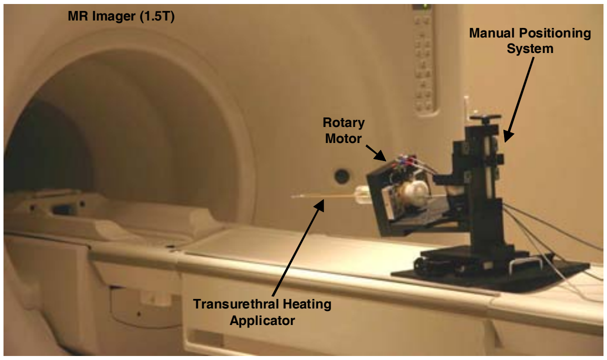

Figure 1: MRI-compatible positioning system and transurethral heating applicator attached to the patient table of a clinical MR imager

RESULTS

Accurate visualization of the prostate gland and localization of heating applicators was achieved using MRI. The MR temperature measurements acquired during heating were very stable, with an uncertainty of approximately 1°C over the course of the treatment. The treatments lasted approximately 15 minutes, and over 50% of the gland was targeted and treated. The error between the 55°C isotherm achieved in the prostate and the desired target boundary was ±1.2mm (~one pixel). Figure 2 (left) shows the maximum temperature distribution measured after treatment with the 55° isotherm shown (dotted line) in reference to the target boundary (solid line). The treatment was designed to extend to the posterior boundary of the prostate gland adjacent to the rectal wall. The contrast enhanced image acquired after treatment is also shown in the figure (right). Two boundaries of thermal damage were defined on subsequent H&E stained tissue sections corresponding to complete thermal coagulation (100% cell kill), and normal appearing prostate tissue (0% cell kill). After careful image registration, the maximum temperature achieved along these boundaries was found to be 55±2°C (100% boundary) and 50±2°C (0% boundary). Histopathology of the rectal tissues confirmed that the cooling protected it from thermal damage during therapy. In the absence of cooling damage was observed in the rectal wall.

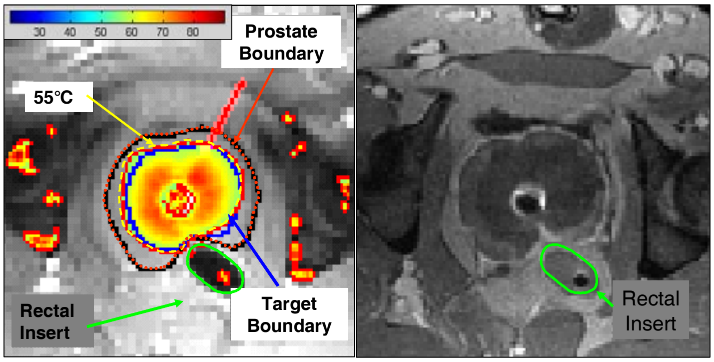

Figure 2: (left) Maximum temperature distribution measured during treatment superimposed on the prostate and target boundary. (right) Contrast enhanced MR image acquired after treatment depicts the region of thermal damage.

CONCLUSIONS

MRI-guided transurethral ultrasound therapy is feasible in a closed-bore 1.5T MR imager. Quantitative measurements of the spatial temperature distribution can be obtained throughout the treatment and can be used to control a precise volume of thermal damage within the prostate. Accurate coagulation of targeted regions of the prostate can be achieved rapidly and safely using this technology.

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