A filtering approach for PET and PG predictions in a proton treatment planning system

M. Pinto[1], K. Kröniger[1], J. Bauer[2,3], R. Nilsson[4], E. Traneus[4], K. Parodi[1]

[1] Ludwig-Maximilians-Universität München, Department for Medical Physics, Garching b. München, Germany.
[2] Heidelberg University Hospital, Department of Radiation Oncology, Heidelberg, Germany.
[3] National Centre for Radiation Oncology NCRO, Heidelberg Institute for Radiation Oncology HIRO, Heidelberg, Germany.
[4] RaySearch Laboratories AB, Research Department, Stockholm, Sweden.

JULY 12–16 2020 VIRTUAL
JOINT AAPM | COMP MEETING
EASTERN TIME [GMT-4]

INTRODUCTION

- Proton therapy exhibits physical advantages with respect to photons.
- However, proton therapy is also more sensitive to deviations from the treatment plan.
- Protons undergo nuclear interactions, which create positron emitters (PE) and prompt gamma (PG) radiation.
- In-vivo monitoring techniques are regarded as means to improve the treatment quality assurance for proton therapy.

AIM

- Due to different underlying physical processes, dose deposition and PE/PG production are not directly comparable to each other, which prevents direct treatment verification.
- To date, predictions mostly rely on Monte Carlo (MC) simulation tools, posing severe time constraints for large-scale use.
- Routine clinical deployment demands fast and accurate tools to obtain monitoring outcome predictions.
- We present a fast and accurate analytical method based on the so-called filtering approach (1) to predict PET/PG distributions.

METHOD

- Treatment planning systems (TPS) are particularly suitable for implementation of the filtering approach, namely with the pencil beam algorithm.
- We implemented the filtering approach for PET and developed a novel method based on the same approach for PG monitoring. Both cases were implemented in a research version of the commercial TPS RayStation (RaySearch Laboratories, Stockholm, Sweden).
- Calculation of a PE/PG prediction for an entire treatment plan in a few seconds.

PET

- ✓ The biological and physical decays are considered to estimate activity.
- ✓ The decays are considered using the delivery timing parameters after importing beam machine records or using a beam delivery time model.
- ✓ The PET scanner response is modeled as a Gaussian response function as an approximation to allow for direct comparison with measurements.

PG

- ✓ The PG emission has a broad energy range, with different energy windows of interest for treatment monitoring. Our implementation allows for arbitrary energy windows to be deployed in any scenario.
- ✓ Our implementation estimates the PG energy spectrum and yields per voxel to predict production maps or use a PG camera model.

RESULTS

- ❑ Four patients treated at Heidelberger Ionenstrahl-Therapiezentrum, Heidelberg, Germany (HIT) with scanned proton beams followed by offline PET were considered.
- ❑ Patients P1 and P3 received one field from a fixed horizontal beamline for an acoustic neuroma and a sacral chordoma, respectively.
- ❑ Patient P2 was treated for an astrocytoma with two fields from the fixed horizontal beamline.
- ❑ Patient P4 was treated for a cervical paraganglioma with two fields from the gantry beamline.
- ❑ Shifts assessed using a NURBS function obtained from the TPS distributions and fit to the Monte Carlo ones.
- ❑ Additional information can be found in Pinto et al. (2).

Figure 1: Comparison of distributions (dose, PE and PG from left to right) between TPS and MC distributions for all patients (P1 to P4 from top to bottom). Patients P2 and P4 display the cumulative result of the two irradiated fields.

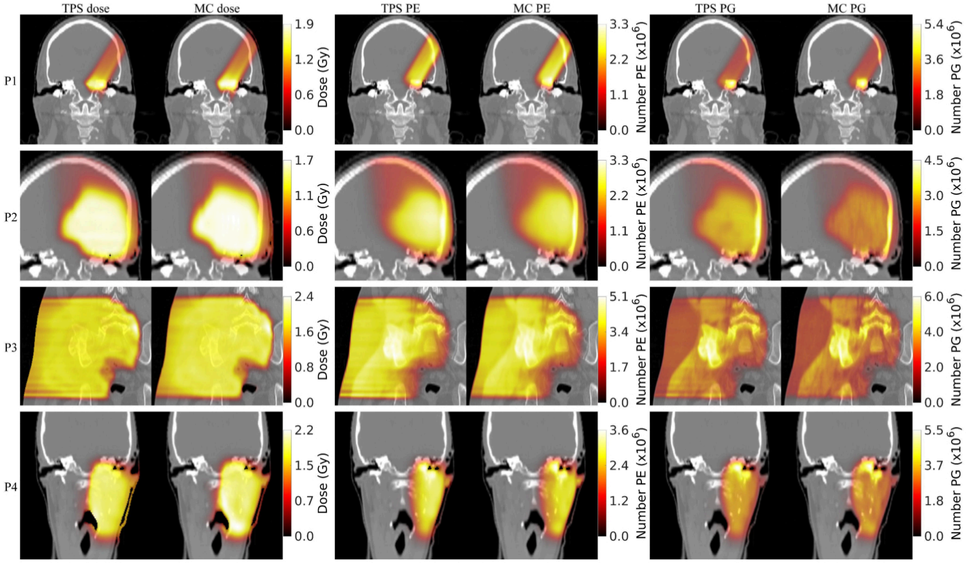
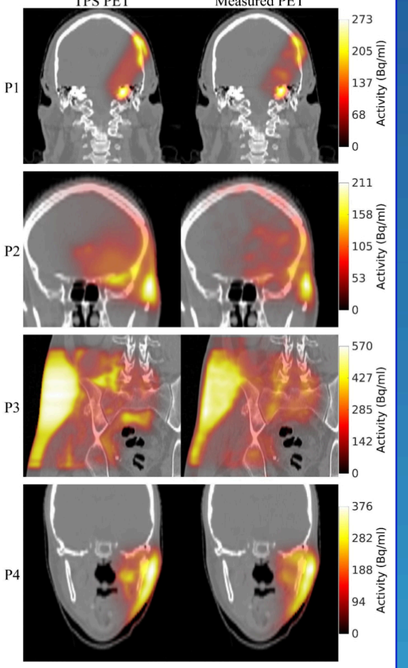


Table 1: Average and standard deviation of the shifts of the longitudinal profiles along the central axis for each spot for a given patient. Dose, PE and PG results are TPS against MC data, while PET results are prediction against measurements. The comparison with measured PET cannot distinguish between fields since the data were collected using an offline PET protocol. Therefore, the cumulative data from the two fields were used, and the values presented for different fields were calculated using the profiles along the longitudinal axis (beam direction) for each pencil beam in the respective field.

Patient		P1	P2 (field 1)	P2 (field 2)	P3	P4 (field 1)	P4 (field 2)
Shifts [mm]	Dose	0.5±1.3	0.2±0.9	0.8±1.3	1.9±1.5	0.5±1.4	1.9±1.2
	PE	-1.0±0.4	-1.7±0.4	-0.2±0.6	0.1±0.7	0.3±0.9	0.9±0.7
	PET	0.7±0.8	-1.1±1.6	0.1±1.1	3.0±1.4	0.8±1.6	0.7±1.4
	PG	-0.7±0.5	-1.3±0.8	0.1±0.6	0.3±0.8	0.3±1.1	0.9±1.0

Figure 2: TPS-predicted PET distribution (left) and measured PET (right) for all patients, receiving a 30 min long offline PET acquisition. The TPS prediction considers machine beam records and biological decay parameters from Mizuno et al (3), Parodi et al (4) for all three washout model components. A Gaussian kernel with σ = 3.6 mm was used to model the full-ring PET scanner response (5).



CONCLUSIONS

- A solution to predict PET and PG distributions in a TPS has been developed, allowing for calculation times of only a few seconds for entire patient cases.
- The solution implemented also allows for PG spectroscopy information and arbitrary energy thresholds to be used with any PG monitoring device.
- Shifts between profiles from analytical and Monte Carlo calculations were within -1.7 and 0.9 mm, with maximum standard deviation of 0.9 mm and 1.1 mm, for PE and PG shifts, respectively. Similar values were found for dose when comparing pencil beam algorithm and Monte Carlo.
- When comparing measured and predicted PET data, the most complex clinical case yielded an average shift of 3 mm, while all other cases were below absolute average shifts of 1.1 mm.
- Validation with PG experimental data is ongoing.

ACKNOWLEDGEMENTS

The authors would like to thank the DFG Munich-Centre for Advanced Photonics (MAP) for financial support.

REFERENCES

1. Parodi K, Bortfeld T. A filtering approach based on Gaussian-powerlaw convolutions for local PET verification of proton radiotherapy. Phys Med Biol. 2006;51(8):1991-2009.
2. Pinto M, Kroniger K, Bauer J, Nilsson R, Traneus E, Parodi K. A filtering approach for PET and PG predictions in a proton treatment planning system. Phys Med Biol. 2020;65(9):095014.
3. Mizuno H, Tomitani T, Kanazawa M, Kitagawa A, Pawelke J, Iseki Y, et al. Washout measurement of radioisotope implanted by radioactive beams in the rabbit. Phys Med Biol. 2003;48(15):2269-81.
4. Parodi K, Bortfeld T, Haberer T. Comparison between in-beam and offline positron emission tomography imaging of proton and carbon ion therapeutic irradiation at synchrotron- and cyclotron-based facilities. Int J Radiat Oncol Biol Phys. 2008;71(3):945-56.
5. Bauer J, Unholtz D, Sommerer F, Kurz C, Haberer T, Herfarth K, et al. Implementation and initial clinical experience of offline PET/CT-based verification of scanned carbon ion treatment. Radiother Oncol. 2013;107(2):218-26.

CONTACT INFORMATION

ORCID

Marco.Pinto@physik.uni-muenchen.de