Robust fine-tune optimization of ion pencil beam scanning plans

Background

Radiation therapy treatment plans can be created in various ways. RayStation provides a method for fine-tune optimization that tweaks plans to better fulfill the clinical goals. This method has proved useful to quickly improve IMRT plans. However, lack of support for robust optimization has hindered its use for ion PBS planning, where uncertainties must be considered. We have therefore developed support for robust fine-tune optimization considering uncertainties in range, setup, and organ motion (4D optimization).

Methods

Fine-tune optimization employs functions directly penalizing deviations from desired clinical goal levels [1], formulated as

$$f\big(\psi_j(d(x)), \hat{\psi}_j\big),$$

where $d(x)$ is the dose distribution given variables x (e.g., spot weights), ψ_j is a function measuring the clinical goal j from the clinical goal set G, and $\hat{\psi}_j$ is the desired level for the goal, which is based on the initial plan, either improving or maintaining the goal. When considering uncertainty, we use a scenario set S and compute the scenario dose $d(x; s)$ for each scenario s. Worst-case robust fine-tuning minimizes the objective

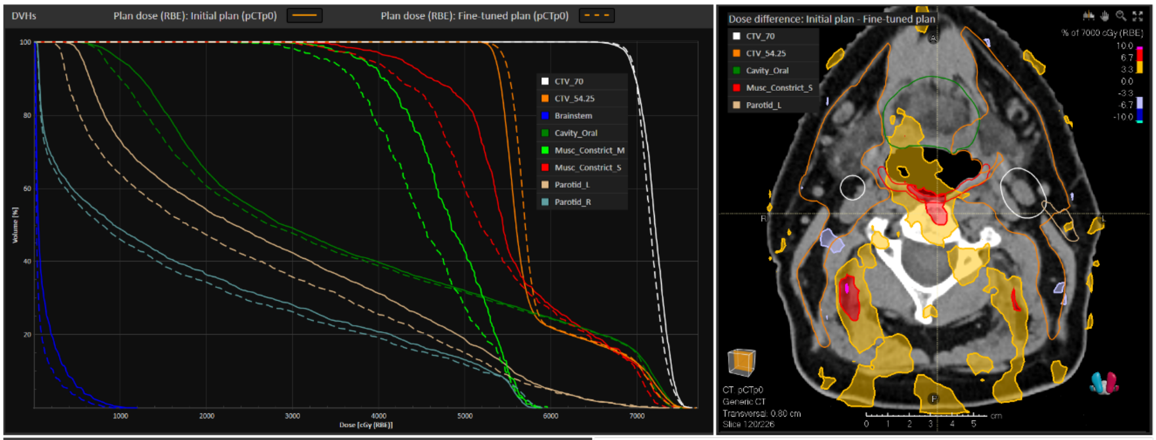
$$\max_{s \in S} \sum_{j \in G} f\big(\psi_j(d(x; s)), \hat{\psi}_{j,s}\big),$$

where $\hat{\psi}_{j,s}$ is the desired level for goal j in scenario s, based on the initial plan and varying across scenarios.

The evaluation was performed on an oropharynx patient with two CTVs with prescriptions 54.25 Gy and 70 Gy. The high dose CTV was encompassed in the low dose CTV. A proton PBS plan was robustly optimized with 3 mm setup and 3% density uncertainty and compared to a fine-tuned version of the plan.

Results

Fine-tuning improved target coverage robustness and decreased the OAR doses. The fine-tuned plan fulfills the clinical goals, including those for the high dose CTV, in more scenarios than the initial plan, as shown in Figure 1.



Robustness evaluation		Initial plan		Fine-tuned plan	
ROI/POI	Clinical goal	Passed	Worst scenario	Passed	Worst scenario
CTV_70	D1.80 cm³ ≤ 7490 cGy (RBE)	67 %	7519 cGy (RBE)	100 %	7487 cGy (RBE)
CTV_70	D98.00 % ≥ 6650 cGy (RBE)	75 %	6622 cGy (RBE)	100 %	6689 cGy (RBE)
CTV_54.25	D98.00 % ≥ 5154 cGy (RBE)	100 %	5271 cGy (RBE)	100 %	5359 cGy (RBE)
Brainstem	D0.00 % ≤ 5400 cGy (RBE)	100 %	1318 cGy (RBE)	100 %	1157 cGy (RBE)
Cavity_Oral	D50.00 % ≤ 3000 cGy (RBE)	50 %	3499 cGy (RBE)	75 %	3397 cGy (RBE)
Musc_Constrict_M	D50.00 % ≤ 5500 cGy (RBE)	100 %	5231 cGy (RBE)	100 %	4982 cGy (RBE)
Musc_Constrict_S	D50.00 % ≤ 5500 cGy (RBE)	67 %	5639 cGy (RBE)	100 %	5433 cGy (RBE)
Parotid_L	D50.00 % ≤ 2600 cGy (RBE)	83 %	3001 cGy (RBE)	100 %	2410 cGy (RBE)
Parotid_R	D50.00 % ≤ 2600 cGy (RBE)	100 %	1452 cGy (RBE)	100 %	1292 cGy (RBE)

Top left: *DVHs for the initial plan (solid) and the fine-tuned plan (dashed).* ***Top right:*** *Dose difference between the initial plan and the fine-tuned plan. Positive values (yellow, red, magenta) correspond to a reduction of dose after the fine-tuning was performed.* ***Bottom left:*** *Robustness evaluation of the clinical goals evaluated over 21 error scenarios. The fine-tuned plan passes the clinical goals in at least as many scenarios as the initial plan and improves on the clinical goal fulfillment in the worst-case scenario.*

Conclusions

Robust fine-tuning was implemented in a research prototype of RayStation. For an oropharynx case treated with protons, it provided improved robust clinical goal fulfillment without requiring manual iterative planning.

References

[1] Zhang, T., Bokrantz, R., & Olsson, J. (2020). Direct optimization of dose–volume histogram metrics in radiation therapy treatment planning. *Biomedical Physics & Engineering Express*, *6*(6), 065018.