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Weekly Vs. Daily Online Adaptation for Head and Neck Intensity-Modulated Proton Therapy

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INTRODUCTION

Head and neck (H&N) cancer patients benefit from intensity-modulated proton therapy (IMPT), as it allows for steep gradients in the target dose distribution, and improved sparing of organs at risk (OARs) close to the tumor. During treatment planning, additional margins are introduced around the target volume to account for various uncertainties, consequently increasing the dose to healthy tissue. Furthermore, target margins do not guarantee target coverage and OAR sparing throughout the treatment. Online plan adaptation accounts for the current patient anatomy and setup, potentially allowing for target margin reduction.

AIM

To investigate the impact of online adaptation frequency on target coverage for three different delivery scenarios:

- Base plan with no adaptation (BP)
- Weekly adaptation (WA)
- Daily adaptation (DA)

METHOD

A representative cohort of six H&N cancer patients with daily acquired cone-beam CT (CBCT) images is evaluated in this retrospective study; tumor locations include the oral cavity, oropharynx, larynx, and tonsils. The total number of daily CBCTs in this study amounts to 171 scans (between 18 and 33 CBCTs per patient). For each patient, an IMPT plan was created based on the planning CT using the commercial treatment planning system RayStation (RaySearch Laboratories, Stockholm, Sweden). The plans were optimized to deliver a homogenous dose to the CTV (60 or 63 Gy) without the addition of target margins while minimizing dose to OARs.

WA was performed on the first available day of each week, and the adapted plan was then used for each fraction until the next weekly adaptation. The online adaptation approach utilized for this study employs GPU accelerated Monte Carlo (gPMC) [1] simulations for dose calculation on CBCT images [2]. The CBCTs were scatter-corrected in the projection domain using an algorithm previously validated for proton therapy [3]. Additionally, the CBCTs were aligned to the plan isocenter by performing rigid registration from each CBCT to the planning CT.

For each fraction, a vector field (VF) is calculated between the planning CT and the CBCT with deformable image registration (DIR) using the GPU parallelized B-spline algorithm in Plastimatch [4]. The deformation VFs map the original planning CT to each CBCT and, as such, are used to propagate the planning contours to the CBCTs. The same propagated contours are used for dose tracking and scoring throughout the treatment. The IMPT plan adaptation, based on the previously calculated deformation VFs, is realized by combining isocenter shifts of the patient with energy modifications of individual beamlets with subsequent weight optimization.

RESULTS

The three delivery scenarios (BP, WA, and DA) were evaluated for both the dose delivered per individual fractions and for the dose accumulated throughout the treatment. Figures 1 a) and b) compare two representative patients:

- **a)** The CTV $V_{95\%}$ and $V_{110\%}$ plotted over all fractions. The BP for patient A exhibits a systematic coverage degradation throughout the treatment, presumably due to weight loss. On the other hand, patient B shows random fluctuations caused by anatomical positioning inconsistencies with the planning CT. One can see that WA noticeably mitigates the target coverage degradation between fractions caused by weight loss while positioning variations are only effectively accounted for by DA.
- **b)** Dose-volume histograms (DVHs) for both patients evaluated for the dose accumulated throughout the treatment. For patient A, the difference in target coverage between WA and DA is less noticeable than for patient B, supporting the previous observations. Both adaptation schemes outperformed the unadapted BP scenario in terms of target coverage, while some OARs received higher mean doses and lower maximum doses.

Different target (CTV) DVH metrics for all six patients are summarized in boxplots in Figure 2, both for the dose scored on individual fractions (171 data points) and for the dose accumulated throughout the treatment (6 data points). For scoring on individual fractions, WA exhibits substantial fluctuations compared to DA due to positioning variations between the fractions, as previously observed in Figure 1 a). For the dose accumulated throughout the treatment, on the other hand, WA and DA yield relatively similar results. Out of the total 171 fractions, 43 were adapted for the WA scheme (25.1% of all fractions). An overview of the introduced dosimetric values is given in Table 1; the table includes the mean, minima, and maxima, including the corresponding standard deviations (SD).

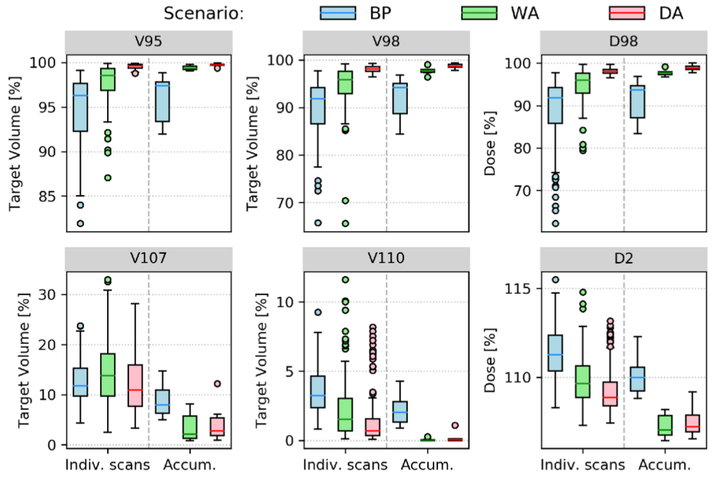

Figure 2: Boxplots summarizing different metrics evaluated for the target (CTV) DVHs for all six patients, both for the dose delivered per individual fractions (171 data points) and for the dose accumulated throughout the treatment (6 data points).

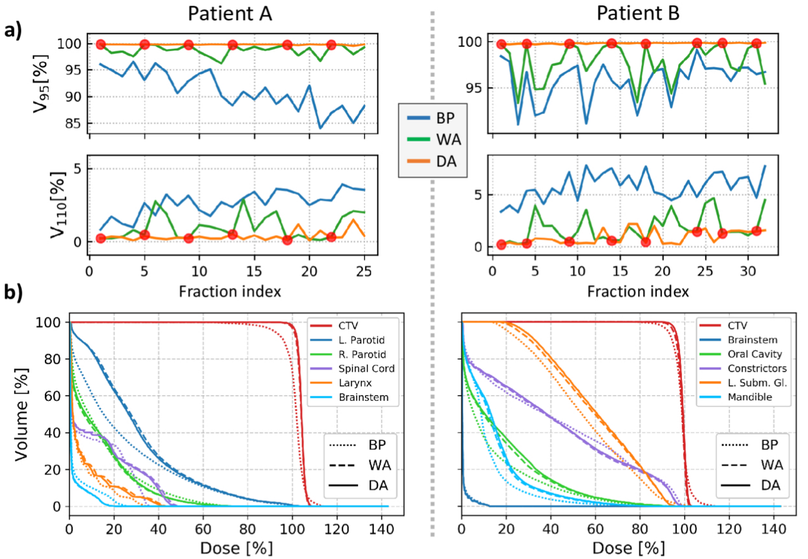

Figure 1: a) The evolution of the CTV $V_{95\%}$ and $V_{110\%}$ for patients A and B over the whole course of treatment. The red dots represent which fractions of the WA scenario were adapted. **b)** DVHs for patients A and B comparing the dose accumulated throughout the treatment for BP (dotted line), WA (dashed line), DA (solid line).

		Individual fractions			Accumulated		
All in %		Min	Max	Mean ± SD	Min	Max	Mean ± SD
V95	BP	81.9	99.1	95.0 ± 3.5	92.0	98.8	95.9 ± 2.8
	WA	87.1	99.9	97.9 ± 2.1	99.1	99.8	99.4 ± 0.2
	DA	98.8	99.9	99.6 ± 0.2	99.4	100.0	99.7 ± 0.2
V98	BP	65.8	97.7	90.0 ± 5.6	84.4	96.9	92.0 ± 4.6
	WA	65.6	99.2	94.8 ± 4.3	96.5	99.0	97.7 ± 0.8
	DA	96.5	99.3	98.1 ± 0.7	97.8	99.4	98.7 ± 0.5
V107	BP	4.3	23.8	12.5 ± 4.0	5.0	14.8	8.9 ± 3.4
	WA	2.5	32.9	14.2 ± 6.4	0.9	8.1	3.5 ± 2.9
	DA	3.3	28.2	12.3 ± 6.1	0.9	12.2	4.4 ± 3.9
V110	BP	0.8	9.3	3.6 ± 1.7	0.9	4.3	2.2 ± 1.1
	WA	0.1	11.6	2.2 ± 2.1	0.0	0.3	0.1 ± 0.1
	DA	0.1	8.2	1.4 ± 1.8	0.0	1.1	0.2 ± 0.4
D98	BP	62.2	97.7	89.2 ± 7.2	83.5	96.9	91.3 ± 5.1
	WA	79.4	99.7	94.9 ± 3.8	96.7	99.2	97.8 ± 0.8
	DA	96.6	99.7	98.1 ± 0.7	97.8	100.1	98.9 ± 0.7
D2	BP	108.3	115.5	111.4 ± 1.4	108.8	112.3	110.1 ± 1.2
	WA	107.3	114.8	109.8 ± 1.3	106.5	108.2	107.3 ± 0.7
	DA	107.4	113.2	109.2 ± 1.3	106.6	109.2	107.5 ± 0.9

Table 1: Dosimetric values achieved in the target (CTV) by the three delivery scenarios for both the dose delivered per fraction and the dose accumulated throughout the treatment.

CONCLUSIONS

- With respect to the dose per fraction, our results show the superiority of DA over WA in terms of target coverage due to positioning inconsistencies between individual fractions
- With respect to the entire treatment, similar dosimetric values for the target volume were achieved by both adaptation schemes
- Systematic target coverage degradation due to weight loss is substantially mitigated by both DA and WA, whereby random variations are only effectively accounted for by DA
- Reducing the number of adapted fractions could be beneficial for the clinical workflow
- Based on the patient cohort evaluated in this study, WA appears sufficient and, therefore, might serve as an alternative approach to DA, assuming a sufficiently large number of fractions

ACKNOWLEDGEMENTS

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