Multislice Treatment Planning and Control for Real Time MR-Guided Prostate Ablation with Transurethral Multisectored Ultrasound Applicators

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Introduction: Targeted prostate ablation with transurethral multisectored ultrasound applicators could be improved with an integrated imaging platform that minimizes procedural setup and treatment time, and can guide the therapy delivery with real-time temperature feedback control. The purpose of this work was to provide this by integrating device localization, prostate-specific planning tools, and multi-slice MR thermometry into a single imaging platform. The system also allows temperature feedback control points to be transferred externally for automated feedback control of ultrasound power levels. Here, we describe this platform and validate it in various phantom experiments.

Methods: The system is based on RTHawk (HeartVista Inc, Los Altos, CA), a flexible real time environment and interventional platform [1]. RTHawk allows for the ability to switch between sequences instantaneously, and also for the creation of sequence specific reconstructions and feedback. A custom graphical user interface was developed as an extension to RTHawk for seamless pulse sequence integration with prostate treatment planning and monitoring.

Three pulse sequences and their reconstructions were incorporated into our prostate ablation platform: a "scout" scan consisting of a fast GRE that provided images every half second, a gradient echo (GRE) sequence with a longer TE for temperature imaging, and a phase-dithered Hadamard-encoded tracking sequence used to locate tracking coils placed on the catheter of the device [2].

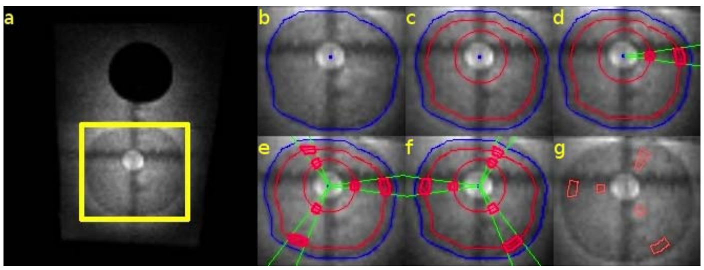

Figure 1: Treatment planning. The inset of (a), a prostate phantom, is shown in (b) through (g). First, the prostate boundary is defined, as well as the center of the applicator per slice (b). Next, the treatment ROI center for each boundary is defined (c). The angle of the desired ROIs and the width are defined (d), followed by the number (e). These ROIs can be rotated around the applicator, following the defined treatment monitoring paths (f). Finally, the ROIs are confirmed (g) and ready to send data to the power control software.

For device positioning, transurethral ultrasound catheters are equipped with MR tracking coils on either side of the transducer elements. In the software, a scout scan is combined with the tracking sequence with the images piped to a monitor inside the magnet room. Inside the magnet room, the physician additionally has access to multiple functions such as pausing, pinging the tracking sequence to reposition the imaging plane, and changing the imaging plane with respect to the device. Once the device is located, slices normal to the catheter are prescribed (3-5), as well as two cross sections through it. These slice locations are then used for multi-slice imaging through the prostate with the temperature sequence. Each slice's position and orientation can be individually adjusted as necessary.

The three normal slices and/or sagittal/coronal through the device are then used for treatment prescription and control. Two sets of treatment control regions of interest (ROIs) per transducer sector are defined according to distances from the device and final treatment boundary. The ROIs are defined as sectors along these boundaries with a defined width, and the sectors/ROIs can rotate around the device. Temperature information from these ROIs is sent to the software controlling the ultrasound power. Figure 1 shows a progression through the various ROI steps on a prostate phantom (Model 053-MM, CIRS Inc, Norfolk, VA).

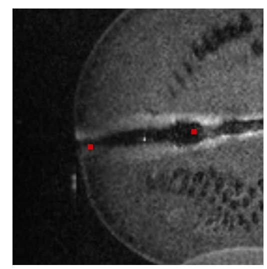

Figure 2: Image of catheter with two tracking coils inside a phantom. The red dots are the coil locations calculated with the MR tracking sequence.

The catheter tracking and multi-slice thermometry were tested separately to demonstrate their functionality. A catheter with two tracking coils was inserted into another phantom, placed in a GE Signa Excite 3.0T scanner (GE Healthcare, Waukesha, WI), and imaged with a 3" and 5" set of surface coils. Our software was then used to determine the tracking coil locations and display a slice through both, centered at the halfway position.

In the second experiment, two interstitial ultrasound applicators were placed inside a gel phantom. Three slices transverse to the applicators and two slices along the applicators were acquired. ROIs were defined in the transverse images, and the mean temperatures in these regions were transmitted to the power control software, which then controlled how the ablations proceeded. The external feedback control software was implemented to (1) regulate peak temperatures and (2) terminate treatment when the desired target volume was adequately heated. A proportional-integral controller was used to modulate power supplied to each transducer, such that maximum temperatures associated with the transducers did not exceed 75°C. Temperatures in the ROIs along the target boundary were monitored during ablation, and power to the corresponding transducers was shut-off once adequate heating was achieved.

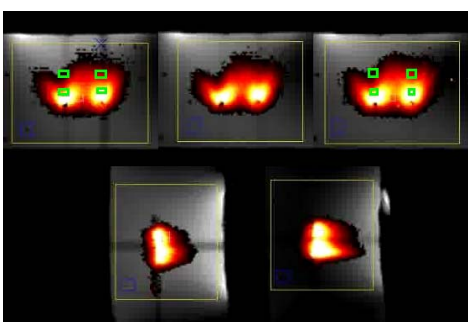

Figure 3: Example heating experiment image using two interstitial ultrasound applicators. Images are acquired transverse to the catheter (top row) and along the catheter (bottom row). The displayed temperatures range from 1-20°C above baseline. The ROIs in green were utilized by the external power control software.

Results: Figure 2 shows the image from the MR tracking validation. The red dots signify the position of the tracking coils with respect to the phantom image, successfully determining their locations. Figure 3 shows images from the phantom sonication. Throughout the ablation, the software successfully sent the temperature data in the ROIs to the external power control software as heat was building up inside the phantom. The power control software monitored the temperatures in the ROIs, eventually shutting off the elements. In this experiment, the GRE sequence parameters of TE = 5.77ms and TR = 60ms allowed for all slices to be fully imaged in 7.7 seconds, although faster dynamic images could be obtained using a sliding window reconstruction. This scan time is sufficient, given the multisectored device is stationary during treatments that typically last 5-15 minutes, and potentially more slices could be included.

Conclusions: We have introduced a real time, MRI software package complete with catheter localization and multi-slice treatment prescription and monitoring. Even though our experiments highlight separate phases of the software, all are integrated such that only this single application (and thus scanner sequence) is necessary to complete a successful transurethral prostate ablation. Our next step will be demonstrating this in an *in vivo* ablation.

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References:

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2. Dumoulin CL, Mallozzi RP, Darrow RD, Schmidt EJ. Phase-Field Dithering for Active Catheter Tracking. Magnetic Resonance in Medicine, accepted, in press.