Feasibility and Functionality of Quantitative Real-time Monitoring During MRI-guided Percutaneous Cryoablation

Jonathan Scalera[1], Gary P. Zientara[2], and Kumal Tuncali[1]

[1]*Brigham and Women's Hospital, Boston, MA, United States,* [2]*US Army Research Institute of Environmental Medicine, Natick, MA, United States*

Purpose: A successful percutaneous ablation must meet three main objectives: to eradicate the target tumor, minimize ablation of surrounding normal parenchyma, and reduce risk of injury to nearby critical structures. Currently, interventionalists rely on their own subjective assessment of pre-, intra- and post-procedural images to determine whether these goals are met. In order to improve the safety and outcomes of these procedures, we developed a quantitative computerized method for monitoring and measuring ablation performance in real-time in order to provide an objective, precise and reproducible assessment of the ablation's efficacy.

Methods: Prior research efforts at our institution[1] had already developed automatic probe detection[2,3] and ice ball segmentation[4] methods. Our objective was to combine these elements to create and evaluate an integrated intra-procedural software package for quantitative real-time monitoring and display of MRI-guided cryoablation procedures. We implemented a novel, unified software package with a graphical user interface (GUI) (Figure 1) for monitoring of MRI-guided cryoablation in real-time. We assessed its feasibility within the workflow of renal tumor ablation cases at our institution. Under an IRB-approved protocol, we retrospectively applied our computerized monitoring tool to intra-procedural 3T HASTE images from 13 kidney tumor cryoablation procedures in 13 patients (6 male; mean age=73 years; mean tumor size=2.0 cm, range:1.3-4.0 cm). Experiments were performed on a commercially available workstation (Dell T7500n; Intel Xeon CPU X5660, 6×2.8 GHz, 12 GB RAM; Red Hat Enterprise Linux 6.0).

Results: The GUI permitted manual segmentation of the target tumor on the baseline images and the identification of adjacent critical structures. Meanwhile, the software automatically segmented the probes (mean time=137s). It then computed (mean time=30s) and displayed the automatically-segmented ice ball volume on intra-procedural image in addition to quantitative data such as ablation coverage metrics, i.e. percent tumor coverage and Dice similarity coefficient (DSC). Automatic rigid image registration (time=1-5s) of the baseline images to the current intra-procedural images was used to translate the segmented tumor, probes and critical structures to their motion-corrected locations on the current intra-procedural images.[5] Furthermore, we developed visual warnings to alert the interventionalist when critical structures are approached by the ice ball margin. Real-time computation times were dictated by the pre-existing clinical workflow of these procedures at our institution. Pre-ablation probe detection computation and manual tumor segmentation were allocated 5 minutes, while intra-procedural monitoring calculations (registration, ice ball segmentation and metric computations) were required to be completed within 1-2 minutes (Table 1). This allows sufficient time to review the results between monitoring images, which are acquired every 3 minutes. In 92% of cases (12/13), this software executed rapidly enough so that imaging and ablation could proceed with no delays to the standard procedure. In one case, the probe segmentation software took 322 seconds to detect 6 probes, which was 22 seconds longer than it was allocated.

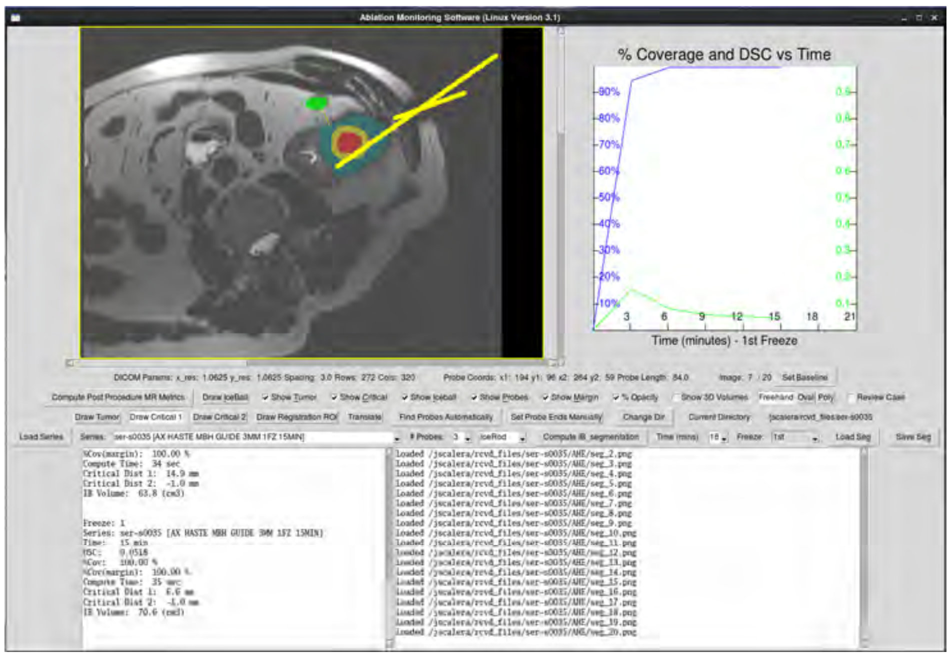

Figure 1: Ablation Monitoring GUI display after 15 min. of cryoablation: manually-segmented tumor (red) and critical structure (green); automatically segmented probes (yellow) and ice ball (blue); computed 5 mm ablative margin (amber); minimum distance from ice ball to critical structure (thin yellow line); DSC (green) and percent coverage (blue) plotted on the right of the GUI for each time point.

Table 1: Real-time Computation Requirements vs. Measured Computation Times

Task	Allocated Time	Measured Computation Time
Auto-Probe Seg./Manual-Tumor Seg.	300 s	Mean 137 s (80-322 s)
Registration/Auto-Ice ball Seg./Metric Comp.	60-120 s	Mean 30 s (17-40 s)

Discussion: We demonstrated the feasibility of using semi-automated, quantitative monitoring software in MRI-guided percutaneous cryoablation procedures. Using previously validated algorithms,[2,3,4] our software clearly proved that procedural monitoring software could be reliable, integrated without significant negative time delays, and yet provide accurate real-time cryoablation monitoring metrics to the interventionalist. This software reduces the monitoring burden on the interventionalist and introduces objective, computed metrics into a currently subjective assessment. These key metrics provide additional input data to the interventionalist, which, when taken into account with critical clinical metrics, will help guide the interventionalist in necessary modifications for a successful and safe procedure.

Conclusion: We developed an integrated, real-time software package for quantitative monitoring of MRI-guided percutaneous cryoablation procedures to guide the eradication of tumors, minimize damage to surrounding parenchyma and prevent damage to nearby critical structures, thereby potentially enhancing patient safety and treatment success. Computation times met the demands of the clinical procedure in 92% of cases. This verifies that this software could be used in real-time. Future studies are needed to validate this software in a prospective trial to determine to what extent these computed metrics influence decision-making and improve the success of ablation procedures.

References: 1. Tuncali K, Liu X, Wells WM III, Silverman S, Zientara GP. Real-time Quantitative Monitoring of Percutaneous MRI-guided Cryoablation of Renal Cancer. Proc. 22st Ann Mtg ISMRM 2014, 2645 **2.** Liu X, Tuncali K, Wells WM III, Zientara GP. Automaic probe artifact detection in MRI-guided cryoablation. Proc. SPIE Med Imag Conf 2013, 86712E. **3.** Liu X, Tuncali K, Wells WM III, Zientara GP. Automatic 3D probe localization and iceball segmentation for MRIguided kidney cryoablation. Proc. 21st Ann Mtg ISMRM 2013, 1821. **4.** Liu X, Tuncali K, Wells WM III, Morrison P, Zientara GP. Fully automatic 3D segmentation of iceball for image-guided cryoablation. Proc. IEEE Conf Engrg Med Bio 2012;2327-30.**5.** Fedorov A, Beichel R, Kalpathy-Cramer J, et al. 3D Slicer as an image computing platform for the quantitative imaging network. Magn Reson Imaging 2012; 30(9):1323-41.

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