Improving proton dose delivery for swelling HN targets via range-based patient setup

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2026 JULY 19–22 VANCOUVER, BC
JOINT AAPM | COMP MEETING

ABSTRACT

Purpose: Proton HN patients often experience target volume changes. Our investigation of daily CBCTs showed the changes from swelling to shrinkage happening mostly within one week. Offline adaptation takes about one week to create a replan and thus very possibly the replan for the swelling target is used in the already shrinking target. We propose range-based registration instead of replanning to improve dose delivery to swelling targets.

Methods and Materials: 5 proton head-and-neck patients replanned due to target swelling were studied. A range-based registration algorithm was developed to register the QACTs to the planning CT. The algorithm rigidly searched the registration parameters (shift only in this work) to minimize the deviation of water equivalent thickness (WET) of the target and meanwhile balance the WETs between their corresponding D95 and V98. The WET deviations corresponding to D95=95 and V98=90 were determined by analyzing the robustness of the treatment plan. With the extra shifts obtained from range-based registration, standard QACT-plan evaluation procedures were performed to deform the target contours from the planning CT to QACTs and then to calculate the dose from the treatment plan to the QACTs in the treatment planning system.

Results: For the 5 investigated QACTs, the mean D95 increased from 90.9% to 97.1% of the prescribed dose. Extra lateral shifts were from 1 to 4 mm determined by our range-based registration. One of them had D95=91.2% in a QACT registered to the planning CT by image-based setup but increased to 98.7% in the QACT with extra shifts (-2, 0, 1) mm in the lateral, AP and SI directions.

Conclusion: Image-guided patient setups for all cases used in this study were acceptable, but delivered doses were not acceptable unless extra shifts were applied. Range-based registration significantly improved proton dose delivery to the intended targets.

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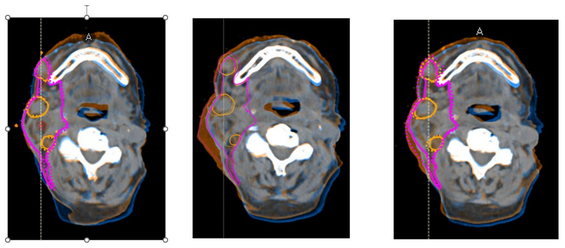
INTRODUCTION

Proton HN patients often experience target volume changes. Weekly or bi-weekly QACTs are usually scheduled to monitor the anatomy changes to determine the necessity of adaptation. For a swelling target, D95 can be significantly affected. Our investigation of daily CBCTs showed the changes from swelling to shrinkage happening mostly within one week. However, offline adaptation procedures from QACT scanning to the replanning ready for treatment take about one week and thus very possibly the replan for the swelling target is used in the already shrinking target. We propose range-based registration instead of replanning to improve dose delivery to swelling targets online.

METHODS AND MATERIALS

5 proton head-and-neck patients replanned due to target swelling were studied. A range-based registration algorithm was developed to register the QACTs to the planning CT. The algorithm rigidly searches the registration parameters (shift only in this work) to minimize the deviation of water equivalent thickness (WET) of the target and meanwhile balance the WETs between their corresponding D95 and V98. The WET deviations corresponding to D95=95 and V98=90 were determined by analyzing the robustness of the treatment plan. With the extra shifts obtained from range-based registration, standard QACT-plan evaluation procedures were performed to deform the target contours from the planning CT to QACTs and then to calculate the dose from the treatment plan to the QACTs in the treatment planning system. In this work, we show the improvement in D95 for swelling head-and-neck (HN) patients.

Figures below show the swelling progress from no swelling on QACT1 on March 5, significant swelling on QACT2 on March 12, and shrinking back on QACT3 on March 19. A replan was triggered by QA2 and started treatment on March 19.



QA1_0305 | QA2_0312 Replanned | QA3_0319

Our range-based registration algorithm is as follows.

$$\max_{\Delta\vec{r}}\left\{\sum_{CTVi}\left[5\,c_i\left(\Delta\mathrm{WET}_{\mathrm{ref}\,D_{95}}(\Delta\vec{r})-\Delta\mathrm{WET}_{D_{95}}(\Delta\vec{r})\right)+d_i\left(\Delta\mathrm{WET}_{\mathrm{ref}\,V_{98}}(\Delta\vec{r})-\Delta\mathrm{WET}_{V_{98}}(\Delta\vec{r})\right)\right]\right\}$$

$$c_i=\begin{cases}1 & \text{if } \Delta\mathrm{WET}_{\mathrm{ref}\,D_{95}}(\Delta\vec{r})>\Delta\mathrm{WET}_{D_{95}}(\Delta\vec{r})\\ -10 & \text{otherwise}\end{cases}$$

$$d_i=\begin{cases}1 & \text{if } \Delta\mathrm{WET}_{\mathrm{ref}\,V_{98}}(\Delta\vec{r})>\Delta\mathrm{WET}_{V_{98}}(\Delta\vec{r})\\ -2 & \text{otherwise}\end{cases}$$

RESULTS

Figures below display the results of the range-based setup on QACTs for one patient who experienced anatomic changes from swelling to shrinking. The changes were caught by pre-scheduled QACTs.

- For the QACT2 with swelling, extra shift = (4, 1, -1) mm after image-based registration that was performed by the dosimetrist for QACT evaluation. Right upper: DVHs from the image-based setup, and Right lower: DVHs from the range-based setup.

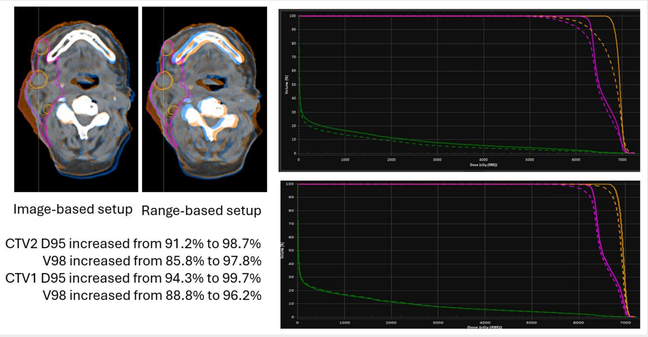
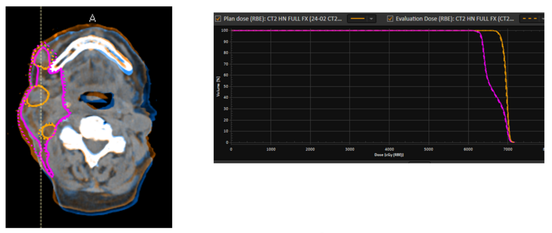


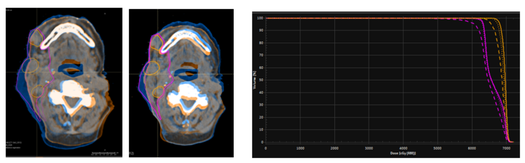
Image-based setup Range-based setup

CTV2 D95 increased from 91.2% to 98.7%
V98 increased from 85.8% to 97.8%
CTV1 D95 increased from 94.3% to 99.7%
V98 increased from 88.8% to 96.2%

- For the QACT3 with shrinkage, shift=(0,-1,0)

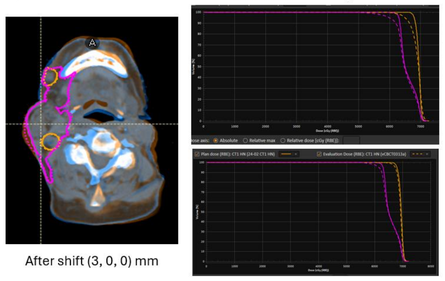


- For the QACT5 with shrinkage, the original registration is not based on bony structures. Using range-based registration, the result is much better.



original new CT2 original new

- For CBCT, we use MIM to obtain vCBCT then perform range-based setup.

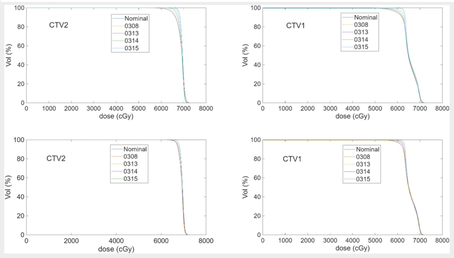


original

new

After shift (3, 0, 0) mm

In total 17 CBCTs before the replan was used, at least 8 setups used bony structure. With range-based setup, 5 setups with bony structure need shift 2 or more mm. Figures below show the DVH improvement from our range-based registration for one patient.



The table below lists the results on 5 investigated HN cases.

Case	target	D95 (%) original	D95 (%) new	Shift (mm)	Improvement (%)
1	CTV_h	91.8	95.0	(0, 1, 1)	3.2
2	CTV_h	86.3	93.4	(-2, 0, -1)	7.1
3	CTV_m	91.6	98.8	(-4, -1, 1)	7.2
4	CTV_m	91.2	98.7	(-2, 0, 1)	7.5
5	CTV_l	93.7	99.4	(-2, 0, 1)	5.7
Average		90.9	97.1		6.1

For the 5 investigated QACTs, the mean D95 increased from 90.9% to 97.1% of the prescribed dose. Extra lateral shifts were from 1 to 4 mm determined by our range-based registration. One of them had D95=91.2% in a QACT registered to the planning CT by image-based setup but increased to 98.7% in the QACT with extra shifts (-2, 0, 1) mm in the lateral, AP and SI directions.

DISCUSSION

Image-guided patient setups for all cases used in this study were acceptable, but delivered doses were not acceptable unless extra shifts were applied. Range-based patient setup mitigates proton beam range deviation due to anatomy changes and thus improves delivery accuracy. Essentially, we are utilizing the plan robustness on setup uncertainties to improve dose delivery.

In the total 80 patients investigated, 19 patients experienced swelling > 3mm in the course of treatment. 3 of them were caught by QACT and replanned. Most cases of the swilling were missed by weekly and bi-weekly QACTs because the swilling period was mostly within one week. From our study, swelling will decrease the target dose coverage significantly.

CONCLUSIONS

Range-based registration can significantly improve proton dose delivery to the intended targets, with much less resource required compared to online adaptative treatment.

REFERENCES

1. Yao W, Krasin M, Far JB, Merchant TE. Feasibility study of range-based registration using daily CBCT for proton therapy. Medical Physics. 45:1191-1203, 2018.
2. Yao W, Zhang B, Han D, Polf J, Vedam S, Lasio G, Yi B. Use of CBCT plus plan robustness for reducing QACT frequency in intensity-modulated proton therapy: Head-and-neck cases. Medical Physics, 2022; 49(11):6794-6801.