Spatial and temporal accuracy of Heating using MRI-guided transurethral ultrasound therapy and active MR temperature feedback

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Introduction

Prostate cancer is the most commonly diagnosed and the third-leading cause of cancer related deaths among Canadian men [1]. Conventional therapies for prostate cancer, prostatectomy and radiotherapy, have high rates of undesirable side-effects and can affect the quality of life of patients significantly [2]. Minimally invasive treatments for localized prostate cancer that can achieve local control with reduced complications to surrounding tissues would be a significant contribution to the management of this disease. One such approach for the treatment of localized prostate cancer is MRI-guided transurethral ultrasound therapy. A device inserted into the urethra delivers high-intensity ultrasound energy to the adjacent prostate tissue to generate a targeted region of thermal coagulation 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, and this information can be used to deliver a precisely shaped energy pattern to a target volume of tissue. The capability for real-time measurement of the temperature distribution in the prostate gland enables adaptive therapy delivery that can compensate for changes in blood flow or ultrasound properties of prostate gland that are known to occur during heating. We have developed a system for MRI-guided transurethral ultrasound therapy that is designed for use in a closed-bore MRI. The purpose of this study was to evaluate the accuracy of heating in the prostate gland using active MR temperature feedback during transurethral ultrasound therapy.

Methods

A prototype MRI-compatible transurethral ultrasound therapy system was used in this study consisting of a transurethral heating applicator comprised of a single element planar ultrasound transducer (4.8x19mm). Rotation of the device during heating was controlled by a custom-built MRI-compatible rotary motor. The acoustic efficiency of the transducer was measured to be 57±5% with a radiation force balance, and a maximum acoustic power of 7.5 W was delivered for all experiments. MRI-guided transurethral ultrasound therapy was performed in five dogs to demonstrate the capability to generate targeted regions of thermal damage within the prostate gland using active MR temperature feedback. The dogs were placed supine on a custom made cradle in a 1.5T MR imager (Signa, GE Healthcare) and a four channel surface coil was placed anterior and posterior to the animal at the location of the pelvis. MR thermometry was performed using a spoiled gradient-echo sequence (TE 10ms, TR 38ms, 128x128, 9mm slice, 20cm FOV) with a temporal resolution of 5seconds and a temperature resolution of approximately 1°C in the prostate gland. The proton resonant frequency shift technique was used to calculate the temperature changes using a subtraction approach. The temperature maps were analyzed along the direction of the ultrasound beam during heating, and the output parameters of the heating applicator were adjusted in order to achieve a target temperature of 55ºC along the target boundary. The target boundary was chosen off T2-weighted anatomical images of the prostate gland prior to treatment.
A device with circulating water (room temperature) was inserted into the rectum to maintain these tissues at protective temperatures during treatment. To eliminate errors in the temperature estimation due to thermal gradients around the rectal device the flow of water through the rectal cooling device was not started until after the baseline image was acquired.

Results

Figure 1 shows the capability to shape the spatial heating pattern to the target boundary in the prostate gland. The 55°C isotherm qualitatively matches the target boundary in the figure. The radial difference between the target boundary and the 55°C isotherm across five experiments as a function of the target boundary radius is given in Figure 2. The error is greatest for short radii (<10mm), often found in the vicinity of the rectum. Figure 3 shows the consistent heating profile measured along the target boundary across all feedback experiments. The mean peak temperature was approximately 55.6°C across all experiment. In addition, although this method of heating uses an unfocused ultrasound beam, a rapid rate of heating is observed along the target boundary.

Conclusion

The feasibility of using active temperature feedback to achieve targeted heating in the prostate gland has been demonstrated through the canine experiments described in this study. Excellent targeting of thermal damage was observed, with a slight increase in the error for short target boundary radii (<10mm). The temperature profile produced along the target boundary was consistent across multiple experiments with a maximum temperature of 55.6°C.

References

1. Canadian Cancer Society, http://www.cancer.ca. 2. Potosky, *et al.*, JNCI, 2004. 3. Chopra, *et al.*, Phys Med Biol, 2006. .

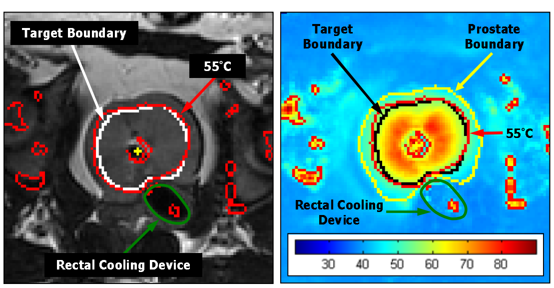

Figure 1: *Results of MRI-guided transurethral ultrasound therapy in-vivo. The spatial heating pattern produced in the prostate gland matched the target region, with good agreement between the 55°C isotherm and the target boundary.*

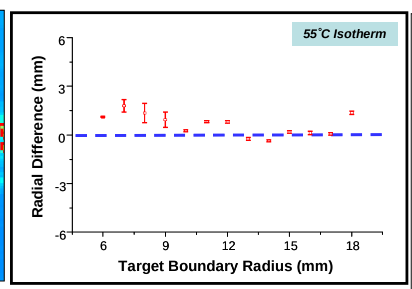

Figure 2: *The targeting capability was measured as the distance between the target boundary and the 55°C. Excellent targeting was achieved with a slight increase in error for radii <10mm*

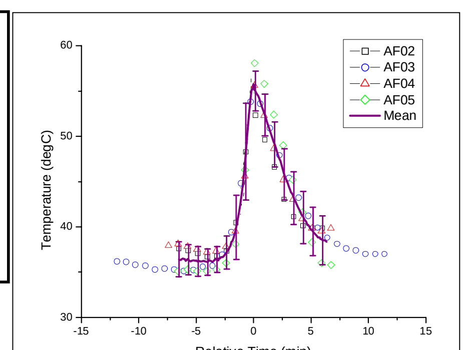

Figure 3: *The temperature profile along the target boundary for multiple canine experiments depicts a well-controlled heating using this technology.*