Spatial and temporal accuracy of MR thermometry during MRI-guided prostate thermal therapy

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INTRODUCTION

A promising method for the treatment of localized prostate cancer is MRI-guided transurethral ultrasound therapy, in which heating applicators deliver high intensity ultrasound energy to the prostate from the urethra to generate a targeted region of thermal damage in the gland. This requires heating technology with precise control over the spatial deposition of energy, as well as the capability to monitor the spatial heating pattern generated in tissue. Magnetic resonance imaging (MRI) has the unique capability to perform quantitative thermometry non-invasively. Accurate measurement of the spatial heating pattern in tissue during heating can be used to deliver a precisely shaped energy pattern to a target volume of tissue [1,2]. We recently described a method for conformal prostate thermal therapy using transurethral ultrasound heating applicators and MR temperature feedback [3,4]. Although the advantages of using MR thermometry for active feedback and control are clear, it is imperative that the temperatures measured with MRI during treatment be accurate. The goal of this study was to evaluate the effect of the transurethral heating applicators on the measured temperature distribution with MRI. In addition, the potential to obtain quantitative and stable temperature measurements with MR thermometry in the prostate for the duration of a typical treatment (~15 minutes) was evaluated in a canine model.

METHODS

All of the experiments described in this study were performed in a clinical-grade 1.5 Tesla closed-bore MR imager (Signa, GE Healthcare). MR thermometry was performed using the Proton Resonant Frequency (PRF) shift method [5], using a gradient echo imaging sequence (FSPGR, TE/TR=10/38.5ms, θ=30°, 128x128, slice=10mm). A head coil was used in the phantom experiments, and a four-channel surface coil array was used in the canine experiments.

A. Impact of treatment delivery system: Although the applicator is constructed from MRI-compatible materials, there still exists a local distortion of the magnetic field around the device that contributes to the background phase distribution. The contribution is not symmetrical; thus, the spatial phase distribution changes as the device is rotated. The effect of this changing phase distribution is that the image subtraction performed in the PRF method results in false temperature changes. The impact of device rotation on the measured temperature distribution was evaluated by acquiring a series of images (using the parameters listed above) in a water-filled phantom while the heating applicator was rotated at a constant rate of 1°/second. No ultrasound energy was delivered in this experiment; thus, any measured phase changes could be described as artifacts arising from the rotation of the heating applicator itself. The images were acquired every 5 seconds, transverse to the axis of the applicator (in the plane of rotation). Phase difference images were calculated through the complex subtraction of a reference image obtained prior to rotating the heating applicator from each image acquired during rotation.

B. Stability of MR prostate thermometry: A series of experiments was performed in a canine prostate model (n=5) to evaluate the capability to generate a targeted region of thermal damage using active MR temperature feedback. A transurethral heating applicator was inserted into the prostate gland, and ultrasound energy was delivered and adjusted based on the measured temperature distribution. Axial MR images were acquired every 5 seconds throughout the treatment to measure the heating pattern in the plane of rotation of the device. Restraints were used to minimize any respiratory-induced motion of the pelvic wall during heating, and an antispasmodic drug (Buscopan®) was injected prior to treatment to stop any peristalsis of the GI tract, including the rectum. The stability of the MR thermometry was evaluated by measuring the temperature at three discrete regions of interest (5x5 pixels) in the images. One region was chosen near the anterior surface of the animal, where the effects of motion due to breathing were most likely to occur. Another point was chosen in the muscle near the back of the animal where little motion was expected to occur. The final region was chosen inside a tube of mineral oil placed under the animal during the treatment which served as a field drift reference.

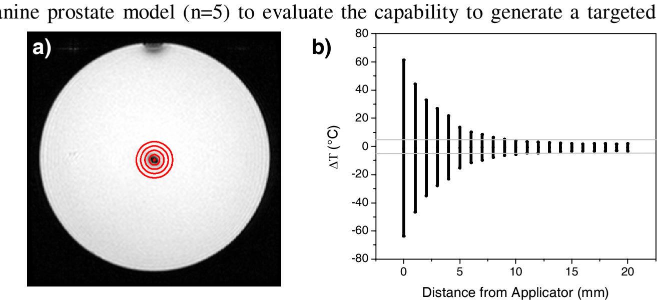

Figure 1: Analysis of the errors in the measured temperature as a function of distance from the heating applicator at 1.5 Tesla.

RESULTS

Figure 1a) shows the magnitude image of the water-filled phantom obtained during device rotation. The temperature was measured at various radii shown as rings in the image. The range of temperatures observed around the applicator as a function of distance from the device is shown in b). It is clear from the figure that large errors in the measured temperature are present in the first 5 mm from the surface of the applicator. Beyond 10mm from the applicator the impact of the heating applicator is no longer significant. All of these measured temperatures represent artifacts arising from the rotation of the device. Figure 2 shows the measured temperature change at the three locations in the image. The effect of respiration can still be seen in the top ROI, resulting in a periodic temperature change with a range of ~3°C. The temperatures measured at the back of the animal were very stable throughout the treatment, and were very similar to the measurements obtained in the reference tube.

SUMMARY

The capability to make accurate temperature measurements with MR thermometry is an essential requirement when considering treatments incorporating active temperature feedback. Results from this study indicate that the transurethral heating applicators produce local field variations which result in large temperature uncertainties within a few millimeters from the device. Beyond 10mm, this effect is negligible, and accurate spatial temperature measurements are possible using a standard subtraction technique. Analysis of the temperature history *in vivo* demonstrated the capability to obtain stable temperature measurements for up to 15 minutes in duration. These results suggest that MR thermometry can be used for MRI-guided transurethral ultrasound therapy at 1.5 Tesla. Further study of the influence of field strength and device orientation is underway.

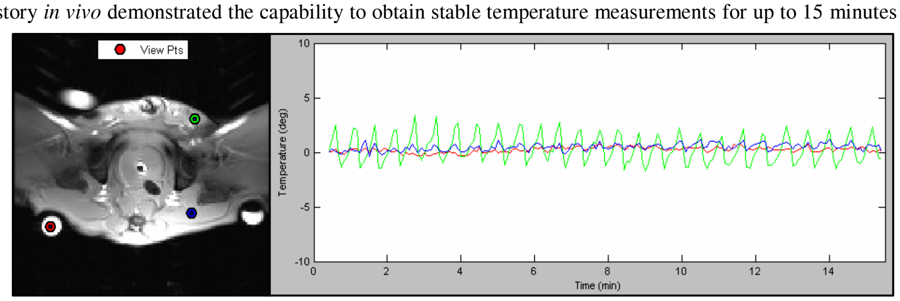

Figure 2: Temperature stability measured *in vivo* during transurethral ultrasound therapy

REFERENCES

[1] F. C. Vimeux et al, *Invest. Radiol.,* 34, 190-193, 1999.
[2] D. Arora et al, *IEEE Trans. Biomed. Eng.,* 52, 191-200, 2005.
[3] R. Chopra et al, *Phys Med Biol,* 50, 4957-4975, 2005.
[4] R. Chopra et al, *Phys Med Biol,* 51, 827-844, 2006.
[5] Y. Ishihara et al, *Magn. Reson. Med.,* 34, 814-823, 1995.