Integration of Active MR Tracking into Adaptive Radiation Therapy Treatment Planning

Wei Wang[1,2], Akila N Viswanathan[2], Antonio L Damato[2], Zion T Tse[3], Yue Chen[3], Ravi T Seethamraju[4], Clare M Tempany[1], Robert A Cormack[2], and Ehud J Schmidt[1]
[1]Radiology, Brigham and Women's Hospital, Harvard Medical School, Boston, MA, United States, [2]Radiation Oncology, Brigham and Women's Hospital, Harvard Medical School, Boston, MA, United States, [3]The University of Georgia, GA, United States, [4]MR R&D, Siemens Healthcare, MA, United States

Target Audience: Scientists and clinicians interested in MR-guided radiation therapy

Purpose: MRI is invaluable in radiation therapy (RT) due to the superior delineation of the clinical target volume (CTV) and the surrounding organs at risk (OARs). In interstitial RT (brachytherapy), interstitial catheters are directly placed into the tumor in order to deliver a high radiation dose to the CTV, while sparing OARs. An initial implant plan is developed with MR diagnostic images, and then catheters are placed with metallic stylets inside under MRI guidance[1]. Currently, since image-based catheter identification with MRI is time-consuming and not sufficiently accurate, CT scans are required after completion of placement to accurately identify the catheters for treatment planning. However, this workflow is not ideal because (1) the final catheter positions usually deviate substantially from the initial plan as a result of tissue resistance, so clinicians attempt to compensate by implanting more catheters than needed; (2) the dose plan is constrained to use the (non-ideal) catheter configuration achieved at the end of catheter placement; (3) the total procedure time is elongated, and the precision of catheter identification lowered due to the need to transport patients from the MRI to the CT. We have developed an active MR-tracking system that provides accurate and rapid localization of metallic devices[2]. Here we propose an adaptive RT planning process based entirely on MRI, which utilizes catheter trajectories generated by active MR tracking. This process would allow for real-time intra-operative dosimetric evaluation and improve target coverage at the end of the insertion procedure.

Methods: The active MR tracking stylet was developed by embedding two planar printed-circuit RF coils onto the distal surface of a commercial metallic brachytherapy stylet **(Fig. 1)**. An advanced MR tracking sequence[2] was used to provide the two coils' positions and the extrapolated tip position simultaneously at 20-40 updates/s with a resolution of $0.6 \times 0.6 \times 0.6$ mm^3.

Fig 1: Photograph of an active MR-tracked brachytherapy stylet enclosed with a plastic catheter. The dashed window shows an enlarged view of the two printed-circuit tracking coils attached to the distal stylet.

Catheter placement procedures were performed in three gynecological cancer patients on a Siemens 3T scanner. 3D T2-weighted images were acquired using a Turbo Spin Echo sequence. Contouring of tumor and OARs was completed on MR images and imported into the Oncentra (Nucletron, Sweden) treatment planning system (TPS) for the initial plan. A set of catheters, with conventional (non-active) stylets inside, was inserted based on the initial plan under MRI guidance. The conventional stylets were then replaced with the active stylets, and MR tracking was performed continuously during the withdrawal of the active stylets from within each catheter. The acquisition time was ~20s/catheter, allowing ~800 instantaneous stylet tip positions recorded during removal. Each series of 3D positional datasets was fit to a smooth curve by a fourth order polynomial using a custom MATLAB program prior to be transferred to the TPS.

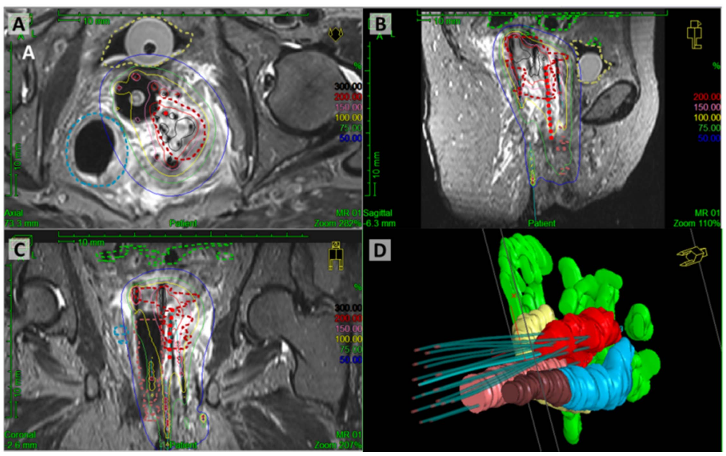

Fig. 2: Screenshot of MR-guided adaptive radiation treatment planning after one interstitial catheter was added to 17 implanted catheters in an endometrial cancer patient. The newly-added catheter trajectory, reconstructed by active MR tracking, is shown as red dots overlaid on the three orthogonal MR images (**A-C**) and as the highlighted blue trajectory in the 3D view (**D**). All the other catheters' trajectories are shown as light blue color in **D**. Dose distribution, updated after the addition of the new catheter, is shown as isodose surfaces (solid lines). MRI-based contouring of tumor (red) and OARs is shown with dashed lines in **A-C** and as volumes in **D** (Yellow: bladder; blue: Sigmoid; brown: rectum; green: bowel).

The newly-added catheter trajectories updated dose calculations on TPS, providing the clinicians with real-time dosimetric feedback on the consequences of the (updated) catheter locations. Existing catheters could be repositioned if the dosimetric changes are not desirable, and/or additional catheters inserted if tumor coverage was insufficient, although in this initial study no treatment changes were made based on this adaptive RT process. After the completion of MR-guided catheter placement, patients were transported to the CT suite for scanning. Catheter trajectories were manually digitized from CT and MR images.

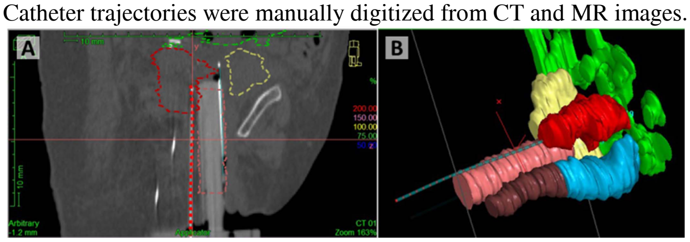

Fig.3: A: The trajectory generated by MR tracking (red dot) overlaid on CT image of the patient, which very consistent with the catheter location shown by CT. Tissue contouring (dashed line) is from the registered MR images. **B**: 3D view of one catheter trajectory digitized from CT images (blue line) and the same catheter trajectory extracted from MR tracking (red dots).

	dx(mm)	dy(mm)	dz(mm)	d_{3D}(mm)
MR Tracking vs **MR Image**	0.3 ± 0.4	-0.1 ± 0.2	1.3 ± 0.0	1.3± 0.2
MR Tracking vs **CT image**	0.3 ± 0.2	-0.7 ± 0.3	4.0 ± 0.0	4.1±0.1

Table 1: Comparison between trajectories generated by MR tracking and the current image-based digitization. Equally spaced dwell points (locations) were generated along each trajectory by interpolation, and the corresponding dwell points from different methods were compared: dx, dy, and dz represents differences along each axis; d_{3D} is the 3D distance between corresponding dwell points.

Results: The fast and accurate catheter identification by active MR tracking (~20s) enables the update of the dosimetric map shortly after catheter insertion (**Fig. 2**). This is well suited for periodic performance of adaptive RT planning during catheter insertion procedure.
The trajectories generated from MR tracking were compared with those generated on TPS from MR images and CT images, respectively. Trajectories acquired by different methods were highly consistent, shown in **Fig.3** and **Table 1**. The small discrepancy between MR tracking and CT may be attributed to changes in patient's movement during transport between the two imaging modalities.

Conclusion: This preliminary study demonstrates the added value and utility of active MR tracking method for intra-operative adaptive treatment planning. Future studies are planned to demonstrate improved treatment outcomes (better tumor coverage and reduced toxicity). Active MR-tracking enables accurate and fast catheter trajectory identification, potentially eliminating the need for post-catheter-placement CT scans.

Reference: 1. Viswanathan AN. Int J Radiat Oncol Biol Phys 2006 (66)91-9; 2. Wang W, et al. Magn Reson Med 2014