ROBUSTNESS IN PROTON ARC TREATMENTS FOR HEAD AND NECK CANCER PATIENTS:

IMPACT OF GANTRY ANGLE SPACING AND NUMBER OF REVOLUTIONS

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PURPOSE

Plan robustness might be a challenge in proton arc therapy since the spots are distributed over multiple directions. We assess the impact of different gantry angle spacings and number of revolutions on robustness with respect to ***setup and density*** uncertainties as well as to ***interfractional*** changes.

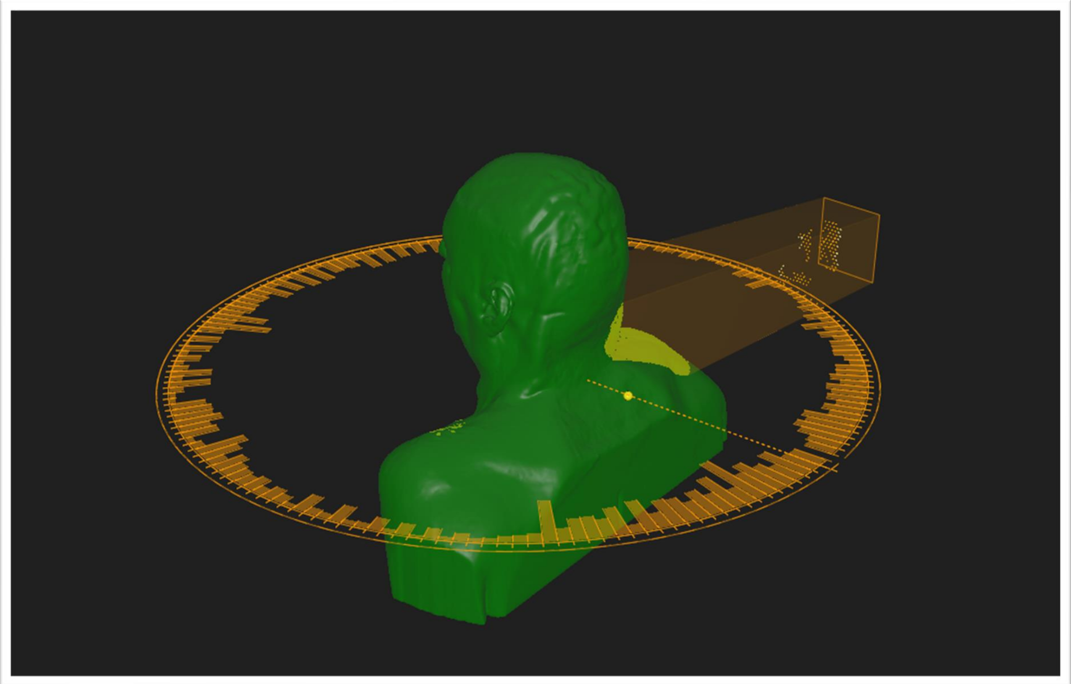


Figure 1. A 3D view of a PBS Arc plan for patient 4. The orange bars represent the relative weight of each energy layer.

METHODS

We employ an Early Layer and Spot Assignment (ELSA) algorithm prior to robust spot weight optimization to design multi-revolutional arc plans for six H&N patients. The arcs are modelled by discrete gantry angles, each angle being assigned no more than one energy layer per revolution.

Multiple plans were created for each H&N patient in a research version of the treatment planning system RayStation: one clinical IMPT plan and six proton arc plans. The six arc plans had 1, 2, or 3 revolutions, and 180 or 360 energy layers spread out evenly over the revolutions. The arc plans used the same objectives as the IMPT plans. All plans were robustly optimized with 3% density and 3 mm setup uncertainty. The spot doses, as well as the final dose, were computed with the Monte Carlo dose engine.

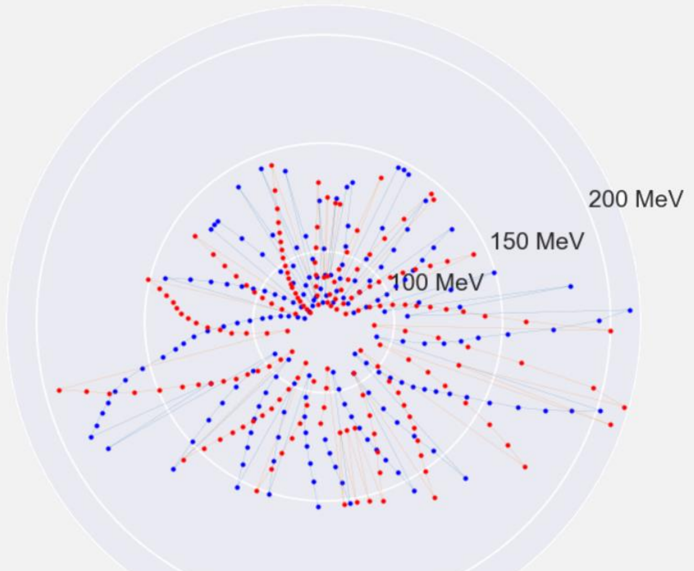
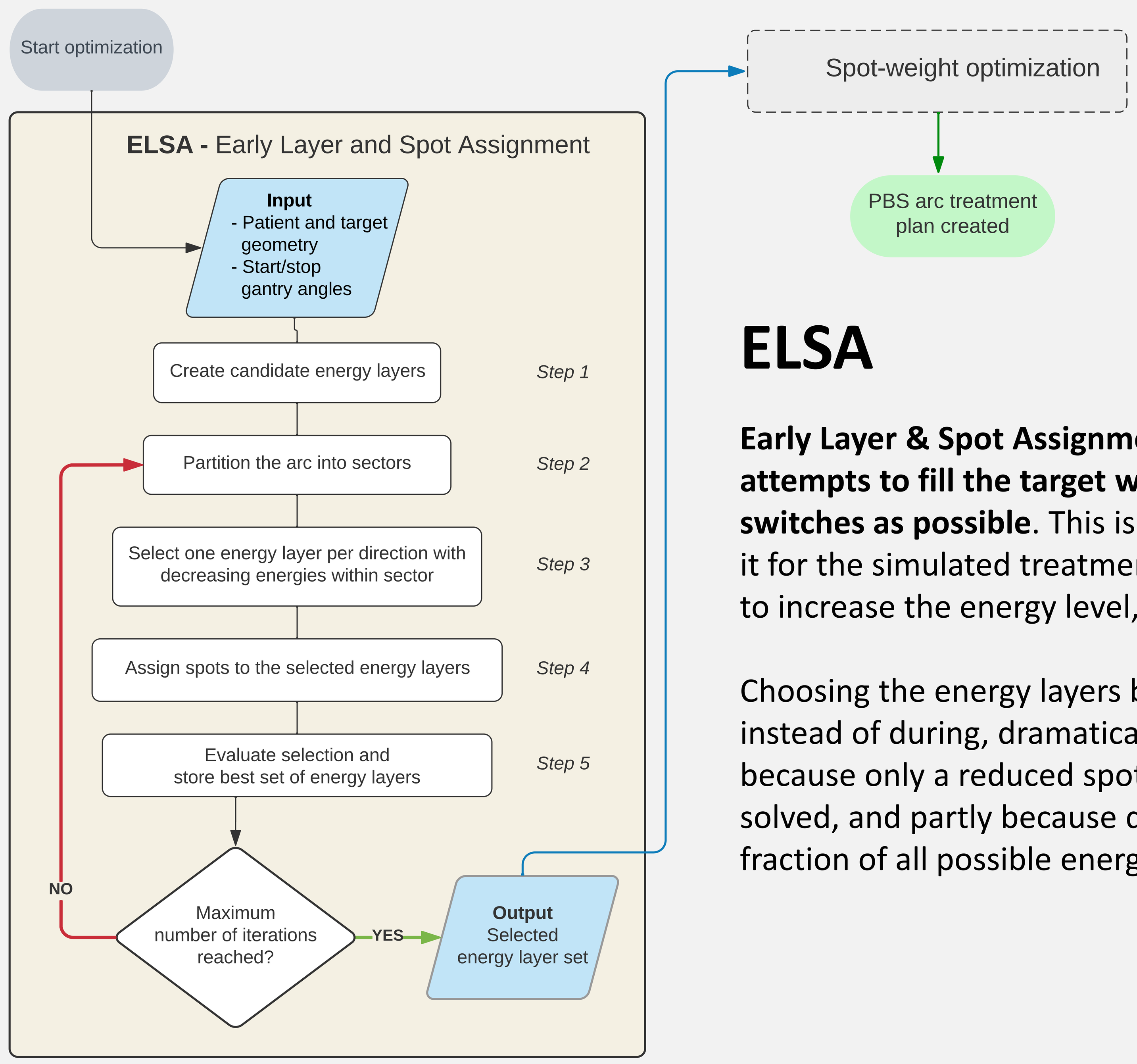


Figure 2. Polar plot of the energy layers for patient 5, with 360 layers on 2 revolutions. Blue depicts the clockwise revolution and the red the counter-clockwise.



ELSA

Early Layer & Spot Assignment is an optimization algorithm which attempts to fill the target with spots using as few upwards energy switches as possible. This is in order to ensure a short delivery time, since it for the simulated treatment machine (IBA ProteusPlus) takes around 5 s to increase the energy level, and 1 s to decrease it.

Choosing the energy layers before the robust spot weight optimization, instead of during, dramatically reduces the running time. This is partly because only a reduced spot weight optimization problem has to be solved, and partly because dose must only be computed for a small fraction of all possible energy layers and spots.

RESULTS

Figure 3 shows robustness evaluation on the planning CT (3% density, 3 mm setup uncertainty) and re-computations on repeated CTs. For a constant number of energy layers distributed over the revolutions, **360 energy layers give better robustness than 180 layers**. Spreading a constant number of layers over several revolutions, i.e., increasing the gantry angle spacing, negatively impacts the robustness.

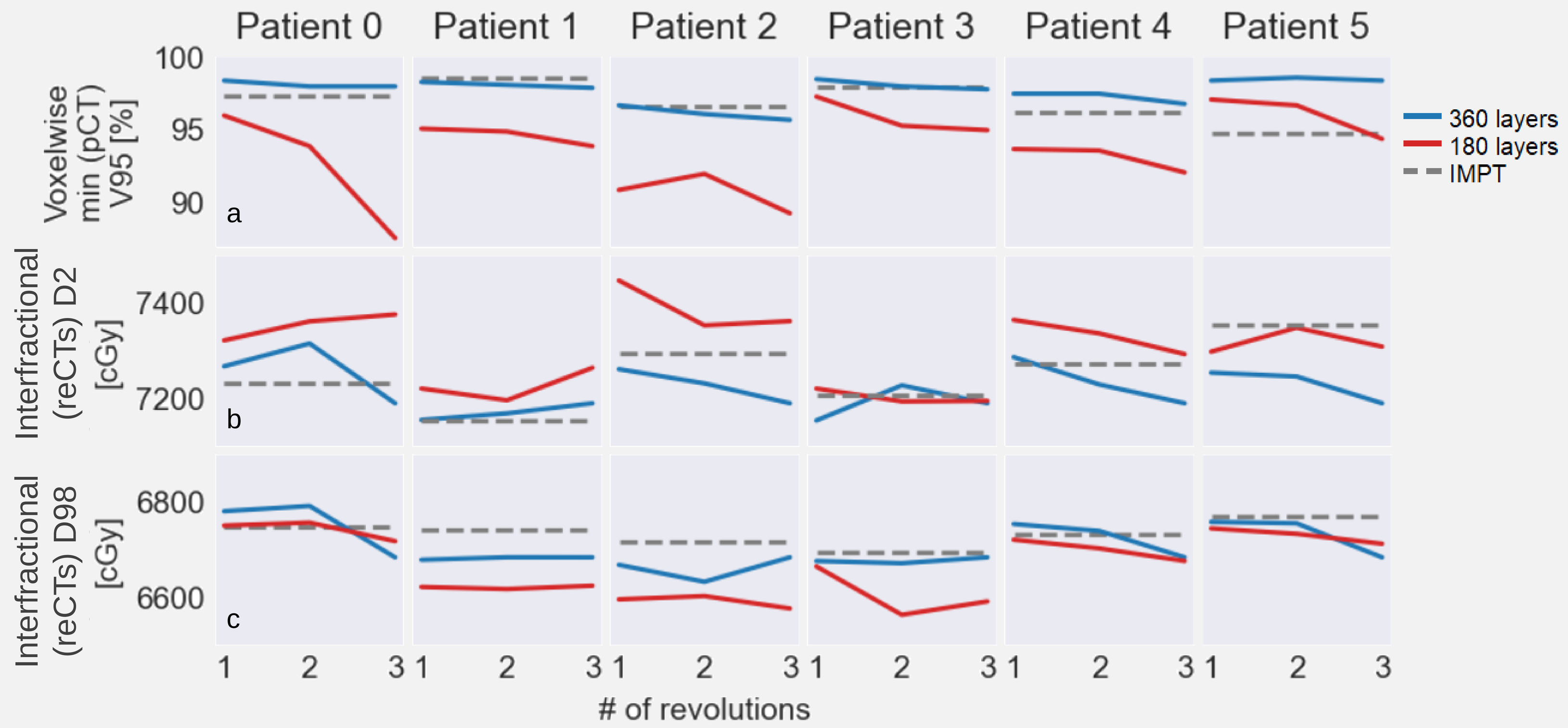


Figure 3. Robustness evaluation, where the rows correspond to (a) the V95 value of the target in the voxelwise minimum dose distribution on the planning CT, (b) the D2 and (c) the D98 of the target for nominal setup and density averaged over all repeated CTs. The columns represent the patients in the study.

	360 Layers			180 Layers		
# of revolutions	1 AVG ± SD	2 AVG ± SD	3 AVG ± SD	1 AVG ± SD	2 AVG ± SD	3 AVG ± SD
CTV_7000 D_{98} [%]	0.1 ± 0.2	0.0 ± 0.2	0.0 ± 0.3	-0.2 ± 0.3	-0.4 ± 0.3	-0.6 ± 0.3
CTV_7000 D_2 [%]	-0.4 ± 0.3	-0.3 ± 0.2	-0.4 ± 0.3	-0.0 ± 0.2	0.2 ± 0.3	0.2 ± 0.2
Spinal cord D_1 [%]	**-72.1 ± 4.4**	**-70.7 ± 5.3**	**-70.0 ± 5.3**	**-66.9 ± 7.5**	**-68.3 ± 4.7**	**-67.3 ± 6.4**
Brainstem D_1 [%]	**-57.8 ± 22.7**	**-58.7 ± 23.4**	**-62.6 ± 20.5**	**-59.4 ± 22.1**	**-56.0 ± 26.6**	**-60.1 ± 24.1**
Parotid_L D_{Mean} [%]	-15.0 ± 2.2	-14.4 ± 2.5	-13.3 ± 1.7	-15.6 ± 2.1	-16.2 ± 2.8	-15.4 ± 1.9
Parotid_R D_{Mean} [%]	-19.9 ± 9.5	-18.2 ± 8.5	-17.9 ± 8.4	-18.0 ± 9.5	-20.9 ± 11.3	-18.8 ± 10.3
Submandibular_L D_{Mean} [%]	-3.2 ± 3.5	-3.1 ± 3.6	-2.5 ± 2.6	-2.8 ± 3.0	-3.0 ± 3.5	-2.5 ± 3.9
Submandibular_R D_{Mean} [%]	-12.6 ± 9.5	-13.0 ± 9.5	-11.7 ± 8.7	-13.7 ± 10.2	-13.8 ± 10.5	-11.9 ± 10.7
Oral cavity D_{Mean} [%]	-1.8 ± 1.4	-1.4 ± 1.3	-0.9 ± 0.6	-1.0 ± 1.1	-0.3 ± 1.1	0.1 ± 1.3
Delivery time [min]	11.3 ± 0.5	13.3 ± 0.9	13.5 ± 1.2	5.7 ± 0.5	8 ± 0.7	9 ± 0.5

Table 1 Dose metrics and delivery time. Dose statistics for the target (CTV_7000) and the OARs in the nominal scenario averaged over all six patients for different number of energy layers and revolutions. The dose statistics are given relative to the clinical IMPT plan. The delivery time (last row) is based on delivery characteristics of an IBA ProteusPlus machine.

All arc plans give increased sparing of OARs compared to the IMPT plans, with drastic improvements in the brainstem and spinal cord (see Table 1), whilst keeping comparable CTV coverages. There is no clear trend between OAR sparing and number of revolutions, nor is there a clear trend between OAR sparing and number of energy layers.

CONCLUSION AND OUTLOOK

In conclusion, robustness in proton arc therapy is a complex topic affected by several factors such as gantry angle spacing and energy layers in non-obvious manners. It is, however, clear that **while 180 energy layers seem to give the desired OAR sparing, more layers are needed to achieve the desired robustness**.

Future studies should investigate the robustness for different treatment sites as well as means to increase robustness of proton arc plans.

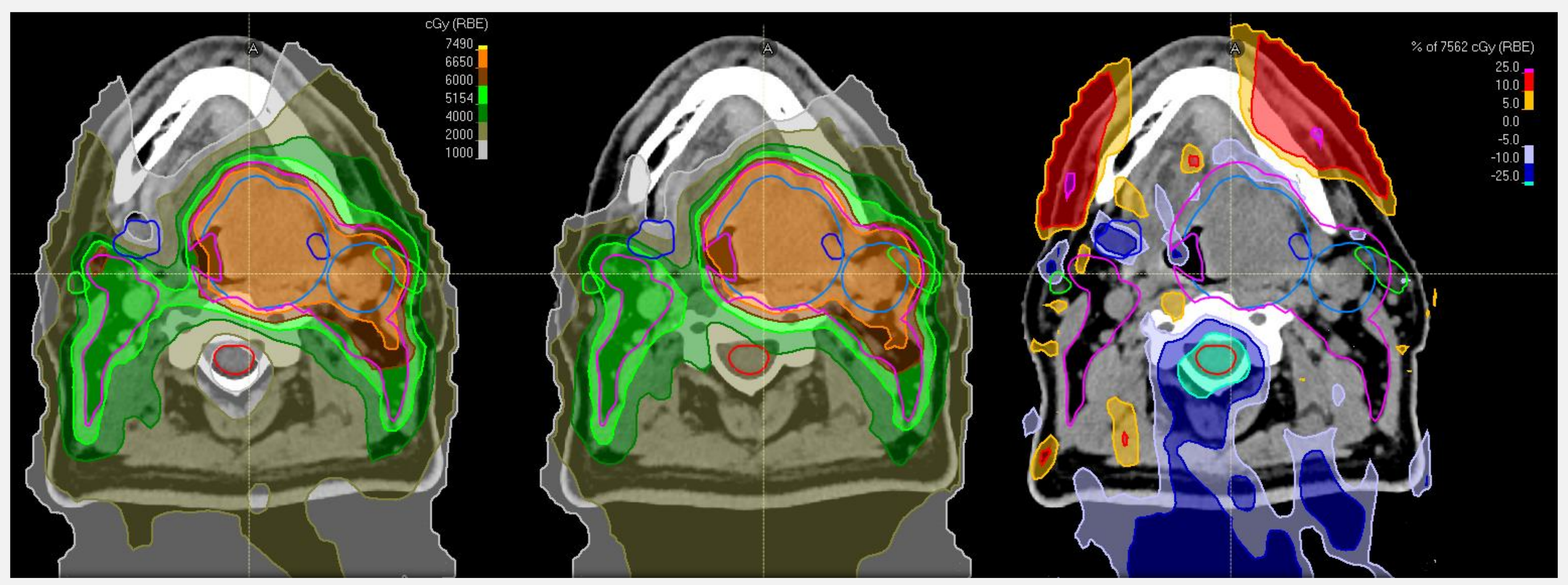


Figure 4. Patient 4. Left: 360 energy layers over 1 revolution. Middle: IMPT. Right: Their difference.