From Subjective to Objective: Quantitative Computerized Monitoring Tool for MRI-guided Cryoablation

Jonathan Scalera[1](✉), Xinyang Liu[2], Gary P. Zientara[3], and Kemal Tuncali[1]

[1] Radiology, Brigham and Women's Hospital and Harvard Medical School, Boston, MA, USA
Jonathan.Scalera@gmail.com
[2] Children's National Health System, Washington, DC, USA
[3] US Army Research Institute of Environmental Medicine, Natick, MA, USA

Abstract. During percutaneous ablations, interventionalists currently rely on subjective assessments of procedural images to determine if the ablation is successful and the extent of injury to the surrounding tissues. In order to provide an objective assessment of these images, we developed a unified software package for monitoring MRI-guided cryoablation in real-time. We assessed its feasibility and functionality within the workflow of renal tumor cryoablation procedures using images from 13 MRI-guided renal tumor cryoablation procedures. This retrospective study demonstrated that the software package met the real-time requirements with 92 % success. We were therefore able to develop a comprehensive, real-time, interventionalist-friendly software package for quantitative monitoring of MRI-guided percutaneous cryoablation procedures, which aides in the assessment of tumor eradication and is compatible with the clinical workflow of these procedure. This tool has the potential to minimize damage to surrounding parenchyma and nearby critical structures, thereby enhancing patient safety and treatment success.

Keywords: Computerized monitoring · Cryoablation · Graphical user interface · MRI

1 Introduction

The incidence of renal cell carcinoma (RCC) has increased by 126 % over the past 50 years in the United States [10] with an associated increase in mortality from this disease [2]. Surgical options for RCC are either total nephrectomy or laparoscopic partial nephrectomies for appropriate patients; however, beyond surgical techniques, there is a great need for and progression towards novel, minimally invasive treatments for RCC. Image-guided percutaneous cryoablation has become one of the most promising and prevailing of these minimally invasive treatment techniques [5,9,11]. Combination of Magnetic Resonance Imaging (MRI) and cryoablation provides excellent visibility for monitoring the ablation

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zone, as well as, the tumor and adjacent structures [4] when compared to other modalities, such as Computed tomography (CT). It is with this superior visualization that the percutaneous eradication of the target tumor can be most successful, while minimizing the ablation of surrounding normal parenchyma and reducing the risk of injury to nearby critical structures.

Intra-procedural monitoring is currently based on a qualitative assessment of images by the interventionalist. During this review, the interventionalist cognitively evaluates the percent coverage of the tumor and the extent of inclusion of normal surrounding parenchyma by evaluating the slowly growing ice ball on intraprocedural images. This task must be interleaved with many other aspects of the procedure, such as probe placement, keeping the skin entry site warm to avoid superficial thermal necrosis and monitoring the patients vital signs. Reviewing 2D images in multiple planes every few minutes during the 15 min freezing cycle of a cryoablation can be a difficult, time consuming task while simultaneously tending to other procedural tasks. Due to potential intraprocedural respiratory motion, images acquired at different time points in the procedure must be registered with each other to determine procedural changes. In addition to the potential oversights that can occur as a result of multi-tasking, inaccurate registration can lead to the omission of subtle regions of non-ablated tumor. The qualitative percent coverage assessment and damage to adjacent normal parenchyma is further complicated by the fact that the developing ice ball obscures the margin between tumor and adjacent parenchyma. Accurate assessment of the ice ball with respect to the tumor and adjacent anatomy is essential as non-ablated tumor could lead to recurrence and ablation of adjacent critical structures could lead to significant complications [12]. Quantitative computerized monitoring of ablation performance in real time could reduce the multi-tasking and subjective assessments involved in these procedures, as well as expedite detection, potentially avoiding significant complications and increasing efficacy of the ablation.

Previous efforts had already developed software components for automatic segmentation of the ice ball on intra-procedural images [6,7] and automatic probe detection algorithms [8]. However, a functional integration of these components as well as display of real time results was needed in order to make these tools functional for the interventionalist within the clinical workflow of ablation procedures.

2 Materials and Methods

We developed a unified graphical user interface (GUI), Fig. 1, for monitoring of MRI-guided cryoablation procedures in real-time and assessed its feasibility and functionality within the workflow of renal tumor ablation cases. The GUI interacts with many background software components, all of which have unique data formats that have to be unified. The GUI passes input data, such as user segmented tumor volumes, segmented adjacent critical structures, and depth to the tumor from the skin surface (target depth) to support pieces of software. Computed results for automatically detected probes and automatically segmented ice ball volumes are returned to the ablation package and displayed for the interventionalist. This integrated tool also computes and displays quantitative data such as ablation coverage metrics (percent tumor coverage and Dice similarity coefficient (DSC) [1,3]) and warnings when critical structures are approached by the ice ball margin. Furthermore, the software package assists the interventinalist in probe placement by displaying the predicted ice ball volume at different timepoints based on experimental results and the probe locations. In addition to the challenges of combining independently developed pieces of software and creating an interventionist friendly GUI with clinical functionality, we established an interface with the MRI scanner for extracting images in real time and communicating them through the monitoring software. The computation speed and ease of use of the software package was preliminary evaluated using images from thirteen MRI-guided renal tumor cryoablation procedures in a retrospective fashion.

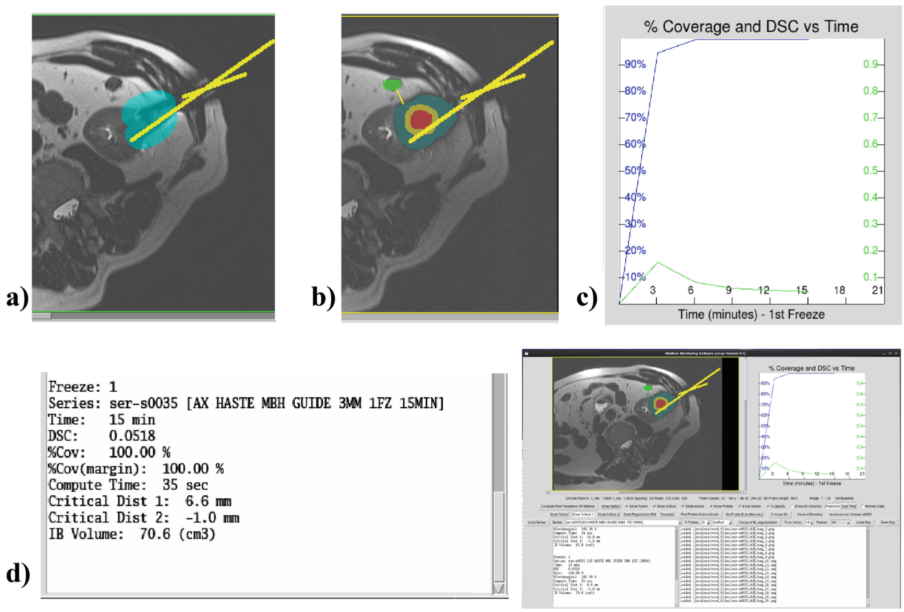

Fig. 1. Screenshot of ablation monitoring GUI after 15 min of cryoablation (lower left). (a) Predicted 15 min ice ball volume (blue) based on probe locations. (b) Overlays on the intra-procedural images after 15 min of Cryoablation showing the segmented ice ball (blue), segmented tumor (red) and ablation margrin (amber). Shortest distance to a critical structure is shown as a thin yellow line overlay and reported in the console (d). (c) Graphical and (d) textual display of percent coverage (blue) and DSC (green) are shown (Color figure online).

Figure 2 illustrates the workflow of a standard MRI-guided cryoablation procedure at our institution. There are three major clinical phases to these procedures:

Planning phase, Probe Placement Phase and Therapy Phase. During the Planning Phase, initial images are acquired that are used to determine the visibility of the target tumor, to assess the appropriate skin entry site and probe placement approach, and to establish the depth of the tumor along the planned approach pathway. During the Probe Placement phase, two to seven cryoprobes are sequentially placed under image-guidance. Once the probes have been placed, a set of images is acquired, using the same imaging parameters employed during the Therapy Phase. The Therapy Phase typically consists of a 15 min freeze cycle, followed by a 10 min passive thaw period, and then a second 15 min freeze cycle. During the freeze cycle, the iceball growth is closely monitored with repeated T2-weighted acquisitions every 3 min. Between these acquisitions, the interventionalist qualitatively assesses the coverage of the tumor by the ice ball and possible involvement of adjacent critical structures.

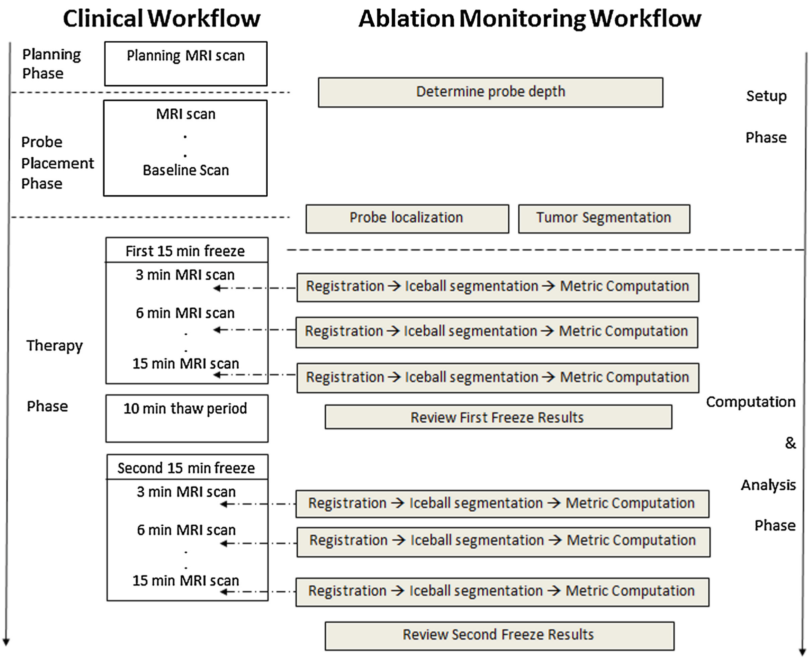

Fig. 2. Clinical and ablation monitoring workflows shown as timelines with first task at the top and last task at the bottom.

The integrated cryoablation monitoring software package was designed to be interleaved with the traditional clinical workflow phases of cryoablation procedures at our institution. That is, this software is able to provide this real time data within the corresponding conventional time allocations of the clinical steps of these procedures. Figure 2 illustrates how the real time computations of our software package were integrated into the clinical cryoablation procedure steps.

Figure 3 illustrates the system design of our integrated software package and the associated relationships between each of the components. Parenthetical text indicates software/programming language used to implement the given component. Exchange of data between software components was mainly through files. This exchange permitted easier debugging and preserves intermediate datasets for future analysis and research. Experiments were performed on a commercially available workstation (Dell T7500n; Intel Xeon CPU X5660, 62.8 GHz, 12 GB RAM; Red Hat Enterprise Linux 6.0).

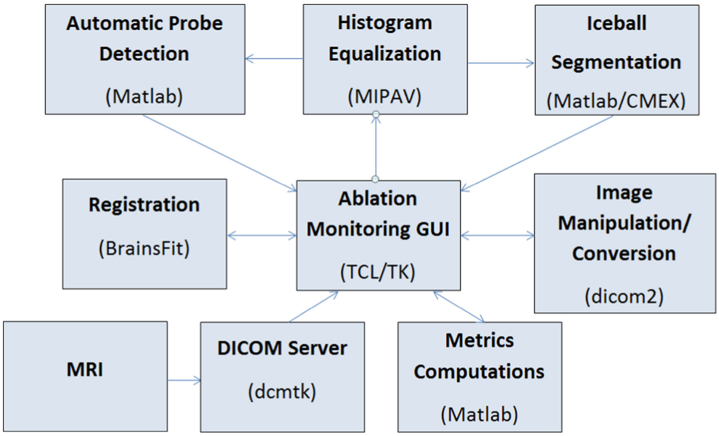

Fig. 3. Ablation monitoring system design. Parenthetical text indicates software/programming language used to implement the given component.

Although previous testing confirmed the software's ability to communicate with the MRI scanner, this offline retrospective study was conducted to ensure that it met the realtime requirements prior to employing it during active cryoablations. The study was performed with an Institutional Review Board (IRB) approved protocol. Consent was waived because the study was performed as a retrospective study using anonymized images from prior cryoablation procedures.

Thirteen MRI-guided kidney tumor cryoablation procedures (6M/7F; age 60–87) with tumor diameter 1.3–4.0 cm (single tumor for all cases) were investigated. All procedures had been performed using a 3 Tesla (T) wide-bore MRI scanner (Siemens Verio, Erlangen, Germany). Body matrix coil (receive; six channel) and spine coils (receive) embedded in the table-top were used in all cases. Axial T2-weighted breath-hold half-Fourier acquisition single shot turbo spin echo (HASTE) sequence (echo time [TE] 200 ms, 320 x 272 voxels/slice, slice thickness of 3–4 mm, in-plane resolution of 1.0625 mm, no gap between slices, interleaved slice order, 16–20 slices, acquisition time of 16–20 s, 28–34 cm field of view) was used. MRI-compatible alloy cryoprobes, IceSeed and IceRod from Galil Medical Inc. (Arden Hills, MN), which are both 17 gauge in diameter and 17.5 cm in total length, were used.

For each of the simulated cases, probe detection and manual tumor segmentation were performed. Subsequently, registration, ice ball segmentation and metric computations were performed for each of the 3–5 min intra-procedural monitoring steps for the two freeze cycles. Computation times for probe detection, registration, ice ball segmentation and metric computations were recorded. Time for the intraventionalist, a radiology fellow with 7 years experience, to manually segment the tumor was also recorded.

3 Results

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 min, while intra-procedural monitoring calculations (registration, ice ball segmentation and metric computations) were required to be completed within 1–2 min (Table 1). This allows sufficient time to review the results between monitoring images, which are acquired every 3–5 min. Of note, manual tumor segmentation was performed in parallel with automatic probe segmentation and always took less than the time required for automatic probe segmentation to execute. 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 of the 13 cases studied, the probe segmentation software took 322 s to detect 6 probes, which was 22 s longer than it was allocated. Therefore, with the exception of one case that exceeded the real time requirements by a small and inconsequential margin, computations were performed in real time.

Table 1. Computation Requirements vs. Measured Computation Times

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

4 Discussion

This study presents results supporting the feasibility of using an integrated software package for quantitative monitoring of MRI-guided percutaneous cryoablation procedures to increase their safety and success. This study proves that the developed software package can be successfully integrated into the clinical workflow model.

This software lessens the monitoring burden on the interventionalist and transforms an imprecise, subjective task to a quantitative, objective assessment.

With the guidance of the interventionist, this software produces accurate metric assessments of percent coverage, DSC and distance of ice ball to critical structure(s). In conjunction with critical clinical metrics, these computed metrics serve as objective input to the interventionalist in determining whether to continue, modify or complete a given cryoablation procedure. As an aside, our retrospective study also found that metric results made subtle regions of non-ablated tissue conspicuous, which could have been overlooked by the interventionalist while managing multiple aspects of these complex procedures. These results speak to the strength of the chosen display format and its potential to enhance procedural safety.

Moreover, since this software was designed by interventionalists, its interface and user interactions were optimized to fit into the pre-established clinical workflow at our institution. Great effort was placed on automating portions of the software and to limit the number of required interactions necessary by the interventionalist to limit the additional burden on the interventionalist. Consensus at our institution based on this preliminary study is that the likely benefits of safety and procedural success, far outweighs the minimal additional tasks it requires.

Given that the ablation monitoring package incorporated pre-existing pieces of software, it was built with a modular architecture. The major efforts of this work provided interoperability, user input to and display of results of these components. This modular structure allows components of the system to be exchanged in the future if new algorithms are employed. For instance, if future study were to determine that non-rigid registration is superior to rigid registration, this component could be replaced with minimal changes to the ablation monitoring package. Furthermore, this modularity permits the monitoring package to potentially be used with other modalities. That is, if a segmentation algorithm were to be developed for computed tomography, it could replace the current MRI segmentation module and the ablation monitoring package could be employed in CT guided ablation procedures.

5 Conclusion

We developed a comprehensive, versatile, integrated software package for quantitative monitoring of MRI-guided percutaneous cryoablation. Our study found that it could be feasibly incorporated into the clinical workflow of these procedures and shows promise in enhancing accurate eradication of tumor, minimizing damage to surrounding parenchyma and preventing damage to nearby critical structures. 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 the extent to which these computed metrics influence intraprocedural decision-making and improve the success and safety of cryoablation procedures.

References

1. Bharatha, A., et al.: Evaluation of three-dimensional finite element-based deformable registration of pre-and intraoperative prostate imaging. Med. Phys. **28**(12), 2551–2560 (2001)
2. Chow, W.H., Devesa, S.S., Warren, J.L., Fraumeni, J.F.: Rising incidence of renal cell cancer in the United States. JAMA **281**(17), 1628–1631 (1999)
3. Dice, L.R.: Measures of the amount of ecologic association between species. Ecology **26**(3), 297–302 (1945)
4. Fennessy, F.M., Tuncali, K., Morrison, P.R., Tempany, C.M.: Mr imaging-guided interventions in the genitourinary tract: an evolving concept. Radiol. Clin. North Am. **46**(1), 149–166 (2008)
5. Gupta, A., Allaf, M.E., Kavoussi, L.R., Jarrett, T.W., Chan, D.Y., Su, L.M., Solomon, S.B.: Computerized tomography guided percutaneous renal cryoablation with the patient under conscious sedation: initial clinical experience. J. Urol. **175**(2), 447–453 (2006)
6. Liu, X., Tuncali, K., Wells, W.M., Morrison, P.R., Zientara, G.P.: Fully automatic 3d segmentation of iceball for image-guided cryoablation. In: 2012 IEEE Annual International Conference on Engineering in Medicine and Biology Society (EMBC), pp. 2327–2330. IEEE (2012)
7. Liu, X., Tuncali, K., Wells, W.M., Zientara, G.P.: Automatic iceball segmentation with adapted shape priors for mri-guided cryoablation. J. Magn. Reson. Imaging **41**, 517–524 (2013)
8. Liu, X., Tuncali, K., Wells, W.M., Zientara, G.P.: Automatic probe artifact detection in MRI-guided cryoablation. In: SPIE Medical Imaging, p. 86712E. International Society for Optics and Photonics (2013)
9. Mouraviev, V., Joniau, S., Van Poppel, H., Polascik, T.J.: Current status of minimally invasive ablative techniques in the treatment of small renal tumours. Eur. Urol. **51**(2), 328–336 (2007)
10. Pantuck, A.J., Zisman, A., Belldegrun, A.S.: The changing natural history of renal cell carcinoma. J. Urol. **166**(5), 1611–1623 (2001)
11. Silverman, S.G., Tuncali, K., Vansonnenberg, E., Morrison, P.R., Shankar, S., Ramaiya, N., Richie, J.P.: Renal tumors: MR imaging-guided percutaneous cryotherapy initial experience in 23 patients. Radiology **236**(2), 716–724 (2005)
12. Tuncali, K., Morrison, P.R., Winalski, C.S., Carrino, J.A., Shankar, S., Ready, J.E., vanSonnenberg, E., Silverman, S.G.: MRI-guided percutaneous cryotherapy for soft-tissue and bone metastases: initial experience. Am. J. Roentgenol. **189**(1), 232–239 (2007)