ROBUST OPTIMIZATION IN RAYSTATION

Setup errors, density errors, and organ motion can lead to delivered dose distributions that deviate highly from the planned distributions in radiation therapy. In particle therapy, the sharp gradients of the pencil beams make the treatments sensitive to uncertainties. The conventional method to take errors into account during treatment planning is to plan with margins such as when using Planning Target Volumes (PTVs). For cases of heterogeneous density, and especially in particle planning, conventional margins often cannot provide the intended robustness against uncertainties.

ROBUST METHOD

To enable the creation of robust plans for cases where conventional margins do not work, RayStation implements a robust optimization method that explicitly takes into account the effects of possible errors. The optimization then strives for plans that are robust against these effects. The basis of this method is minimax optimization, in which the optimization functions that have been selected to be robust are considered under the worst case scenario [1].

The worst case scenario is the realization of uncertainty under which a robust function attains its highest value. If several functions are selected to be robust, their weighted sum in the worst case scenario is considered. Minimax optimization of n functions f1,…,fn, which are all required to be robust over the scenarios enumerated by the set S, and which have nonnegative importance weights w1,…,wn, can be formulated as an optimization problem on the form

$$\min_{x \in X} \max_{s \in S} \sum_{i=1}^{n} w_i f_i(d(x; s)), \qquad (1)$$

where X is the set of feasible variables (e.g., MLC leaf positions and segment weights for IMRT or spot weights for IMPT), and d(x;s) is the dose distribution as a function of the variables x and the scenario s. Functions applied only to the nominal scenario can also be added to the objective. Moreover, nominal and robust constraints can be used in combination with formulation (1).

UNCERTAINTIES

The set of scenarios forms a discretization of the errors against which the plan should be robust. If patient setup errors and range errors are considered, each scenario determines a specific combination of a setup and a range error. Setup uncertainties are specified similar to an expansion of a ROI, whereas range uncertainty is specified as a percentage, see Figure 1.

The setup uncertainty can be considered to be the same for all beams, or to independently affect each beam. The latter case can be used to create robustly matched fields.

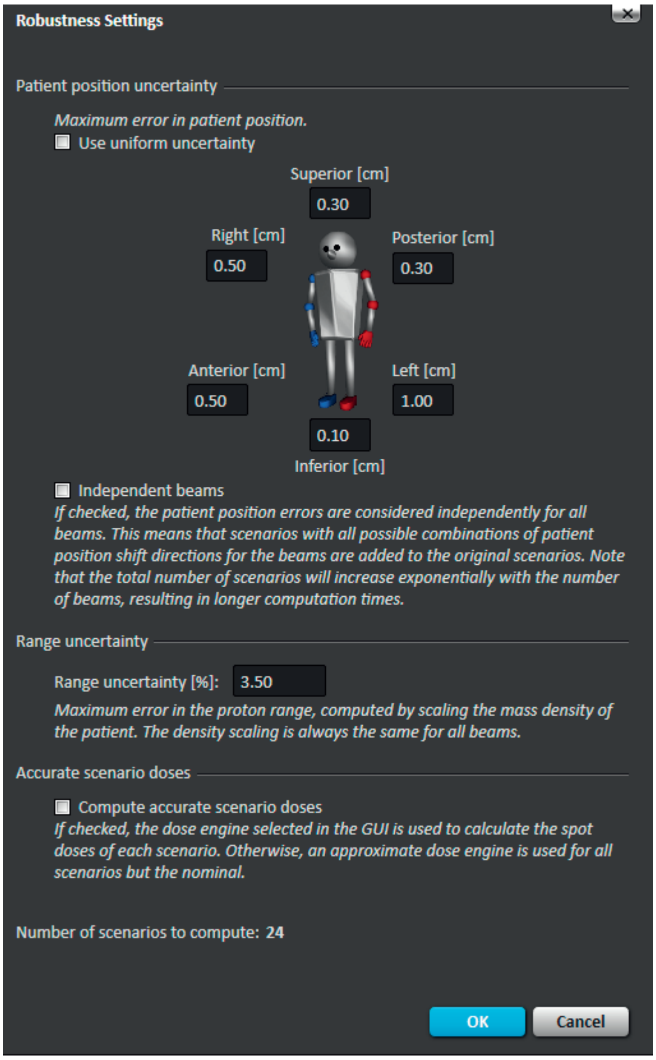
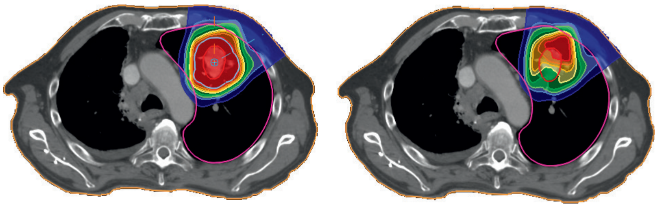


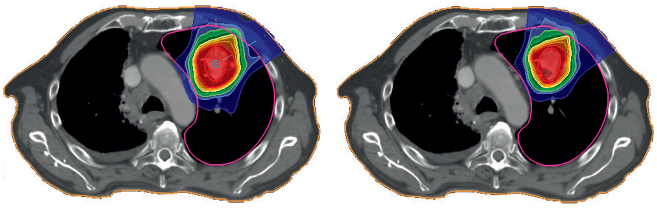
Figure 1. *In the robustness settings dialog, the user can specify the maximum magnitude of the uncertainties to be taken into account.*

Example 1

Robust optimization for IMPT applied to a lung case subject to at most 0.5 cm setup errors and 3.5 % density errors was compared to margin-based planning. Transversal slices under the nominal scenario and under a perturbed scenario are shown in Figure 2. The figure illustrates that robust optimization can lead to improved robustness at the same time as decreased integral dose compared to conventional margins.



(a) Margin-based plan, nominal scenario *(b) Margin-based plan, perturbed scenario*



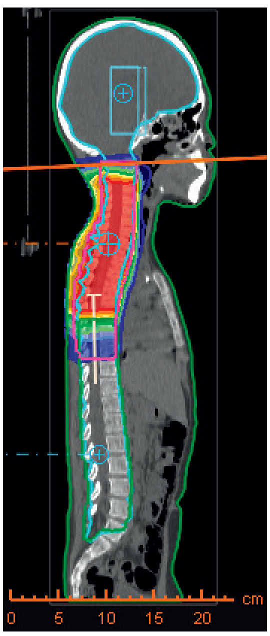
(c) Robust plan, nominal scenario *(d) Robust plan, perturbed scenario*

Figure 2. *Comparison between a robustly optimized plan and a margin-based plan applied to a lung case under the nominal scenario and under a 0.5 cm superior setup shift and a 3.5 % density increase. The robustly optimized plan retains target coverage when the perturbation occurs, while the target coverage of the margin-based plan deteriorates substantially.*

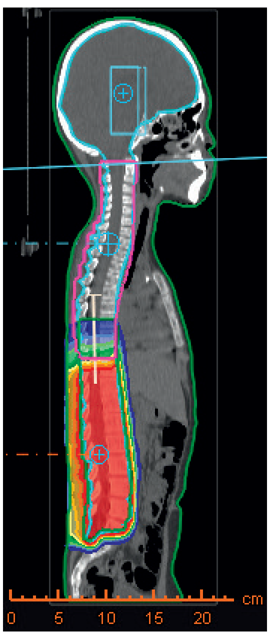
Example 2

Robust optimization was applied to a craniospinal case treated with IMPT. Setup uncertainty along the craniospinal axis affecting the beams independently was assumed in order for the optimization to yield robustly matched fields. Figure 3 shows the resulting field junction between the lower and upper spine fields.

(a)



(b)



(c)

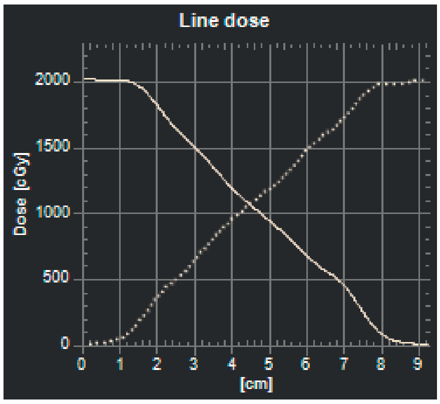


Figure 3. *(a) and (b) Beam doses of the beams irradiating the upper and lower spine. (c) The line dose over the field junction.*

STUDIES

RayStation's robust optimization has been applied to treatment planning for IMPT, for which it was found to improve robustness compared to margin-based IMPT planning, also when the margin-based planning used the single-field uniform dose technique [1,2]. It has also been found to provide robustness against setup errors more effectively in terms of normal tissue sparing than intensity-modulated photon therapy plans using PTVs [2,3]. The benefit of using robust optimization increased with the magnitude of the uncertainties [3].

CONCLUSION

Planning with a PTV has proven to be effective for photon therapy. However, in particle planning, the high beam dose gradients make conventional margins ineffective. To overcome this challenge, RayStation features robust optimization, which provides robustness also in cases where conventional margins fail. This ensures the precision of particle therapy can be utilized even in the presence of uncertainties.

REFERENCES

[1] Fredriksson, A., Forsgren, A., Hårdemark, B., *Minimax optimization for handling range and setup uncertainties in proton therapy*, Med. Phys. 38(3): 1672–1684, 2011.

[2] Stuschke, M., Kaiser, A., Pöttgen, C., Wolfgang, L., Farr, J., *Potentials of robust intensity modulated scanning proton plans for locally advanced lung cancer in comparison to intensity modulated photon plans*, Radiather. Oncol., 104(1): 45–51, 2012.

[3] Stuschke, M., Kaiser, A., Abu-Jawad, J., Pöttgen, C., Levegrün, S., Farr, J., *Multi-scenario based robust intensity-modulated proton therapy (IMPT) plans can account for set-up errors more effectively in terms of normal tissue sparing than planning target volume (PTV) based intensity-modulated photon plans in the head and neck region*. Radiat. Oncol. 8(1): 145, 2013.

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