Dose accumulation of daily adaptive plans to decide optimal plan adaptation strategy for head-and-neck patients treated with MR-Linac

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ABSTRACT

Advances in magnetic resonance linear accelerators (MR-Linacs) allow for superior visualization of soft tissue to guide online adaptive replanning for precise radiotherapy delivery. Elekta Unity MR-Linac provides two plan adaptation approaches, the adapt-to-position (ATP), plan re-optimization based on the iso-shift of daily MR scans without the need to recontour, and the adapt-to-shape (ATS), full plan re-optimization based on the re-contoured daily MR scans. Our study aims to close the gap in knowledge regarding the use of the ATP technique in the treatment of head and neck (HN) cancers through the analysis of accumulated dose of daily ATP plans to organs at risk (OARs).

Daily accumulated doses of 8 HN patients using deformable registration were analyzed to estimate the actual delivered dose versus the planned dose to evaluate the impact from daily anatomical changes and setup uncertainties. This process was completed through the collection of doses to OARs, which were chosen based on the rigidity and size of the organ and the substantial dose it received. Results showed that the actual dose delivered to some OARs was significantly higher than the originally planned dose, and more pronounced in structures that were within the high dose gradient. These findings suggest that the ATS approach should be used for plan adaptation in HN patients where OARs receive substantial dose with anatomy changes that could not be accounted for by the ATP approach.

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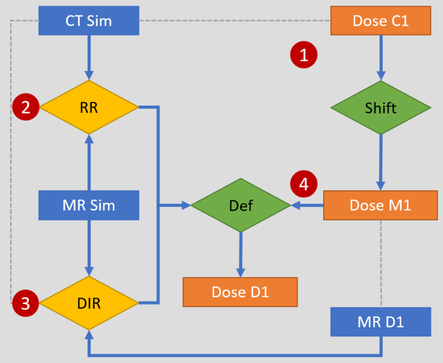
INTRODUCTION

- Treatment with the 1.5 Tesla MR-Linac
  - Daily online plan adaptation
  - Simultaneous tumor imaging with MRI
- Two adaptation approaches:
  - Adapt-to-position (ATP)
  - Adapt-to-shape (ATS)
- Analyze accumulated dose received by patients treated with the ATP approach on an MR-Linac:
  - To create dosimetric criteria for sub-disease sites of HN patients to assist clinicians in choosing proper daily adaptation methods
  - To evaluate whether an ATS approach should be used for a specific sub-disease site
- Evaluate prediction accuracy of actual OAR dose during a treatment course to determine how soon the ATS approach should be performed to achieve better dosimetric goals

METHODS AND MATERIALS

- Patient data (Table 1)
  - Eight HN patients treated on MR-Linac
  - Selection criteria
    - Long treatment course
    - ATP approach for daily plan adaptation
    - At least one OAR near the treatment target
  - Four sub-disease sites for analysis
    - Sinus
    - Tonsil-hypopharynx (TH)
    - Base of tongue (BOT)
    - True vocal cord (TVC)
- Dose deformation



Dotted lines indicate the association of a dose to the image, e.g. Dose C1 is associated with CT sim

- Calculation of summed ATP dose
  - Represents the planned delivered dose

$$[D]^n_{ATP} = \sum_{i=1}^{n} \frac{1}{N}[D_{ATP}]_i + \frac{N-n}{N}[D_{ATP}]_n \quad (1)$$

- Calculation of accumulated deformed dose
  - Represents the actual delivered dose when n=N

$$[D]^n_{DEF} = \sum_{i=1}^{n} \frac{1}{N}[D_{DEF}]_i + \frac{N-n}{N}[D_{ATP}]_n \quad (2)$$

SUB-ANATOMICAL SITES	NUMBER OF PATIENTS	EVALUATED OARs	CONSTRAINTS
Sinus	1	Cochlea	Max < 35 Gy
		Parotid	Mean < 26 Gy
		Optic Chiasm	Max <54 Gy
		Optic Nerve	Max <54 Gy
		Spinal Cord	Max < 45 Gy
Tonsil-Hypopharynx	2	Cochlea	Max < 35 Gy
		Parotid	Mean < 26 Gy
		Spinal Cord	Max < 45 Gy
True Vocal Cord	2	Spinal Cord	Max < 45 Gy
Base of tongue	3	Brachial Plexus	Max < 66 Gy
		Cochlea	Max < 35 Gy
		Parotid	Mean < 26 Gy
		Spinal Cord	Max < 45 Gy

Table 1. Summary of patients and OARs evaluated

RESULTS

- Differences in planned and delivered dose vary significantly (Table 2)
  - Delivered doses to the spinal cord of BOT patients ranged from 3-4 Gy higher than planned doses
  - BOT#1 patient's spinal cord dose exceeded constraints
  - 4 of 6 patients received markedly higher doses than planned for the parotids

Dose (Gy) D_p=planned D_d=delivered	SINUS		TH#1		TH#2		BOT#1		BOT#2		BOT#3		TVC#1		TVC#2	
	D_p	D_d	D_p	D_d	D_p	D_d	D_p	D_d	D_p	D_d	D_p	D_d	D_p	D_d	D_p	D_d
Spinal Cord	42.27	42.38	43.18	46.53	45.13	46.41	44.29	48.25	33.19	37.09	41.71	44.85	11.63	14.97	13.13	17.84
L Cochlea	30.75	33.55	9.83	15.55	38.14	45.51	35.84	32.45	60.57	59.67	59.69	59.44	-		-	
R Cochlea	28.40	29.96	6.36	7.42	35.55	30.64	35.78	36.88	4.98	3.88	37.90	52.14	-		-	
L Parotid	23.96	25.05	24.06	25.22	57.79	56.52	30.49	31.55	18.93	17.09	24.91	28.70	-		-	
R Parotid	25.29	24.80	24.52	25.25	24.60	23.87	28.77	21.87	20.99	17.48	27.15	28.24	-		-	
Optic Chiasm	50.33	51.64	-		-		-		-		-		-		-	
L Optic Nerve	53.85	52.15	-		-		-		-		-		-		-	
R Optic Nerve	51.66	52.61	-		-		-		-		-		-		-	

Table 2. Final planned and delivered dose to OARs for all patients

- OAR dose prediction using Equation (2) was plotted as a function of fraction numbers
  - Serial structures evaluate maximum dose, whereas parallel structures evaluate mean dose criteria
  - Serial structures tend to fluctuate more with larger margins compared to parallel structures (Figures 1 and 2)
  - Parotid dose can be predicted accurately around 14 fractions; dose to cochlea cannot be predicted until the treatment course is nearly complete

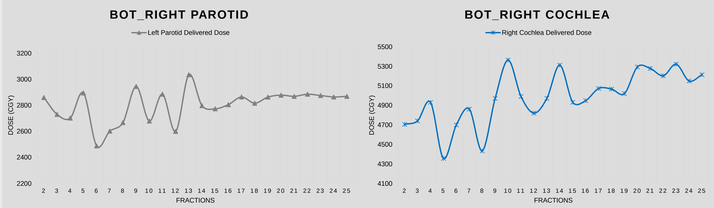


Figure 1. Delivered dose to Right Parotid and Right Cochlea in BOT#3 patient

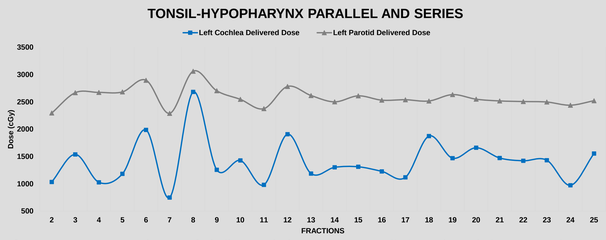


Figure 2. Comparison of delivered doses to parallel and serial organs in TH#1

DISCUSSION

- Results demonstrate that the ATS approach is best for BOT patients
  - Most OARs receive substantial dose
  - Setup uncertainty and daily anatomy changes greatly affect OAR dose
  - ATS can optimize dose delivered to these OARs
- Study of dose prediction in a treatment course helps determine the OAR to be used in each sub-disease site to trigger ATS approach if necessary.
  - Serial structures are more sensitive to setup uncertainties
- A notable limitation of this study is the number of patients in each sub-anatomical site
- Further research should optimize a combination of ATP and ATS approaches to balance treatment efficiency and accuracy

CONCLUSIONS

- The ATP approach meets more dosimetric goals for TVC patients
- The ATS approach is more suitable for BOT patients with high OAR doses
- A combination of the ATP and ATS approaches may the best for sinus and TH patients
- The process of predicting final delivered dose is more reliable for parallel organs than for serial organs. The accuracy of dose prediction may be influenced by the organ's location (e.g. high dose gradient area) and setup accuracy

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