A comparison of various scanned proton pencil beam delivery strategies for the treatment of moving targets

C. O. Ribeiro¹, D. Dumont², J. Terpstra¹, G. Janssens³, J.A. Langendijk¹, S. Both¹, E. Sterpin⁴, A. Knopf¹, A. Meijers¹

¹Department of Radiation Oncology, University Medical Center Groningen, University of Groningen, The Netherlands

²Université catholique de Louvain (UCL), Institut de Recherche Expérimentale et Clinique, Molecular Imaging, Radiotherapy and Oncology, Brussels, Belgium

³Ion Beam Applications (IBA), Advanced Technology Group, Louvain-la-Neuve, Belgium

⁴KU Leuven, Department of Oncology, Laboratory of Experimental Radiotherapy, Leuven, Belgium

PURPOSE

The treatment of moving targets with pencil beam scanned proton therapy (PBS-PT) relies on rescanning strategies to smooth out motion-induced dosimetric disturbances. PBS-PT machines, such as IBA's (Louvain-la-Neuve, Belgium) ProteusPlus (PPlus) and ProteusOne (POne), deliver a continuous or a pulsed beam, respectively. In PPlus, non or scaled rescanning can be applied, while POne implies intrinsic rescanning due to its pulsed delivery. We investigate here the efficacy of these two machine characteristics for the treatment of thoracic tumours.

MATERIALS & METHODS

- 4D optimised PBS-PT treatment plans were calculated for eight non-small cell lung cancer (NSCLC) patients with different target volumes and motion characteristics (**Table 1**)
 - Target motion amplitudes were computed based on 4DCT and averaged over a planning 4DCT and one available verification 4DCT (acquired after half of the treatment course of the patient).
- All created plans were delivered in dry runs at the two types of facilities to obtain machine log files:
 - PPlus (plans with/without range shifter and with/without five times layered rescanning); POne (plan with range shifter).
- By using the acquired log files per plan and all patient 4DCTs, a 4D robustness evaluation method (4DREM) was executed [1]
 - Plan evaluation of the combined impact of PBS-PT disturbing effects: setup and range errors, machine errors, anatomy changes, breathing motion, and interplay effects.
- Treatment plan robustness was then assessed in terms of target coverage through the voxel-wise worst-case dose distribution resultant from the 4DREM.

RESULTS

- In PPlus, rescanning and/or the addition of a range shifter improved the robustness of 4D optimised plans for most patient cases (**Figure 1**).
- Compared to the most robust PPlus plans, no clinically relevant differences in target coverage were observed when constructing POne plans except for one case
 - The voxel-wise worst-case $V_{95}(\text{CTV})$ decreased from 100.00% (PPlus) to 96.84% (POne) for patient Pt.1.
- For the remaining cases, target robustness in the POne plans was maintained compared to the PPlus plans (**Table 1**).

A

Voxel-wise worst-case DVH in CTV

B

Figure 1 – Results of the 4DREM in all created 4D optimised plans of exemplary Pt.5 (PPlus with/without range shifter and non-rescanned, PPlus plan with range shifter and five times layered rescanned, and POne plan with range shifter). This is the patient presenting the largest variations in target robustness between plans. **A**: Voxel-wise worst-case dose distributions resultant from the inclusion of the combined PBS-PT disturbing effects. Values in the colour bar are in % of the prescribed dose to the CTV (66Gy). In orange is the delineated CTV and the green line shows the 95% isodose. **B**: Computed CTV DVH curves of the voxel-wise worst-case dose.

Table 1 Target characteristics (volume and motion) for all eight NSCLC patients included in this study. Voxel-wise worst-case dose distribution $V_{95}(\text{CTV})$ values extracted from the 4DREM for all evaluated PPlus and POne plans.

Patient	CTV		Plan			
			Voxel-wise worst-case $V_{95}(\text{CTV})$ [%]			POne
	Volume [cm ³]	Motion [mm] (mean ± SD)	No rescanning	Rescanned	With range shifter	
Pt.1	1.7	4.5 ± 0.4	98.26	99.56	100.00	96.84
Pt.2	9.5	3.1 ± 1.4	90.32	97.94	99.75	99.13
Pt.3	6.9	4.0 ± 1.8	96.65	100.00	100.00	99.07
Pt.4	148.2	6.5 ± 0.4	99.73	98.89	98.98	99.81
Pt.5	9.3	7.3 ± 1.4	94.13	96.07	98.51	99.99
Pt.6	48.9	10.7 ± 0.5	99.89	99.44	99.80	99.91
Pt.7	333.2	2.0 ± 1.0	97.17	98.94	99.08	99.90
Pt.8	123.3	5.5 ± 1.5	95.19	99.69	100.00	99.22

Abbreviations: $V_{95}(\text{CTV})$ = volume of CTV receiving at least 95% of the prescribed dose.

CONCLUSION

Rescanning enables the mitigation of potential disturbing effects of PBS-PT treatments of moving targets. In general, with both PPlus and POne machines, clinically acceptable plans can be achieved. The intrinsic rescanning of POne did not show to be more effective than the scaled rescanning of PPlus to treat NSCLC.

References:

[1] C. O. Ribeiro, A. Meijers, E. W. Korevaar, C. T. Muijs, S. Both, J. A. Langendijk, A. Knopf, "Comprehensive 4D robustness evaluation for pencil beam scanned proton plans", *Radiotherapy and Oncology* 2019, Volume 136, Pages 185–189.

E-mail:

c.oraboni.ribeiro@umcg.nl