Editorial

Dear colleagues and friends of the RAPTOR community,

As we approach the final stages of the RAPTOR project, it is with great pride and appreciation that we present you this summer 2025 newsletter. Over the past four years, RAPTOR has grown into a vibrant and productive research network, united by a shared ambition: to bring online adaptive proton therapy closer to clinical reality. This newsletter highlights one of the most dynamic and technically challenging aspects of this mission—Work Package 4: Treatment Verification.

As WP4 coordinator, I've had the privilege of accompanying a group of highly motivated Early Stage Researchers (ESRs) whose contributions have significantly advanced the field of in vivo dose monitoring and verification. The featured work in this issue reflects the diversity of innovative approaches our ESRs have pursued: from prompt-gamma imaging and range probing to dose reconstruction algorithms and log-file–based plan adaptation. While each ESR tackled a different piece of the puzzle, they all shared a commitment to increasing the safety, precision, and robustness of proton therapy workflows.

These projects have not only produced impressive scientific results—many of which have already been published or presented at leading conferences—but have also demonstrated how collaborative, interdisciplinary research can translate into clinically meaningful advances. Across Europe, our partners brought together clinical experience, technical innovation, and computational expertise to support the development of next-generation verification strategies. Whether simulating dose deviations, validating synthetic CTs, end-to-end testing of new approaches or evaluating adaptive scenarios in real patient data, the work in WP4 has laid a strong foundation for integrating real-time feedback into adaptive treatment decision-making.

Inside this issue

I would like to sincerely thank all ESRs, supervisors, secondment hosts, and consortium partners for their commitment to excellence and their spirit of collaboration. Special thanks also to those who contributed to this newsletter. While the RAPTOR project may soon be concluding, the impact of its research—and the professional networks it has fostered—will undoubtedly continue to shape the field in the years to come – within RAPTOR+ and beyond.

Enjoy reading!

Christian Richter

Title: Daily dose refinement to account for the spot position displacements.

ESR 9: Sergei Diuzhenko, Cosylab, Slowenia

Supervisors: Kristjan Anderle, Robert Jeraj

Background and Aim:

In pencil-beam scanning (PBS) proton therapy, dose accuracy is highly sensitive to variations in the positioning and composition of tissue heterogeneities relative to the intended beam paths. One source of the positioning variation is the displacement of spots from their lateral positions due to dynamic beam delivery effects and random noise in accelerator beamline components. Here, we aim to propose a penalization term for the optimization objective informed by machine log files from the previous treatment fraction to mitigate the dosimetric impact of spot displacements.

Material and Methods:

1. Daily dose re-optimization to account for beam position displacements.

Previous retrospective analyses of delivery log files from the PSI Gantry2 machine revealed a strong correlation between individual spot position deviations observed during the first fraction and those in subsequent fractions. Due to this correlation, the machine log file from the previous fraction can be used to determine the relative importance of a specific spot for dose delivery accuracy. The following penalization term is proposed for inclusion in the daily dose re-optimization objective function:

$$s(\boldsymbol{\omega}) = \sum_i \varepsilon_i{}^2(r_i) \cdot \omega_i^2$$

$$\varepsilon_i \sim exp(r_i / r_{interlock})$$

where i is a spot index, ω is a spot weights vector, ε_i is a spot importance factor, r_i is a magnitude of a spot position deviations recorded in the log-file of a previous fraction, r_interlock is a maximum allowed spot displacement and ω_i is a spot weight.

2. Treatment delivery simulation

A liver treatment case was used to simulate fractionated dose delivery with adaptation. An initial plan prescribing 5 Gy to the clinical target volume (CTV) via a single anterior field was created on the planning CT. To mimic imperfect delivery, each spot in the first fraction was randomly shifted using Gaussian-distributed displacements (σ = 0.75 mm). For the second fraction, daily plan adaptation was performed using the original objectives and the proposed penalization term, with the perturbed first fraction serving as simulated log file data. Only changes in spot weights were allowed during the re-optimization process. Fraction-specific and planned dose distributions were evaluated using dose–volume histogram (DVH) metrics.

Results:

Figure 1 presents the DVHs for the initial treatment plan and two simulated delivery fractions. A comparison of DVH metrics between the first delivery fraction—with introduced spot displacements—and the planned dose reveals a reduction in target coverage (ΔD98% = –0.12 Gy and ΔD2% = +0.10 Gy). However, incorporating the beam displacement penalization term into the daily re-optimization for the second fraction reduces these deviations (ΔD98% = –0.04 Gy and ΔD2% = +0.05 Gy).

Discussion and conclusion:

We introduced a beam displacement penalization objective term designed to refine daily treatment plans by utilizing delivery log files from the previous fraction, with the aim of reducing the dosimetric impact of spot position displacements. The proposed objective redistributes spot weights toward those with smaller displacements measured during the preceding dose delivery, thereby minimizing their influence on the dose distribution in the subsequent treatment fraction. Ongoing research aims to extend this approach to a broader range of clinical scenarios and to experimentally validate that the simulated improvements lead to a measurable reduction in dose discrepancies.

Figures/Tables

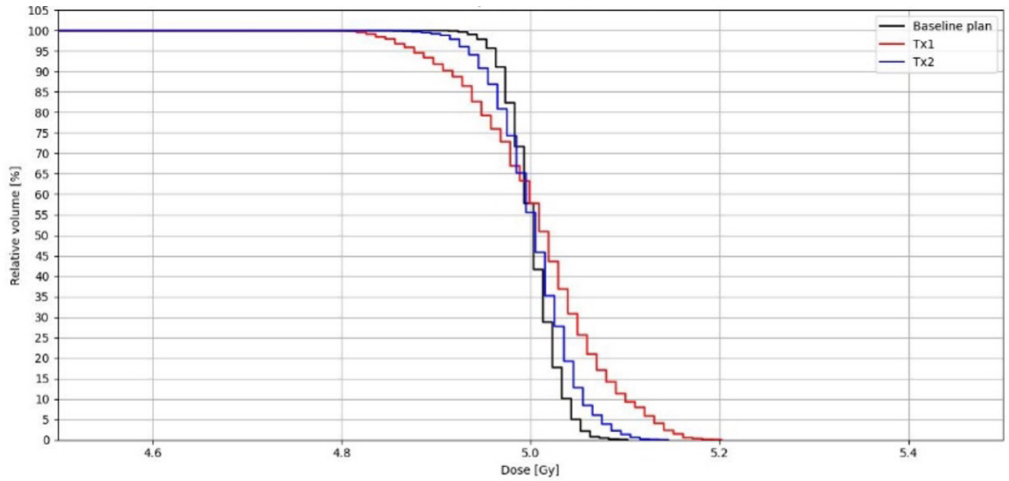


Figure 1. DVHs of the CTV for baseline treatment plan (black curve), for uncorrected treatment plan at fraction 1 including spot position errors (red curve) and spot displacement corrected treatment plan at fraction 2 (blue curve).

Conferences and Publications:

- Diuzhenko. S, Smolders. A, Lomax. A, Weber. D, Albertini. F, Anderle. K. “Assesment of dosimetric impact and systematicity of proton therapy machine delivery uncertainties” PTCOG 62, 10-15 June 2024, Singapore.

- Diuzhenko. S, Smolders. A, Lomax. A, Weber. D, Albertini. F, Anderle. K. “Dosimetric impact of deviations in machine delivery parameters”. ESTRO 2024, 3-7 May 2024, Glasgow, UK.

- Diuzhenko. S, Smolders. A, Anderle. K, Albertini. F. “Quantifying the Impact of Individual Machine Parameters on Delivered Dose in Pencil Beam Scanning Proton Therapy: A Feasibility Study” Submitted to phiRO journal, 2025.

Secondments:

- PSI, Villigen, Switzerland, July - August 2023, 2 Months

Title: Investigating a one-size-fits-all framework for testing adaptive particle therapy components

ESR12: Jacob Brunner, Medical University of Vienna, Austria

Supervisors: Barbara Knäusl, Dietmar Georg, Markus Stock

Background and Aim:

(Daily) adaptive particle therapy (DAPT) has gained prominence as an approach to efficiently deliver more effective particle therapy to patients across the radiotherapy spectrum. With this uptick in interest, research and development has branched out into various forms and 'flavors' of adaptation all of them aiming to optimize target coverage, minimizing toxicity and thus maximizing the therapeutic window.

The strong network of the RAPTOR consortium provided a unique opportunity to investigate the strengths and weaknesses of a framework to test adaptive particle components in the clinical setting. A total of six clinical institutions covered a variety of in-room image guidance systems, accelerator types and provided access to unique DAPT components.

This study developed a framework including an adaptive phantom to test a variety of novel components for DAPT developed within RAPTOR and investigated the feasibility of an one-size-fits-all approach to testing adaptive treatment workflows.

Materials and Methods:

Three scenarios were prepared, where target coverage was measured using ionization chambers and radiochromic films. Scenario 1 represented the 'nominal' scenario with the patient anatomy (anatomy A) being identical to the planning CT. Scenario 2 represented the non-adapted case, where an anatomical change (anatomy B) was not accounted for or evaded detection. Scenario 3 represented the adapted case, where the treatment plan was adapted based on the anatomical change presented on the day.

Additionally, specific analysis was done to investigate the unique components the institutes contributed (e.g. prompt gamma imaging, log-file based QA, proton radiography).

Results:

Across all scenarios and all institutes the target coverage decreased when not adapting to the anatomical changes. The decreased could be recovered when adapting the treatment plans to the changed anatomy. The median dose to the target decreased by 13.9% [Interquartile range (IQR): 1.5%] in the non-adapted case and in the adapted case the initial dose coverage could be achieved to within 0.2% [IQR: 0.8%]. Similarly, the gamma-pass-rate (2%/2mm) for radiochromic film measurements in the non-adapted scenario was 82.9%[IQR: 16.2%], which increased to 98.7% [IQR: 3.4%] for the adapted scenario.

Discussion and Conclusions:

Despite the differences in equipment, adaptation approaches and infrastructure, the framework successfully showed a recovery in target coverage for all participating institutes. Thus, the suitability of the testing framework and accompanying phantom for a wide range of DAPT applications could be shown. A more detailed investigation will be included in a future publication. The 3D-files of the used phantom will be published on a public repository with a brief set of manufacturing instructions.

The promising results of this study will contribute to building trust in DAPT as a promising future of particle therapy and emphasize the strength of collaborative efforts in the field.

Figures/Tables:

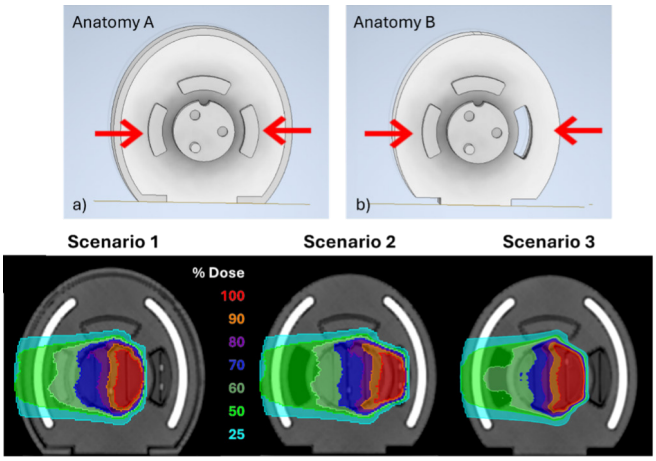


Figure 1: Overview of the setups and scenarios used in the end-to-end test. a) shows Anatomy A, the initial anatomy for treatment planning. b) shows Anatomy B, the changed anatomy, where the shell structure and a lateral insert are removed. The red arrows in a) and b) show the incidence angles of the particle beams. c) shows three irradiation scenarios for one beam. In Scenario 1 the planned dose is delivered on the initial Anatomy A, in Scenario 2 the initially planned dose is delivered on the changed Anatomy B and dose coverage in the central insert decreases. In Scenario 3 the initial target coverage is restored, by reoptimizing and delivering the plan on Anatomy B.

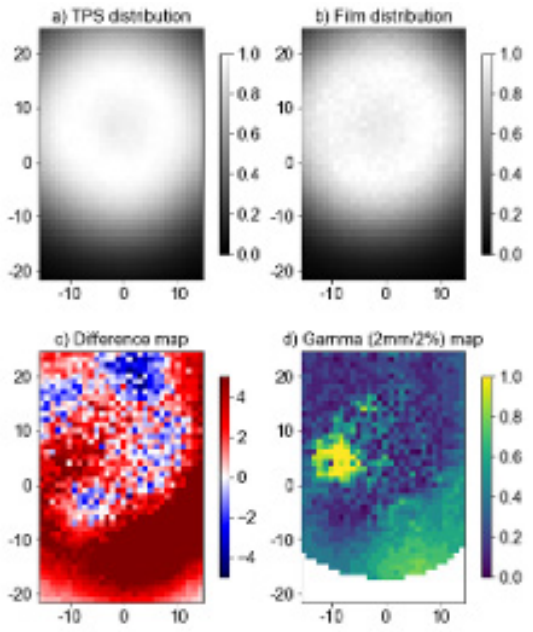


Figure 2: Example evaluation of the 2D dose distribution extracted from a) the TPS and b) the average dose measured with three radiochromic films. The film dose was measured for Scenario 3. Each dose has been normalized to the 98th percentile. The pixel-wise difference map in percentage points is shown in c). A 2%/2mm gamma map is shown in d), where gamma values above 1 are considered as failed pixels. A dose cutoff of 20% was chosen as threshold for the gamma evaluation. The gamma pass rate in this example was 98.5%.

Conferences and Publications:

- Brunner, Jacob, et al. "Dosimetric characteristics of 3D-printed and epoxy-based materials for particle therapy phantoms" Frontiers in Physics (2024): 12:1323788
- Brunner J., Dyuzhenko S., Bertschi S., Foglia B., Perotti Bernardini G. "Raptor Workpackage 4 'Verification' " ESTRO 2024, 3-7 May 2024, Glasgow, UK.

Secondments:

- UMCG, Groningen, Netherlands (October 2022 & August 2024)
- UPTD, Dresden, Germany (May 2024)
- PSI, Villigen, Switzerland (July 2024)
- PARTICLE, Leuven, Belgium (July 2025)
- DCPT, Aarhus, Denmark (September 2025)

Title: Feasibility of prompt gamma verification for cone-beam computed tomography-based online adaptive proton therapy*

ESR13: Stefanie Bertschi, OncoRay, Dresden

Supervisors: Christian Richter, Kristin Stützer

Background and Aim:

Prompt-gamma based in vivo treatment verification, such as prompt-gamma imaging (PGI), is crucial for detecting anatomical changes and serving as safety net during proton therapy (PT) treatments.

Cone-beam CTs (CBCT) are a promising solution for 3D in-situ imaging in online adaptive proton therapy (OAPT), however at the cost of increased uncertainties in determined CT numbers, therefore increasing the need for online treatment verification.

This study investigated whether PGI, proven effective to detect relevant anatomical changes in clinical settings, can also verify treatment plans adapted on CBCTs, particularly the reliability of CBCT-based PGI-simulations of expected prompt-gamma distributions, a key requirement for PGI-based verification.

Material and Methods: For a homogeneous PMMA phantom and an anthropomorphic head phantom, a fan-beam CT and a CBCT were acquired. Two commercially available algorithms were used to generate a corrected CBCT and a virtual CT from the CBCT. On all four datasets, PGI simulations were performed and spot-wise range shifts relative to the reference PGI simulation on the fan-beam CT were extracted, as shown in Figure 1. Since PGI simulations are based on both the underlying depth-dose distribution and the PG emission spectra, independent dose calculations and integrated depth-dose (IDD) profile extractions were performed on all datasets for each spot. Spot-wise IDD-based range shifts were compared to corresponding spot-wise PGI-based range shifts to distinguish uncertainties in depth-dose distribution from uncertainties in the PG emission spectrum.

For clinical PT plans of three head and neck cancer patients, PGI simulations were performed on a fan-beam CT as well as on a synthetic CT, which was generated from a daily CBCT with an institute-internal deep learning algorithm. Spot-wise PGI-based range shifts were compared to line-dose based range shifts extracted from clinical dose calculations.

Results:

For the homogeneous phantom, all CBCT datasets enabled adequate PGI simulations and PGI-based range shifts correlated very closely to IDD-based range shifts. For the anthropomorphic head phantom, considerable PGI-based range shifts were observed between the fan-beam CT and the raw CBCT due to the lower image quality of CBCTs. However, for both the corrected CBCT and the virtual CT, PGI-based range shifts close to zero (median ≤ 0.5 mm) were observed. For the anthropomorphic head phantom and for all patient datasets, observed PGI-based range shifts were correlated to IDD-based shifts, hence caused by differences in dose and not by uncertainties in PG emission spectra.

Discussion and conclusion:

For phantom and patient data, PGI simulations depended mainly on the reliability of depth dose distributions on the planning image while additional uncertainties from PG emission spectra were negligible. For PT adaptation based on CBCTs, correct depth dose distributions are required. Hence, PGI is a promising treatment verification tool also for CBCT-based OAPT.

Figures/Tables:

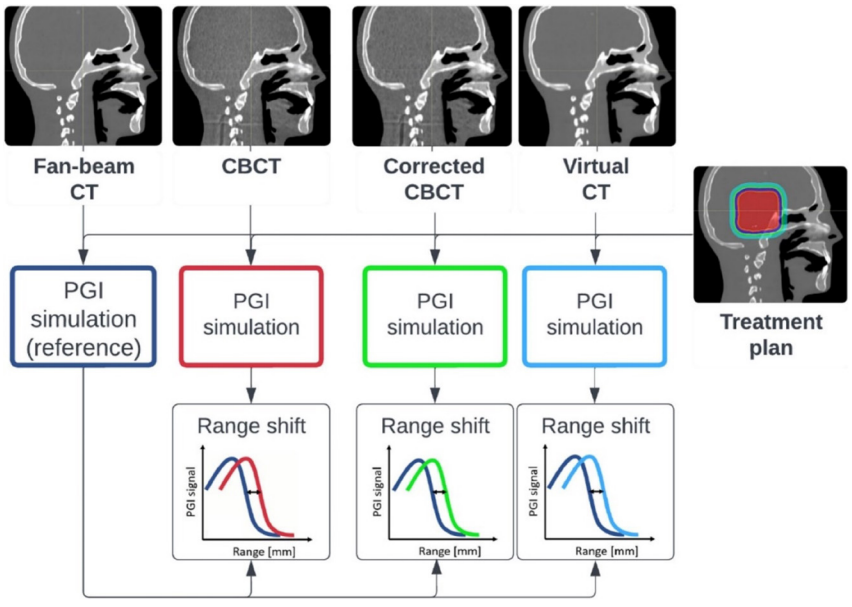


Figure 1: Workflow of the spot-wise comparison of PGI simulations for the anthropomorphic head phantom.

Conferences and Publications:
*This work was presented at ESTRO2024 and has been published recently.

- Bertschi, Stefanie, et al. “Feasibility of prompt gamma verification for cone-beam computed tomography-based online adaptive proton therapy.” Physics and Imaging in Radiation Oncology (2025): 100778.

- Bertschi, Stefanie, et al. “831: Online-adaptive proton therapy: Feasibility of prompt-gamma verification for CBCT-based adapted plan.” Radiotherapy and Oncology 194 (2024): S4189-S4193.

Secondments:

- Aarhus (2 months), CT and CBCT scans of phantom data,

- Groningen (1 month), preparation of patient data

Title: Evaluation of algorithms for dose reconstruction from prompt-gamma radiation in proton therapy

ESR: Beatrice Foglia, LMU Munich, Munich, Germany

Supervisors: Katia Parodi, Marco Pinto

Background and Aim:

Many factors can cause proton range uncertainties in clinical practice and thus limit the full potential of protons. To achieve a more conformal dose distribution in the tumour target, it is necessary to monitor and, where needed, correct for such uncertainties. One possibility for monitoring is through secondary prompt gammas (PG). PG emission along the penetration path is correlated to the dose, and PG measurements can be used to infer information about the proton range and the deposited dose.

Material and Methods:

Following promising initial investigations in phantoms presented at ICCR2024 (figure 1) and at AAPM2024 (figure 2) meetings for 1D and 3D scenarios, respectively, the deconvolution approach1, in its original implementation and in a modified one, the evolutionary algorithm2-4 and the maximum- likelihood expectation-maximization (MLEM) algorithm5-6 were investigated for dose reconstruction from PG for clinical cases. These techniques were applied to simulations (for ideal PG emission in the patient) of a head and neck (H&N) tumour indication, considering two pencil beams delivered to regions with different heterogeneity levels. A systematic analysis depending on PG statistics was also performed. Extension to PG from emission to detection is in progress, considering 1D PG signals acquired with a knife-edge slit camera7 during several treatment fractions for two additional H&N patients8-9.

Results:

The accuracy of the reconstructed 3D dose distributions was evaluated via γ-index

and range analyses with different settings. Regarding dose reconstruction from simulated 3D PG distributions at emission, the γ(1%/1mm) passing rate10 was found above 97% for every algorithm used. Results of dose reconstruction from simulated and experimental clinical data will be presented at the next AAPM2025 meeting and are meant to be published in the near future.

Discussion and conclusion:

The feasibility of the investigated dose reconstruction techniques applied to simulated 3D PG distributions at emission considering a H&N patient was verified. Since the emission of PG happens in a timescale below nanoseconds, the algorithms are potentially suitable for real-time adaptive particle therapy.

References

1.Remmele et al.,Phys.Med.Biol.56(2011)

2.Schumann et al.,Phys.Med.Biol.61(2016)

3.Hofmann et al.,Phys.Med.Biol.64(2019)

4.Yao et al.,Nucl.Sci.Tech.34(2023)

5.Masuda et al.,Phys.Med.Biol.64(2019)

6.Masuda et al.,Phys.Med.Biol.65(2020)

7.Smeets et al.,Phys.Med.Biol.57(2012)

8.Xie et al.,Int.J.Radiat.Oncol.Biol.Phys.99(2017)

9.Xie et al.,Brit.J.Radiol.93(2020)

10.Low et al.,Med.Phys.25(1998)

Figures/Tables

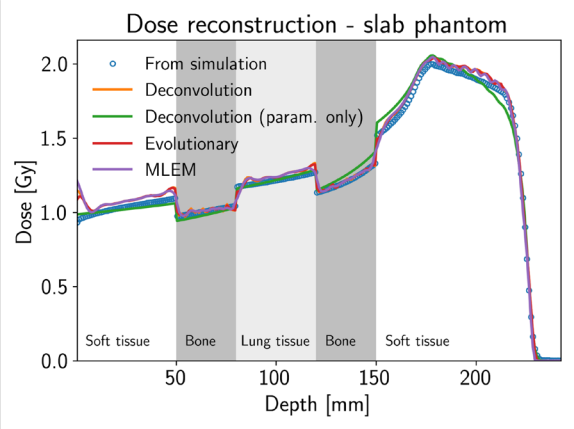


Figure 1: 1D reconstruction of a SOBP dose in a slab phantom (presented at ICCR2024)

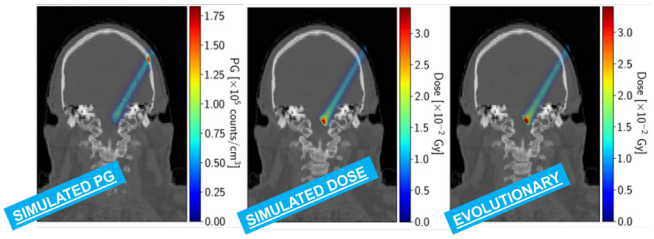


Figure 2: 3D dose reconstruction in a patient (preliminary results, final results to be published and to be presented at AAPM2025)

Conferences and Publications

- Foglia B., Gianoli G., Bortfeld T., Parodi K., Pinto M., "Comparison of strategies of dose reconstruction from prompt-gamma radiation in proton therapy", PTCOG 60, Miami (FL, US), 27.06-02.07.2022

- Foglia B., Gianoli G., Masuda T., De Bernardi E., Bortfeld T., Verburg J., Parodi K., Pinto M., "Evaluation of strategies of dose reconstruction from prompt gamma radiation in proton therapy", ESTRO 2023, Vienna (Austria), 12.05-16.05.2023

- Foglia B., Gianoli G., Masuda T., De Bernardi E., Bortfeld T., Verburg J., Parodi K., Pinto M., “Dose reconstruction methods using secondary prompt-gamma radiation in proton therapy”, . PTCOG 61, Madrid (Spain), 10.06-16.06.2023

- Foglia B., Gianoli G., Masuda T., De Bernardi E., Bortfeld T., Du T., Parodi K., Pinto M., “Evaluation of algorithms for dose reconstruction from prompt-gamma radiation in proton therapy”, ICCR 2024, Lyon (France), 08.07-11.07.2024

- Foglia B., Gianoli G., Masuda T., De Bernardi E., Bortfeld T., Parodi K., Pinto M., “Prompt gamma-based dose reconstruction strategies in proton therapy”, AAPM 2024, Los Angeles (CA, US), 21.07-25.07.2024

- Foglia B., Fredriksson A., Nilsson R., Depauw N., Adams J., Bortfeld T., Parodi K., Pinto M., “Treatment plan optimization for prompt-gamma monitoring in proton therapy”, ECMP 2024, Munich (Germany), 11.09-14.09.2024

Secondments

- Massachusetts General Hospital, June-August 2022, 2.5 months

- RaySearch Laboratories, November 2023 and April-May 2024, 2 months

- Oncoray, October 2024, 1 week

Title: In vivo proton range assessment for lung cancer patients by range probing quality control

ESR15: Giuliano Perotti Bernardini, University Medical Center Groningen, The Netherlands.

Supervisors: Stefan Both, Gabriel Guterres Marmitt

Background and Aim:

Proton beam therapy enables highly conformal radiation delivery to tumours. However, treatment planning margins can impact conformality. This study investigates the feasibility of utilising range probing (RP) as a patient-specific quality control (QC) tool for patients with lung cancer (LC). Additionally, it investigates RP's potential to validate virtual CT (vCT) scans, thereby facilitating its integration into online-adaptive proton therapy (OAPT) workflows.

Methods:

Seven LC patients with tumours in the mid/upper lung regions underwent RP-QC procedures during intensity-modulated proton therapy (IMPT) at our UMCG proton center. RP-QC was performed twice per patient, during weeks 1–2 and 3–5 of treatment, coinciding with repeat CT (rCT) scans.

Patients were positioned at the treatment isocenter using 3D cone-beam CT (CBCT), from which corresponding vCTs were generated for each treatment fraction. A multi-layer ionization chamber (MLIC) detector placed beneath the treatment table measured integral depth dose (IDD) curves for each proton spot exiting the patient at a gantry angle of 0°. RP fields comprised 81 spots at 225 MeV, covering a 4×4 cm^2 area. IDD curves for RP were calculated individually using RayStation's Monte Carlo algorithm with 0.5% accuracy on a 1 mm dose grid, adding less than 1 cGy RBE to the treatment dose.

Proton range accuracy was evaluated by simulating the RP fields on both 3D rCT and vCT datasets within RayStation and computing relative range errors (RRE) compared to actual measurements from the MLIC detector. Mean RREs were then compared against the ±3% range uncertainty margin employed for robust plan optimization.

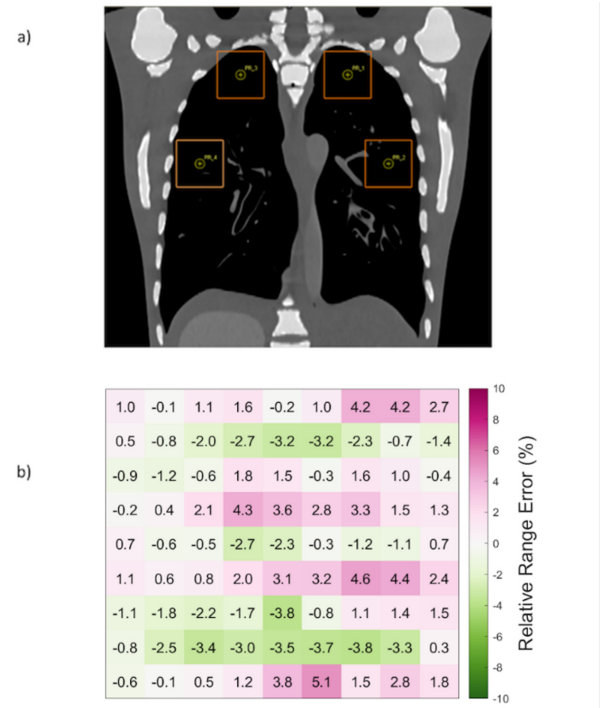


Figure 1. a) RP field composed of 81 spots arranged in a 4×4 cm^2 square area with 5 mm spot spacing, positioned at four possible locations overlapping with treatment beams in the mid-to-upper lung. b) RRE map illustrating relative range errors for patient #4, based on measured water-equivalent path lengths for the 81 spots in the RP field. Positive range errors (pink) indicate simulated IDD exceeds measured range, whereas negative range errors (green) signify simulated IDD is shorter than measured.

Results:

RRE maps based on measured water-equivalent path lengths of proton spots through the patient were obtained, as shown in Figure 1 b) for patient #4 as an example. Range accuracy evaluations revealed that during the first RP-QC session, mean RRE values calculated using vCT were within the ±3% planning uncertainty margin for all patients, whereas only four out of seven patients met this criterion when evaluated using rCT (Figure 2). In the second RP-QC session, five out of seven patients maintained mean RRE within ±3% on vCT, with slight deviations (3.2%–3.5%) observed for the remaining two. Using rCT, however, only four out of seven patients remained within the acceptable margin. Anatomical changes and setup inaccuracies, particularly evident in rCT scans acquired in different rooms, significantly contributed to the observed RRE variations.

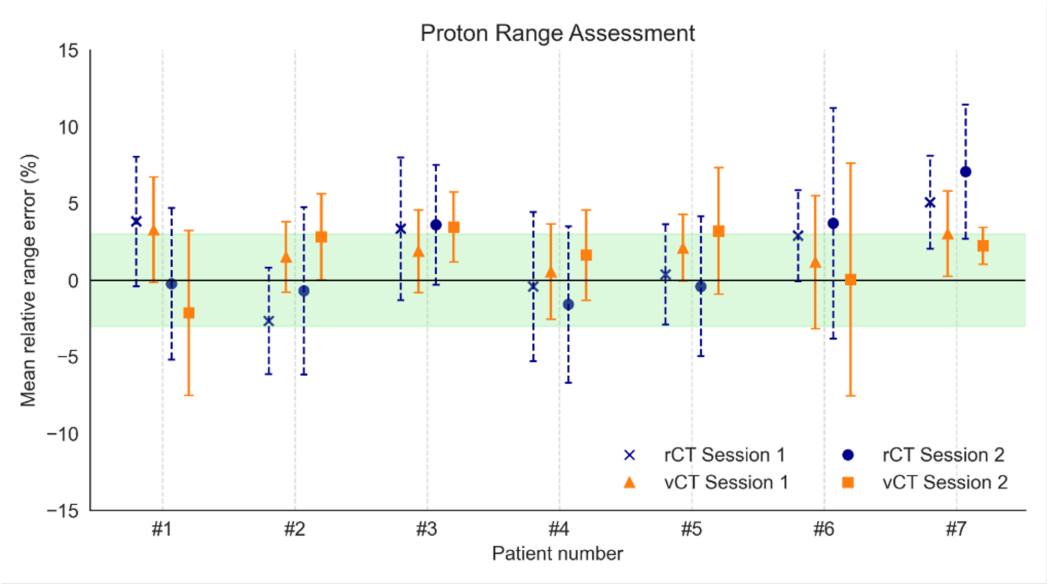


Figure 2. Overview of mean RRE values obtained through RP-QC assessments. The mean RREs and their associated error bars (representing ±1.5 SD) are displayed for each patient across measurement sessions. MLIC-measured IDD curves for 81 spots were compared against RayStation-simulated IDD curves, using averaged repeat CT (rCT) and virtual CT (vCT) data from both RP-QC sessions. The ±3% range uncertainty margin is highlighted in green.

Conclusions:

The patient-specific RP-QC procedure demonstrated promising feasibility in our lung clinical practice. Evaluations on vCTs provided reliable in vivo range assessment, conducted immediately after CBCT-based patient positioning in the treatment room, effectively minimizing anatomical and positional discrepancies. These findings support further investigation toward integrating daily vCT scans into clinical practice.

Conferences and Publications:

- G. Perotti Bernardini, G. Guterres Marmitt, A. Galapon, P. van Ooijen, J. Langendijk, S. Both. “AI-enhanced proton radiography: deep learning for assessing treatment deviations in proton therapy”. ESTRO 2024, 3-7 May 2024, Glasgow, UK.

- G. Perotti Bernardini, J. Free, P. Pisciotta, R. Wijsman, G. Guterres Marmitt, E. Korevaar, G. Meulman, F. Ubbels, J. Langendijk, S. Both .“First experience with in vivo range probing quality control procedure for moving targets treated with intensity-modulated proton therapy”. PTCOG 62, 10-15 June 2024, Singapore.

- Galapon, D. Wagenaar, G. Perotti Bernardini, J. Langendijk, S. Both. “A method to increase range probing interpretation accuracy in adaptive proton therapy”. PTCOG 62, 10-15 June 2024, Singapore.

- Zapien Campos, Z. Ahmadi Ganjeh, G. Perotti Bernardini, J. Free, S. Both, P. Dendooven. “Best in physics (Therapy): Quasi-Real-Time In Vivo Range Verification By Nitrogen-12 Positron Imaging in Proton Therapy”. AAPM 66, 21-25 July 2024, Los Angeles, USA.

- S. Bertschi, G. Perotti Bernardini, J. Berthold, J. Free, E. Bodenstein, G. Marmitt, G. Janssens, K. Stützer, S. Both, C. Richter. “Prompt-Gamma-Imaging vs. Proton-Radiography: Experimental comparison of two range verification approaches for proton therapy”. ECMP 2024, 11-14 Sep 2024, Munich, Germany.

- G. Perotti Bernardini et al. “Proton radiography interpretation with artificial intelligence for treatment deviation detection in proton therapy”. Submitted to phiRO journal, 2025.

Secondments:

- Oncoray, Dresden, Germany, August 2023, 3 months .

- Ion Beam Applications (IBA) S.A., Louvain-la-Neuve, Belgium, September 2024, 1 month.

Secondment Reports

Arthur Galapon

Who:
Arthur Galapon collaborating with Francesca Albertini and Andreas Smolders

Where:
Paul Scherrer Institute, Villigen, Switzerland

When:
January 12 – March 16, 2025 (9 weeks)

Why:
Developing a metric-based synthetic CT quality check workflow for online adaptive proton therapy

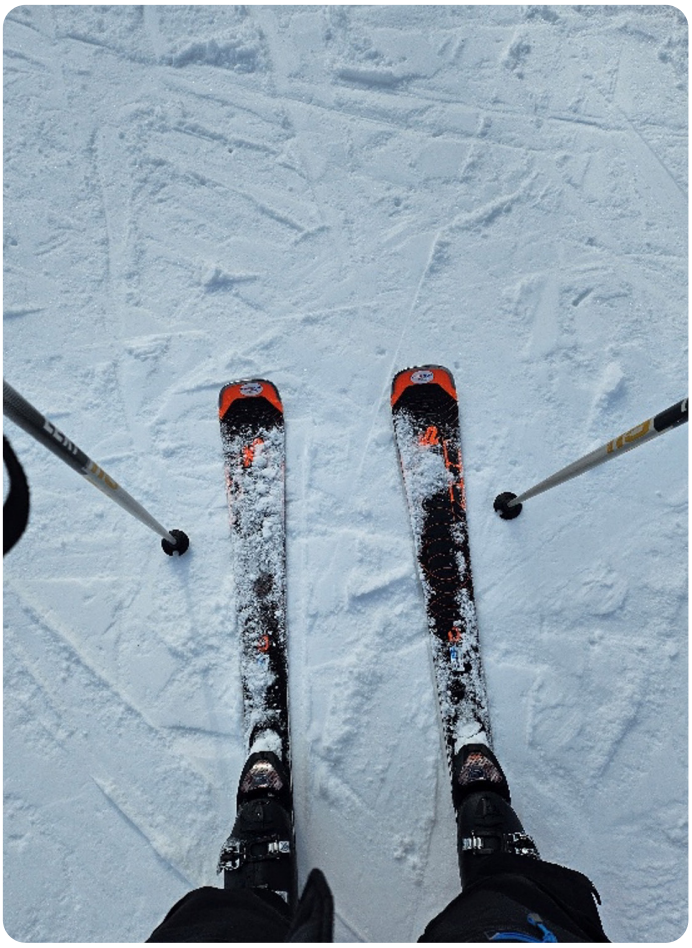
During my last RAPTOR secondment, I collaborated with Andreas (ESR1) to develop and evaluate a potential synthetic CT quality check method using standard image and dose quality metrics. The approach was data science–oriented, involving extensive data processing to determine suitable metric thresholds. If successful, I believe this method could support and accelerate the integration of synthetic CTs into the online adaptive workflow.

I was fortunate that my secondment coincided with the PSI Winter School on Proton Therapy. It was a valuable opportunity to explore various aspects of proton therapy presented by outstanding lecturers. Naturally, you can't visit wintry Switzerland without experiencing the mountains—so on my days off, I took the chance to explore the area and try some winter sports. Overall, my stay at PSI exposed me to a unique research culture and inspired me to continue pushing forward in the field of medical physics.

How would you describe your secondment in one word?
Wintry

What did you take home from your secondments (message, object, recipe....)?
Cheese and Ski bruises

Which song describes your secondment best?
Send to You by Luv



New ESR publications

- Choulilitsa, Evangelia, et al. “Multi-institution investigations of online daily adaptive proton strategies for head and neck cancer patients.” Physics in Medicine & Biology 70.6 (2025): 065012.

- Steinsberger, Timo, Nakas, Anestis et al. “Evaluation of motion mitigation strategies for carbon ion therapy of abdominal tumors based on non-periodic imaging data.” Physics in Medicine & Biology 70.6 (2025): 065002.
  Anestis, Nakas, et al. “Deep-learning synthetized 4DCT from 4DMRI of the abdominal site in carbon-ion radiotherapy.” Physica Medica 133 (2025): 104963.

- Bertschi, Stefanie, et al. “Feasibility of prompt gamma verification for cone-beam computed tomography-based online adaptive proton therapy.” Physics and Imaging in Radiation Oncology (2025): 100778.

- Smolders, Andreas, Tony Lomax, and Francesca Albertini. “The bone rigidity error as a simple, quantitative, and interpretable metric for patient-specific validation of deformable image registration.” Physics and Imaging in Radiation Oncology (2025): 100767.

- Vestergaard, Casper Dueholm, Vatterodt, Nadine et al. “Comparing methods to improve cone-beam computed tomography for dose calculations in adaptive proton therapy.” Physics and Imaging in Radiation Oncology (2025): 100784.

Conference contributions:

2025 has already seen a strong start for our RAPTOR students in terms of conference participation, with several contributions at leading international meetings. At ESTRO 2025, Evangelia Choulilitsa presented a poster investigating whether online adaptive proton therapy can improve delivery speed while maintaining treatment quality using unconventional beam arrangements. Andreas Smolders contributed three times: with two posters—one comparing human versus machine performance in landmark annotation, and another introducing a novel metric, the bone rigidity error, for patient-specific validation of deformable image registration—and an oral presentation on the influence of daily imaging and margin reduction on secondary cancer risk in adaptive radiotherapy.

At PTCOG 2025, even more RAPTOR students showcased their research. Arthur Galapon delivered an oral presentation evaluating the potential of uncertainty-conditioned synthetic CTs to replace verification CTs in head and neck workflows. Evangelia Choulilitsa contributed with an oral presentation on the influence of deformable image registration uncertainties on dose accumulation. Andreas Smolders followed with a short oral on predicting dose accumulation reliability for adaptive plan selection. Suryakant Kaushik presented his work on anatomy-preserving virtual CTs for CBCT correction in adaptive head and neck treatments. Cosimo Galeone and Nadine Vatterodt also shared their research, with Nadine giving two talks—one on triggered plan adaptation using multi-image optimization for improved robustness in head and neck cancer patients, and another as an invited speaker on additional evaluation concepts when assessing plan quality in particle therapy.

*Listed in alphabetical order.

Editorial Board:
Kristjan Anderle, Francesco Russo, Stine Korreman, Christian Richter, Francesca Albertini, Andreas Smolders, Stefani Bertschi

Layout and Design:
Valentina Margaria, Tanja Gerkman

Privacy Statement
The personal data and the other information entered in RAPTOR Newsletter will be treated according with the provision set out in Legislative Degree 196/2003 (known as Privacy Code) and subsequently integration and amendment.

RAPTOR project has received funding from the European Union's Horizon 2020 Marie Skłodowska-Curie Actions under Grant Agreement No. 955956