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Practice-based training strategy for therapist-driven prostate MR-Linac adaptive radiotherapy

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ABSTRACT

Purpose: To develop a practice-based training strategy to transition from radiation oncologist to therapist-driven prostate MR-Linac adaptive radiotherapy.

Methods and materials: In phase 1, 7 therapists independently contoured the prostate and organs-at-risk on T2-weighted MR images from 11 previously treated MR-Linac prostate patients. Contours were evaluated quantitatively (i.e. Dice similarity coefficient [DSC] calculated against oncologist generated online contours) and qualitatively (i.e. oncologist using a 5-point Likert scale; a score $\geq$ 4 was deemed a pass, a 90% pass rate was required to proceed to the next phase). Phase 2 consisted of supervised online workflow with therapists required no intervention from the oncologist on 10 total cases to advance. Phase 3 involved unsupervised therapist-driven workflow, with offline support from oncologists prior to the next fraction.

Results: In phase 1, the mean DSC was 0.92 (range 0.85–0.97), and mean Likert score was 3.7 for the prostate. Five therapists did not attain a pass rate (3–5 cases with prostate contour score < 4), underwent follow-up one-on-one review, and performed contours on a further training set (n = 5). Each participant completed a median of 12 (range 10–13) cases in phase 2; of 82 cases, minor direction were required from the oncologist on 5 regarding target contouring. Radiation oncologists reviewed 179 treatment fractions in phase 3, and deemed 5 cases acceptable but with suggestions for next fraction; all other cases were accepted without suggestions.

Conclusion: A training stepwise program was developed and successfully implemented to enable a therapist-driven workflow for online prostate MR-Linac adaptive radiotherapy.

Introduction

Adaptive magnetic resonance (MR) image guided radiotherapy (IGRT) on the MR linear accelerator (MR-Linac) requires a multidisciplinary team of radiation therapists, medical physicists, and radiation oncologists [1,2]. Two clinical workflows are available on the Unity MR-Linac (Elekta Unity, Stockholm, Sweden): adapt-to-position (ATP), where the beam segments are adapted based on rigid translational registration between the daily pre-treatment MR images (MRI) and reference MRI; and, adapt-to-shape (ATS) where contour propagation, re-contouring and plan optimization occurs on the daily pre-treatment MR [3]. As such, MR-Linac treatments are more resource-intensive than established Linac treatments, and require innovative approaches to the traditional roles and responsibilities of the multidisciplinary team.

With the introduction of new technologies, the clinical practice, skillsets and competencies of radiation therapists must adapt accordingly [4]. McNair *et al* indicated that a shift in professional responsibilities and implementation of training programs would be the most efficient and effective process to implement online adaptive radiation therapy on the MR-Linac [5]. Various studies have reported the successful delegation of responsibilities from the oncologist to the radiation therapists: Pathmanathan *et al* noted minimal interobserver

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variability between radiation therapists with regard to prostate contouring on MRI [6]; Hales *et al* reported the implementation of a clinician-lite ATP model for prostate treatments [7]; and clinician-lite ATS prostate treatments have been implemented as standard practice at various centres [8,9].

Through training and education, daily autonomous online assessment of cone-beam CT (CBCT) images by radiation therapists at our institute has been standard practice since 2006 [10]. Although a significant technology shift, the fundamentals of MR-guided delivery remain consistent with CBCT-IGRT. With a strong foundation in image guidance, MRI acquisition, and treatment planning skills, therapists practicing on the MR-Linac at our institute are poised to integrate responsibilities from other disciplines, such as contouring and online treatment plan evaluation, into their standard practice.

Implementing a new treatment paradigm offers the opportunity to evaluate and optimize the skillset and distribution of responsibilities of the multidisciplinary team members to maximize efficiency. To refine the resources and skillset allocation on the MR-Linac, this study outlines a 3-phase training strategy developed to transition from an oncologist to a therapist-driven workflow for whole gland prostate MR-Linac adaptive radiotherapy.

Materials and methods

A three phase practice-based competency training program was developed by a multidisciplinary team of radiation therapists, medical physicists and radiation oncologists. Seven MR-Linac RTs (see Table 1) were recruited for training over 2 cycles (5 in the first cycle, 2 in a second). Training MRI were retrieved from patients who consented to an institutional review board approved study (ID 19-5843). This project was reviewed and approved by the institutional quality improvement review committee (ID 21-0269).

Phase one - contour training

The therapists initially attended a tutorial led by a genitourinary oncologist to review MRI prostate anatomy, including T1- and T2-weighted diagnostic and MR-Linac images, and discuss common contour-related pitfalls. Additionally, participants were encouraged to review online education tools and references pertaining to MRI prostate anatomy [11,12].

A training database was created in the MR-Linac treatment planning system (Monaco v5.4, Elekta AB, Stockholm, Sweden). Single fractions from 11 previously treated MRL prostate patients using the T2-weighted 2-minute acquisition (1 mm slice thickness) for MRI based planning were randomly selected. Patient data was anonymized and sorted by a medical physicist and radiation oncologist into two categories, dependent on patient anatomical features and time required by the oncologist to perform online contours:

- Simple (6 cases): distinct borders, may include seminal vesicles and/or median lobe, minimal variation in bladder and bowel preparation, with or without rectal spacer, mean (range) reference oncologist contouring time = 4.7 (3.3–6.6) minutes
- Complex (5 cases): difficult to distinguish borders due to changes in OAR or target volume, large changes in bladder and bowel preparation, no rectal spacer, mean (range) reference oncologist contouring time = 6.9 (4.0–12.0) minutes
- Additional delineation round (5 cases): 3 simple, mean (range) reference oncologist contouring time = 4.9 (4.3–5.4) minutes; 2 complex, mean (range) reference oncologist contouring time = 6.0 (5.8–6.1) minutes

The therapists proceeded to independently contour the prostate, bladder, rectum and other organs-at-risk (OAR), such as the small and large bowel, on images in the training database over three sessions to minimize contouring fatigue. Using the reference planning images in the treatment planning system and contours as a guide, participants were required to complete contouring in under 10 min to mimic the online clinical environment.

Initial assessment through quantitative Dice similarity coefficient (DSC) and Hausdorff distance (HD) comparison was performed [13], calculated against the oncologist-generated contours during the online session to provide a baseline for evaluation. When contours overlap perfectly, DSC = 1 and HD = 0 mm. A qualitative contour review by an oncologist followed, ranking the contours on a 5 point Likert scale (range: 1 = very poor, 5 = excellent). A Likert score of $\geq$ 4 for the assessed contours was required to pass the case. A pass rate of 90% was required to advance to phase 2. Review of images with the radiation oncologist was undertaken in the event of score of $\leq$ 3 followed by a further round of delineation assessment on 5 cases; DSC and Likert scoring was repeated, and a pass rate of 90% in the additional delineation round was required to advance to phase 2.

Phase two - online assessment

In phase 2, during the online ATS workflow, the radiation therapist at the MR-Linac was evaluated by the supervising oncologist. A team of 5 genitourinary radiation oncologists were involved in supervision. The evaluation included the processes and tasks related to: image registration and fusion, contouring of the target and relevant OARs, and generation of the adapted plan and corresponding plan review against reference target and OAR dose-volume metrics and clinical considerations. Each step was performed in conjunction with the medical physicist as part of the consensus-based decision making clinical workflow. The time taken for contouring and overall treatment was tracked.

During each case and for every step (e.g. image fusion, target and OAR contouring, and plan generation/review), therapist performance was scored by the supervising oncologist using the following categorical scale:

- Direction – major corrections and direction required from radiation oncologist
- Support – minor corrections and direction required from radiation oncologist

Table 1
Participant demographics prior to training.

Question	Category			
Years of Radiation Therapy Experience	<5 years	5–10 years	10–20 years	>20 years
# of responses	2	1	3	1
Experience with Treatment Planning	<1 year	1–5 years	5–10 years	>10 years
# of responses	2	3	0	2
Clinical MR-Linac Experience	<6 months	6–12 months	1–2 years	>2 years
# of responses	0	3	4	0

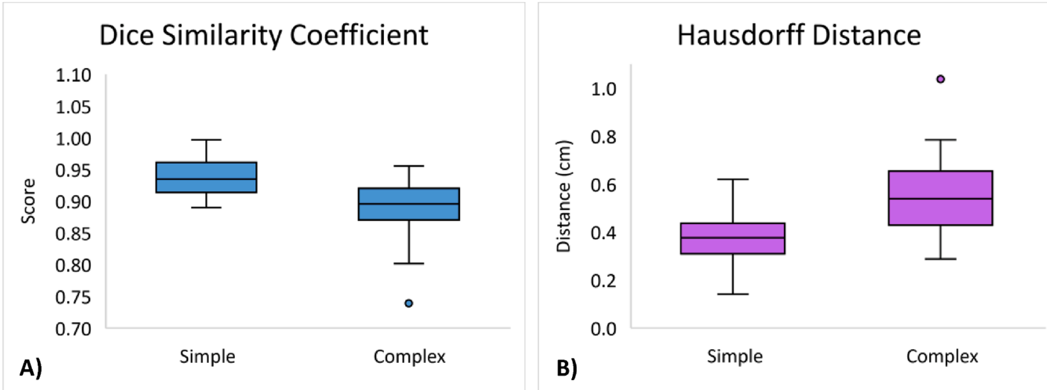

Fig. 1. Phase 1 prostate contour results. The a) Dice similarity coefficient and b) Hausdorff distance results are shown for simple and complex cases. Box plots for contouring and overall time for an online adaptive radiation therapy session for each participant during Phase 2. Box plots display the median values (central bar) with the interquartile range (lower and upper hinges), whiskers define the minimum and maximum values, and outliners shown with circles.

- Autonomy - no direction required from radiation oncologist.

Phase 2 was complete after the therapist achieved a minimum of 10 online single fraction cases (minimum of 8 different patients) signed off with "autonomy" in each of the three domains.

Phase 3 - ongoing quality control

In this phase, the online adaptive ATS MR-Linac workflow was performed independently by the therapist in conjunction with the medical physicist. The duty MR-Linac oncologist was contacted once the plan was generated and provided final plan sign-off remotely. In this consolidation period, the plans and contours generated by the therapist during the adaptive session were reviewed retrospectively by the responsible radiation oncologist. A minimum of 10 cases from each therapist were reviewed for both contours and adapted plan quality, and were scored as: acceptable, acceptable with suggestions for next fraction, or unacceptable.

Participant surveys

Participants were surveyed pre- and post-training to evaluate the training program strengths and identify areas for improvement. Participants provided self-assessment of their skill level in regards to: target and OAR contouring, online image fusion, adapted plan generation, plan review and approval. The following scale was used:

- Novice - needs close supervision or instruction
- Beginner - able to achieve some steps using own judgment, but supervision required
- Competent - able to achieve most tasks using own judgment
- Proficient - able to take full responsibility for own work
- Expert - able to take responsibility for going beyond existing standards

Results

Phase one - contour training

The mean DSC scores for the prostate was 0.92 (standard deviation [SD] 0.04, range 0.85–0.97), bladder 0.90 (SD 0.12, range 0.65–0.99), and rectum 0.98 (SD 0.01, range 0.96–1.00). The mean HD was 0.46 cm (SD 0.13, range 0.29–0.68 cm) for prostate, 0.96 cm (SD 0.74, range 0.30–2.39 cm) for bladder, and 0.40 cm (SD 0.23, range 0.11–0.85 cm) for rectum. Mean Likert scores for the prostate was 3.7, bladder 4.1, and rectum 4.3. The DSC and HD prostate contour scores are shown in Fig. 1, grouped by level of difficulty. Both the bladder and rectum contours achieved high DSC scores as the oncologist made minimal or no edits to the structures for the online adapted plan, while in the offline training activity, the therapists made all appropriate edits to both contours. The main challenges identified qualitatively with prostate contours included under-delineation at the base in patients in the complex category (both median lobe and/or seminal vesicles), and variations in defining the

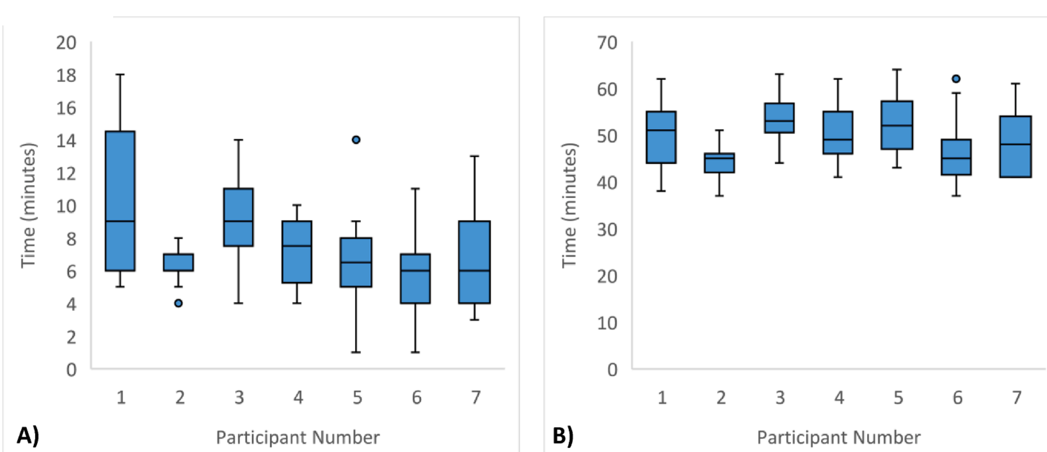

Fig. 2. Box plots for a) contouring and b) overall time for an online adaptive radiation therapy session for each participant during Phase 2. Box plots display the median values (central bar) with the interquartile range (lower and upper hinges), whiskers define the minimum and maximum values, and outliners shown with circles.

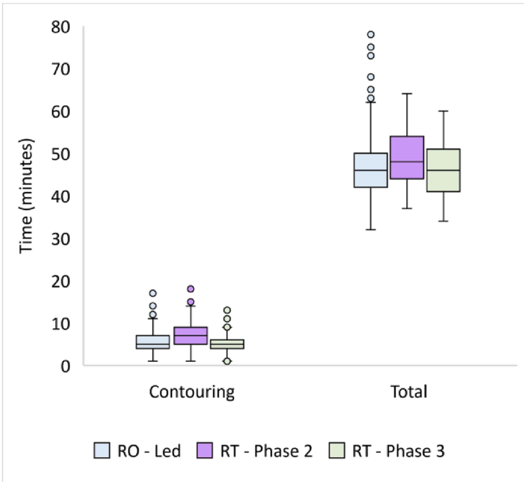

Fig. 3. Box plots comparing contouring and total session time during the oncologist (RO)-led workflow, and Phase 2 and 3 training periods for Radiation Therapists (RT). Box plots display the median values (central bar) with the interquartile range (lower and upper hinges), whiskers define the minimum and maximum values, and outliners shown with circles.

apex in both categories.

Five RTs did not attain a pass rate of 90% and attended follow-up one-on-one review with the oncologists. The participants were required to contour an additional training set of 5 cases; a Likert score of $\geq$ 4 for the assessed contours was achieved by all participants on the cases and advanced to phase 2.

Phase two - online assessment

The median number of cases completed per participant in this phase was 12 (range 10–13), totaling 82 fractions over all participants. Fig. 2 shows the contouring and overall treatment times per participant. The mean time for target and OAR contouring was 7 min (SD 3 min, range 1–18 min). The mean overall treatment time (from patient set-up to patient leaving the treatment room) was 49 min (SD 6 min, range 37–64 min). A comparison to oncologist-led treatment times, 524 fractions, is shown in Fig. 3. The mean time for oncologist-led target and OAR contouring was 5 min (SD 2 min, range 1–17 min). The corresponding mean overall oncologist-led treatment time was 47 min (SD 7 min, range 32–78 min).

A total of 7 cases early in the online assessment phase across all participants did not attain a score of "autonomy". Minor directions were required from the oncologist on 5 cases related to target contouring, specifically about the contour shape, and contour variability at the rectum and prostate interface, base, and apex. In one case, major direction was required from the oncologist for target contouring due to therapist uncertainty about the prostate and rectum interface. Finally, 1 case was scored with minor direction for both target and OAR contouring due to both therapist uncertainty and lengthy time required for online contouring activities (18 min).

Phase 3 - ongoing quality control

In this phase, 179 treatment fractions were reviewed over a 5 month period. The median number of fractions completed per participant in this phase was 28 (range 12–49). Retrospective review of the contours were performed by 5 different genitourinary radiation oncologists. The mean time for target and OAR contouring was 4 min (SD 2 min, range 1–13 min). The mean overall treatment time was 46 min (SD 6 min, range 34–60 min) (see Fig. 3).

Iterative feedback ensured ongoing competence and consistency in care provided with the therapist-driven MR-Linac workflow. There were 5 fractions (3%) that scored "acceptable with suggestions for next fraction", 4 involved contours and 1 referred to the adapted plan. Case 1 indicated the penile bulb was contoured too superior. Case 2 indicated an additional inferior slice (i.e. 1 mm) was required to the prostate, and in case 3, an additional superior prostate slice was requested. Case 4 required an additional inferior slice to the prostate and expansion of the small bowel contour. Finally, on case 5, the oncologist indicated that the adapted plan should be scaled to meet target coverage criteria on subsequent fractions. No case was marked "unacceptable".

Survey results

Pre- and post-training self-assessment results are shown in Fig. 4, where all participants reported themselves as either competent, proficient or expert in all categories on completion of training. Participants indicated that the most useful component of the training was the immediate feedback provided after phase 1 and during phase 2. One participant reported conflicting feedback received over different online adaptive sessions from different oncologists to be the least useful. A suggestion for improvement to the training was to have the same designated oncologist available to provide consistent feedback for all cases during phase 2.

Discussion

Development and implementation of the training program required multidisciplinary collaboration to ensure participants gained the skills, knowledge and judgment to deliver high quality care. In this study, a three phase practice-based competency training program is described for radiation therapists to facilitate the implementation of a therapist-driven model for online adaptive treatment on the MR-Linac. The training program for prostate is reproducible and sustainable as demonstrated by our 2 completed cycles. The program's format and learning objectives can be used as a template for other treatment sites on

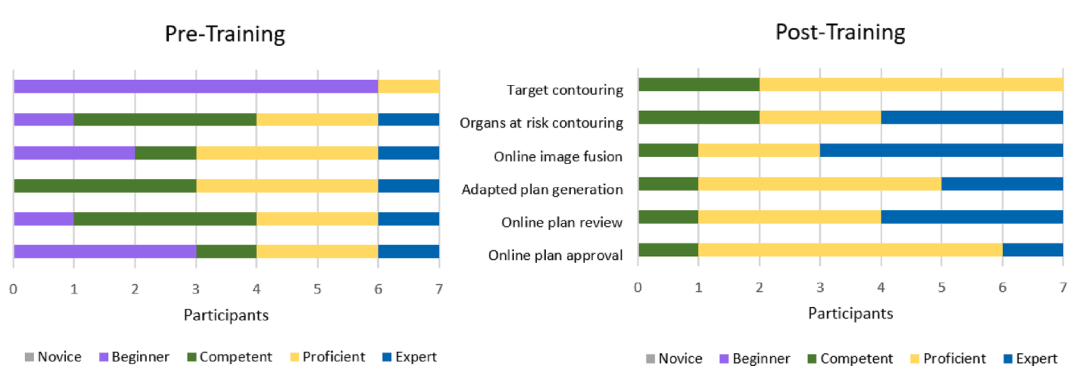

Fig. 4. Participant self-assessment pre- and post- training.

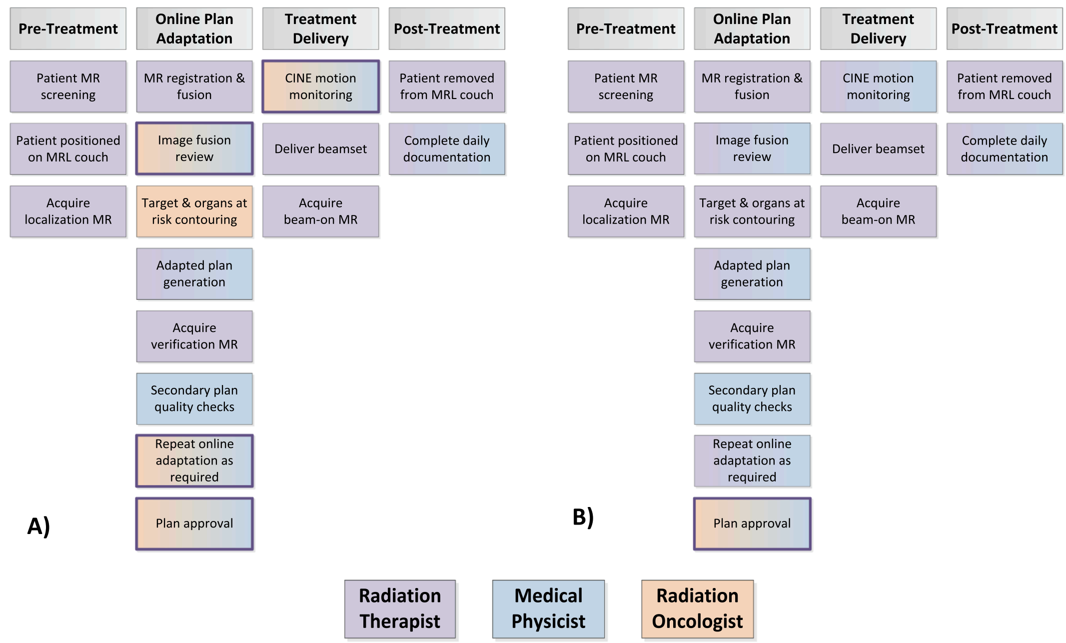

Fig. 5. Process maps comparing roles and responsibilities between A) multidisciplinary and B) therapist-driven model for online adaptive MR-Linac treatment.

the MR-Linac at our institution and perhaps at other institutions aiming to introduce a therapist-driven model.

The therapist-driven model has now been implemented at our institution for whole gland prostate treatments starting at the second fraction (see Fig. 5). As there was no significant difference in contouring or overall treatment times (see Fig. 3), the patient's time on the MR-Linac remains unaffected by the resource shift. A radiation oncologist is required to attend in-person for the first fraction to assess potential anatomical differences between simulation and treatment, as some changes to patient anatomy are expected in the subset of patients who undergo brachytherapy procedures prior to external beam radiation [14]. Similar volume changes are sometimes observed during the course of MR-Linac extreme hypofractionation [15], and this is communicated to the covering oncologist prior to remote plan approval. The treatment session may be paused should the oncologist be required on the treatment unit for an online consultation to assess the changes.

Discrepancies noted on prostate contours across all phases were similar to other published reports of interobserver variability for MRI guided prostate radiotherapy delineation. In a study where a DSC of 0.94 was reported on ten prostate patient contours on T2-weighted MR-images generated across 5 oncologists [6], and high DSC prostate contour scores were noted between the therapist generated online contour and subsequent single oncologist observer comparison [8]. In other studies, similar to our assessment, adapted bladder and bowel contours between oncologists and therapists resulted in high agreement [16,17]. It should be noted that in this study, the cases in phase 1 were stringently scored, akin to prostate and OAR contours generated on an offline reference dataset (e.g. no time constraints or online pressures of a patient on the treatment couch) to provide strict contouring guidelines. As expected, DSC and Likert scores decreased with increasingly difficult cases where the prostate contour borders were not as well defined due to poor image quality resulting from internal organ motion (e.g. rectum and bowel peristalsis).

Post-training assessments demonstrated participant confidence with the training process as all participants categorized themselves as competent and beyond in all categories of contouring and planning. As participants indicated that the most useful component of the training was the immediate feedback provided during the phases, this will be continued for future iterations. To improve the learner experience, we will aim to limit the number of oncologists providing supervision during phase 2 to ensure more consistent feedback.

Based on our experience in phase 3, structured daily quality control activities have been discontinued, but ad-hoc random auditing by the radiation oncologist is still recommended. Ad-hoc review of adapted contours and plans should be performed by the radiation oncologists, and feedback communicated to the MR-Linac therapists as required. To ensure skill maintenance, each MR-Linac therapist should perform at least 10 adapted fraction every 6 months as previously recommended [18].

It should be noted that other strategies are being implemented at various MR-Linac centers to decrease the resource burden of online adaptive radiation therapy. The use of remote contouring and plan review on a virtual private network [19], and case specific video clips outlining anatomy and plan details to covering oncologists has alleviated oncologist resource burden at the front lines [20]. Research and development with fast and accurate contour auto-segmentation [21,22], and online auto-planning [23] may reduce the overall time for an adaptive treatment session, further decreasing human resource requirements per adaptive treatment fraction. Even with automated methods for contour and adapted plan generation, the training strategy reported here is still applicable for therapist-driven contour and plan review.

Future steps for this work aim to assess the inter-observer variability on target and OAR contouring on the same data set from a cohort of radiation oncologists, allowing benchmarking and direct comparison of performance, including quantification of any material impact (e.g. dosimetric) of the observed differences. Reassuringly, previous work comparing the dosimetric impact of contour differences between oncologists and therapists adapted plans found these were clinically insignificant. [8,9,16].

There are several limitations to this study as it included a small cohort of participants from one institution. The pass rates and scoring criteria for the different phases were defined arbitrarily by the study team. Further, the roles and responsibilities of the multidisciplinary team may vary across different jurisdictions and professional governing bodies. As such, the methods and results described here may not be broadly generalizable.

Conclusion

In conclusion, a training strategy was developed to enable a therapist-driven workflow for prostate adaptive radiotherapy on the MR-Linac. The training strategy was successfully implemented for seven therapists as assessed via oncologist evaluation and the self-assessment survey. This model may be adopted and tailored for other anatomical sites to maximize efficiencies of MR-Linac radiotherapy by shifting resources and eliminating the need to have an oncologist present at the treatment unit for online adaptive processes.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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