A novel MR-guided treatment planning tool reduces accumulated critical organ dose in prostate cancer

Ellen H.A. Loeters, Roel G.J. Kierkels
Radiotherapiegroep, Arnhem/Deventer, the Netherlands

Introduction

MR-guided adaptive radiotherapy (MRgART) ensures target coverage and optimal organ at risk (OAR) sparing at each fraction. However, evaluation of accumulated over- or under-dosage over treatment fractions, has not been integrated into the current clinical workflow of the 1.5 T Unity MR-Linac.[1]

Purpose

- **To develop and evaluate a dose accumulation pipeline** to estimate and compare the accumulated given dose (D_{Acc}) with the pre-treatment planned dose (D_{PT}), for hypo-fractionated prostate cancer patients;
- Additionally, we aimed to introduce **a novel (adaptive) treatment planning workflow** for the pre-treatment and adaptive MRgART plans.

Materials/Methods

Clinical IMRT treatment plans of six randomly selected prostate cancer patients, treated with the 1.5 T Unity MR-Linac (Elekta AB, Stockholm), receiving 35 Gy in 5 fractions over 2 weeks, were included. The pre-treatment plans, adaptive plans and contours from the **Monaco** TPS (TPS_{MON}) (Monaco v5.51.11) were used to evaluate the dose accumulation pipeline in **RayStation** (TPS_{RAY}) (RayStation v2023-R, RaySearch Laboratories AB, Stockholm). In TPS_{MON} the adaptive planning was based on the adapt-to-shape and adapt-to-position procedure.[2] Pre-treatment and adaptive plans were also created in TPS_{RAY} and compared with the clinical plans (table 1).

Dose accumulation pipeline

- Hybrid ANACONDA deformable image registrations with controlling ROIs: CTV, bladder and rectum
- TPS_{MON} and TPS_{RAY} fraction doses mapped onto the pre-treatment reference MRI on a voxel-by-voxel level.
- Dosimetric evaluation of D_{Acc} in TPS_{RAY}.

RayStation MRgART planning

- Beam modeling for the 1.5 T MR-Linac with cryostat and MRI coils
- Deformable CT mapping to T2-weighted MRI for dose calculations
- Final Monte Carlo dose with 1.5 T B-field and 1% MC uncertainty
- Adaptive plans: warm restart of pre-treatment plan (4 x 40 iterations)

***Table 1**. Intensity modulated MRgART treatment plan optimization settings*

TPS	Min. segment area cm2	Min. Segment width cm	Min. MU / segment	Max. Number of segments
Monaco	6.0	0.7	7.0	70
RayStation	4.0	0.3	4.0	70

Results

For all patients, the V95% of the CTV was >99.0% in the D_{PT} and the D_{Acc} in both TPSs. A T2-weighted MRI overlayed with a dose difference distribution between the TPS_{MON} and TPS_{RAY} of a typical patient illustrates lower peripheral doses in the TPS_{RAY} plan (Figure 1AI). In D_{PT}, on average (1 SD), the rectum V28 was 1.5 (1.2) % lower in the TPS_{RAY} plans. The D_{mean} of the evaluated OARs was (range) 0.1 – 6.8 Gy lower in TPS_{RAY} ($p < 0.001$) for all patients compared to TPS_{MON} (Figure 2A). Lower OAR doses may be attributed to a higher degree of modulation within TPS_{RAY} plans. On average, the number of beam segments was 51 (range: 45 – 57) in TPS_{MON}, and 69 (68 – 70) in TPS_{RAY}.

On average, the OAR D_{mean} between the D_{PT} and D_{Acc} was similar ($p = 0.26$). However, for one patient, a higher bladder D_{mean} was observed due to inaccurate bladder deformation (Figure 1BI and 2B).

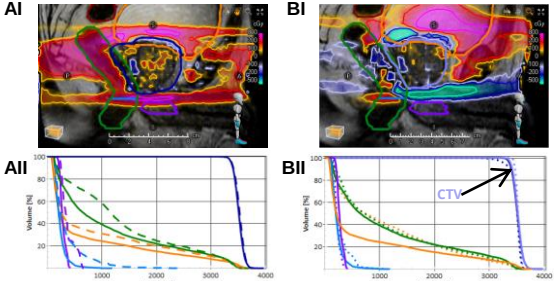

***Figure 1. (AI)** Sagittal cross section of a T2-weighted MRI overlayed with a dose difference distribution between the Monaco and RayStation pre-treatment doses (D_{PT}) [red colors indicate lower doses in the RayStation plan], and **(BI)** between the D_{PT} and the accumulated dose. The corresponding dose volume histograms illustrate the target and OAR doses of the **(AII)** Monaco D_{PT} (dashed lines), the RayStation D_{PT} (solid lines), and the accumulated dose distribution (dotted lines) **(BII)**. Line colors correspond to the figure 2 legend.*

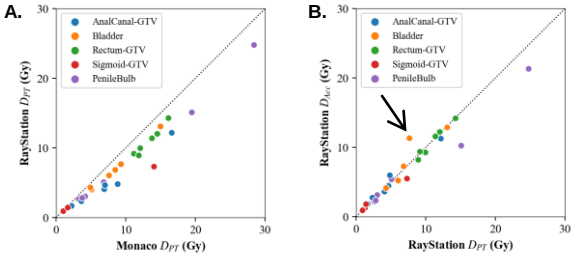

***Figure 2.** Scatter plots showing the relationship between **(A)** the OARs D_{mean} of the Monaco pre-treatment dose distributions (D_{PT}) and the RayStation D_{PT} and **(B)** between the OAR D_{mean} of the RayStation D_{PT} and the estimated actually given accumulated dose (D_{Acc}). The arrow points towards the bladder D_{mean} of the patient shown in figure 1b.*

Conclusion

- The dose accumulation pipeline provides an estimate of the actually given dose, which was demonstrated for prostate cancer patients treated at the 1.5 T MR-Linac. However, the quality of the deformable registrations should be critically reviewed.
- The novel pre-treatment and adaptive planning class solution in RayStation results in prostate IMRT plans with lower mean OAR doses as compared to the clinical plans created in Monaco.

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References

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Contact

r.Kierkels@radiotherapiegroep.nl

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