# *Editorial*

Dear Reader,

Welcome to this edition of our Newsletter on the RAPTOR "Real-Time Adaptive Particle Therapy Of Cancer" project.

## Inside this issue



In the following pages you will find the results relevant to Work Package WP3 "Intervention" describing the activities that our brilliant ESRs conducted to achieve the objectives of this scientific WP.

The implementation of real-time adaptive therapy puts increased demands on both the speed and complexity of optimization of radiation dose to the patient. The whole process has to be completed while the patient is on the table in the treatment room, taking into account the accumulated dose of the part of the treatment course already completed. This work package aims to address issues associated with the intervention of performing adaptive particle therapy, at time scales ranging from the planning stage before start of treatment to accounting for changes happening during beam-on time.

Overall, the work is focused on prediction of anatomical changes, dose optimization methods, online quality assurance, as well as visual representation for decision support. In this newsletter, we present some of the specific studies recently carried out by the ESRs in WP "Intervention".

At the planning stage of the treatment chain, ESR7 works on including predicted anatomical changes into both robust evaluation and robust optimization schemes, on individual and population levels. This can enable the optimal choice of adaptation strategy for each individual patient.

For the fast optimization needed on a day-to-day basis, ESR6 is developing novel methods for automated re-optimization according to original plan objectives. Clinical validation has demonstrated both the needed time efficiency as well as plan quality.

ESR10 has compared two different approaches to daily dose restoration at two different institutions and has shown that effective re-optimization can be achieved even for large anatomical variations. Both methods achieved sufficient quality and were better than no adaptation.

A different approach was tested by ESR11 for tumours moving during treatment in the thoracic region. The method employs a dose mimicking method based on a 4DCT scan representing the tumour motion, and exhibited superior performance compared to other methods.

Finally, ESR8 investigated how delivered dose to tumours moving during treatment can be calculated and shown in a graphical user interface in real time for particle therapy. Results showed good performance in both speed and dose representation, even for tumours with irregular motion.

All ESRs have presented their work at international conferences, including at ESTRO and PTCOG, and collaboration is fostered through multiple secondment visits at institutions abroad. Together, we push the boundaries of knowledge within the field, and ultimately pave the way for better individualized treatment for all patients receiving particle therapy.

# Anatomical robust plan evaluation for head and neck cancer proton therapy

**ESR7: Nadine Vatterodt – Department of Clinical Medicine, Aarhus University, Aarhus, Denmark**

**Supervisors: Stine Korreman, Albin Fredriksson**

**Background and Aim :** Robust plan evaluation with respect to anatomical variations prior to treatment may allow for triage of patients who will benefit most from certain adaptive or robust planning strategies in particle therapy. We tested the potential of anatomical robust plan evaluation for head and neck cancer patients using a non-selective population-based principal component analysis (PCA) model.

**Materials and Methods:** Twenty-five oropharyngeal cancer patients were divided into 20 model and 5 test patients. The workflow described in the following is sketched in Figure 1.

For the model patients, deformation Vector Fields (DVFs) between planning CT and daily CBCTs were calculated and exported. An average anatomy was generated from the 20 planning CTs using groupwise registration using NiftyReg. A PCA model was derived from 120 weekly DVFs, mapped to this average anatomy.

For test patients, the model was mapped to the planning CT and simulated DVFs were created by summing weighted eigenvectors of the first 29 principal components, explaining > 90% of cumulated variance. The same 50 sets of weights were used for the simulated DVFs of all patients to ensure reproducibility and explainability of our results. These DVFs were imported to RayStation, invereted and used to deform the planning CT into simulated CTs.

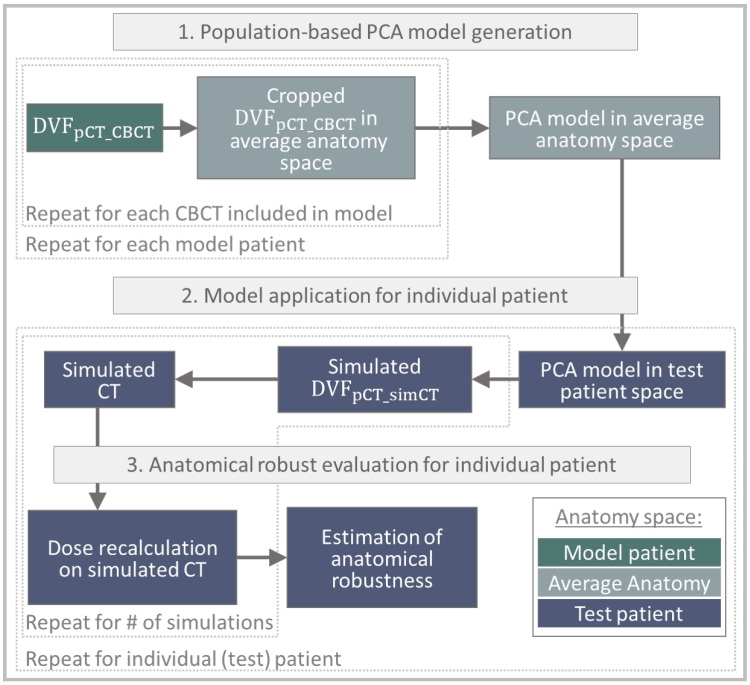



**Figure 1.** Workflow of general population-based PCA model generation, followed by model application for a specific (test) patient and its use for anatomical robust evaluation.

Virtual CTs were derived from the daily CBCTs to serve as ground truth. Two plans, a clinic-like plan with our clinic's robustness settings (±4mm, ±3.5%) and a less robust plan (±3.5%), were made for all patients. These were then recalculated on the daily images (±3.5%), simulated CTs (±3.5%), and the conventional robust evaluation scenarios for setup and range uncertainty using the planning CT (±4mm, ±3.5%).

Target coverage change (ΔD98) of the primary CTV was then assessed by median and 90% inter-percentile range (R90) to evaluate:

- **Model accuracy: How close is our robustness prediction to the actual robustness?** Deviation between robustness on simulated compared to daily images was compared for the same plan.
- **Sensitivity: Can we distinguish different levels of plan robustness for a patient?** Deviation between change in robustness for plans of different robustness level on simulated compared to daily images.
- **Rationale: Do we gain additional knowledge?** Comparison to conventional robust evaluation based on setup and range uncertainty scenarios.

**Results:** Figure 2 illustrates the results on population and patient level. Model accuracy on population level was 0.18 Gy for median and 0.25 Gy for R90. On patient level accuracy was 0.50 Gy for median and 0.75 Gy for R90. Sensitivity with deviations of the difference between plans of <0.35 Gy (0.13 Gy) for median and <0.4 6Gy (0.10 Gy) for R90 (population level), aligned with model accuracy. Conventional robust evaluation showed comparable accuracy for clinic-like plans but was less accurate for plans not including the same setup uncertainty for robust optimization, showing discrepancies in R90 of up to 2.68 Gy at the individual patient level.

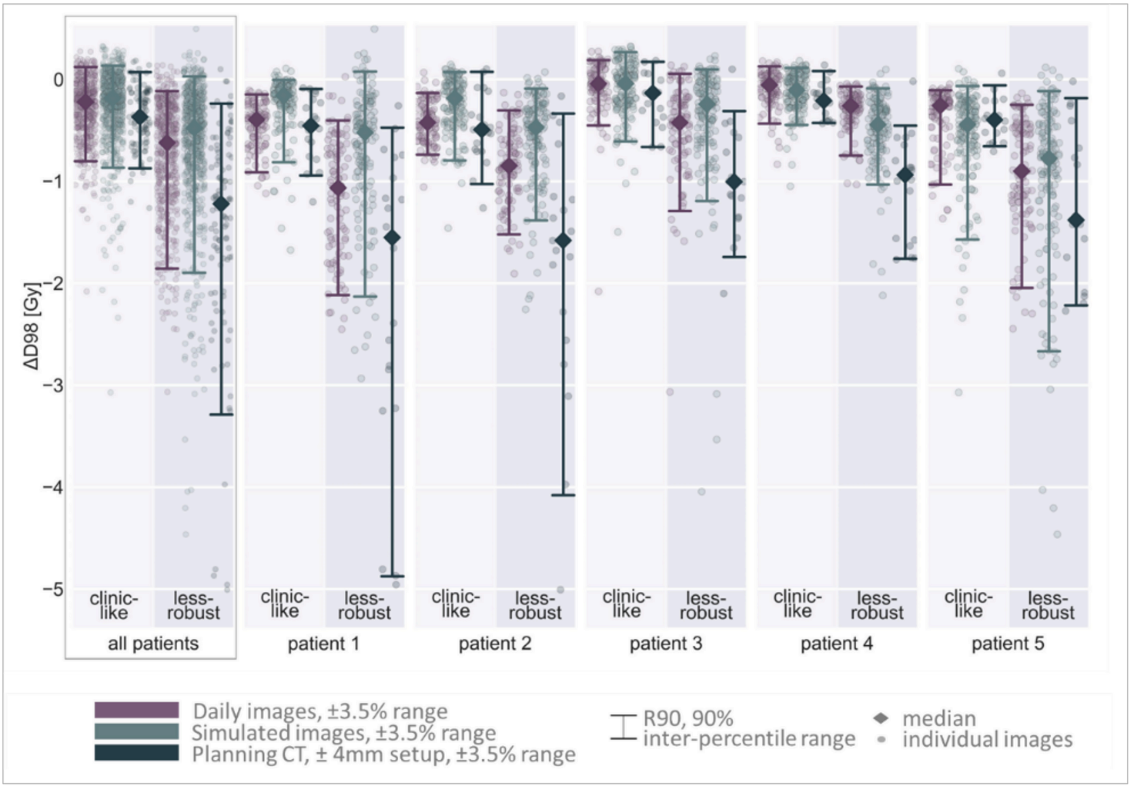



**Figure 2.** Change in target coverage ΔD98 of the primary CTV for recalculated dose of the clinic-like (bright background) and less-robust plan (dark background) on daily images as ground truth (purple) and on simulated images (bright green) for anatomical vs. setup and range uncertainty scenarios for conventional robust evaluation (dark green) with respect to the planning CT.

**Conclusion:** We have successfully implemented an automated workflow using a non-selective population-based principal component analysis (PCA) model for anatomical robust plan evaluation for oropharyngeal cancer with RayStation 12A R. Good performance of the non-selective population-based PCA-model was found at population level. Our results indicate that the anatomical robust evaluation may be used for guiding robust planning settings or need of adaptation for individual patients by predicting probability of target coverage. Furthermore, the proposed method outperformed conventional robust evaluation for varying robust planning settings.

## Conferences and Publications

Vatterodt N. Fredriksson A., Winey B., Korreman S., "Robust plan evaluation using a population-based anatomical model for head and neck cancer proton therapy", PTCOG62, Singapore (Singapore), 10-15.06.2024

Vatterodt N., Elstrøm U. V., Korreman S., "Cross-platform assessment of CBCT-based dose evaluations for head and neck cancer proton therapy", ASTRO 2023, San Diego (USA), 01.-04.10.2023

Vatterodt N., Argota-Perez R., Sharma M. B., Holm A.I.S., Elstrøm U. V., Jensen K., Korreman S.S. "Proof-of-concept: Novel CBCT-based adaptive robust optimization in sinonasal cancer proton therapy", ESTRO 2023, Vienna (Austria), 12.05.-16.05.2023;

Vatterodt N., Argota-Perez R., Sharma M. B., Elstrøm U. V., Jensen K., Korreman S.S. "The potential of including anatomical error scenarios for nasal cavity filling in robust optimization", PTCOG 60, Miami (USA), 27.06.-02.07.2022

## Secondment

Raysearch Laboratories, February -June 2023, 3 months –
Massachusetts General Hospital, September-November, 7 weeks -

# A reference-point-method-based online proton treatment plan re-optimization strategy and a novel solution to planning constraint infeasibility problem

**ESR6: Zihang Qiu, University of Amsterdam, The Netherlands**

**Supervisors: Dick den Hertog and Thomas Bortfeld**

**Background and Aim :** Patients' anatomy changes daily. The mismatch between the treatment plan and the anatomy can severely compromise tumor control and organs at risks (OARs) sparing. This is even more pronounced for intensity-modulated proton therapy (IMPT) for its sensitivity. Ideally, a patient's treatment plan should be re-optimized daily so that it is optimal with respect to the latest anatomy and the mismatch is minimized. The main challenge of daily treatment plan re-optimization is the limited time. Only tenths of minutes are available for the daily re-optimization process. Therefore, human intervention should be minimized, and a highly automated re-optimization strategy is required.

**Materials and Methods:** A reference-point-method-based (RPM) re-optimization strategy was proposed for online treatment plan re-optimization, as depicted in figure 1. It includes an RPM model that minimizes l-infinity norm between the daily replan and the initial treatment plan in the objective space was validated on six head and neck (H&N) and four breast patients. Each patient received IMPT at Massachusetts General Hospital and one offline treatment plan adaptation during the course of treatment.

Another contribution of this work is that it proposed a highly automated solution to planning constraints infeasibility issue in the re-optimization process. Conventionally, a planner would address the infeasibility issue by relaxing replanning constraints on a trial-and-error basis and, therefore, it can cost a significantly amount of time. The proposed solution includes an optimization problem that estimates the daily planning constraint violation, and a relaxed RPM model that iteratively converts planning constraints into objectives based on planner's choice.

**Results:** Compared to the manually adapted offline treatment plan, the RPM replans showed no statistically significant differences in key dose-volume histogram (DVH) parameters on the H&N and breast patients. The average target D95 and relevant OAR sparing parameter differences between the RPM replans and manually adapted offline replans were −0.23, −1.62 Gy for the H&N cases, as shown in figure 2, and 0.29, −0.39 Gy for the breast cases, as shown in figure 3. The RPM replans were generated within the online time requirement, The average, minimum, and maximum time costs were 4m39s, 1m57s, and 9m03s.
3 H&N and 1 breast patient encountered the planning constraint infeasibility issue. The proposed solution efficiently addressed the infeasibility problem after one iteration and subsequently lead to quality replans.

**Discussion and Conclusion:** The RPM-based re-optimization strategy demonstrated its effectiveness both in terms of time-efficiency and resultant plan quality. The proposed solution to the planning constraint planning issue provides a novel approach to a critical problem in the online treatment plan re-optimization process that has not yet brought too much attention.

## Conferences and Publications


1. Qiu, Z., Olberg, S., den Hertog, D., Ajdari, A., Bortfeld, T., Pursley, J. Online adaptive planning methods for intensity-modulated radiotherapy. Phys Med Biol 2023;68: 10TR01. https://doi.org/10.1088/1361-6560/accdb2.
2. Qiu, Z., Depauw, N., Gorissen, B., Madden, T., Ajdari, A., den Hertog, D., & Bortfeld, T. (2023, June 14). Online adaptive planning for proton therapy using the reference point method [Talk]. PTCOG61, Madrid, Spain.
3. Qiu, Z., Depauw, N., Gorissen, BL., Madden, T., Ajdari, A., den Hertog, D., Bortfeld, T. A reference-point-method-based online proton treatment plan re-optimization strategy and a novel solution to planning constraint infeasibility problem. Phys Med Biol. 2024 Jun 3;69(12). https://doi.org/10.1088/1361-6560/ad4a00.

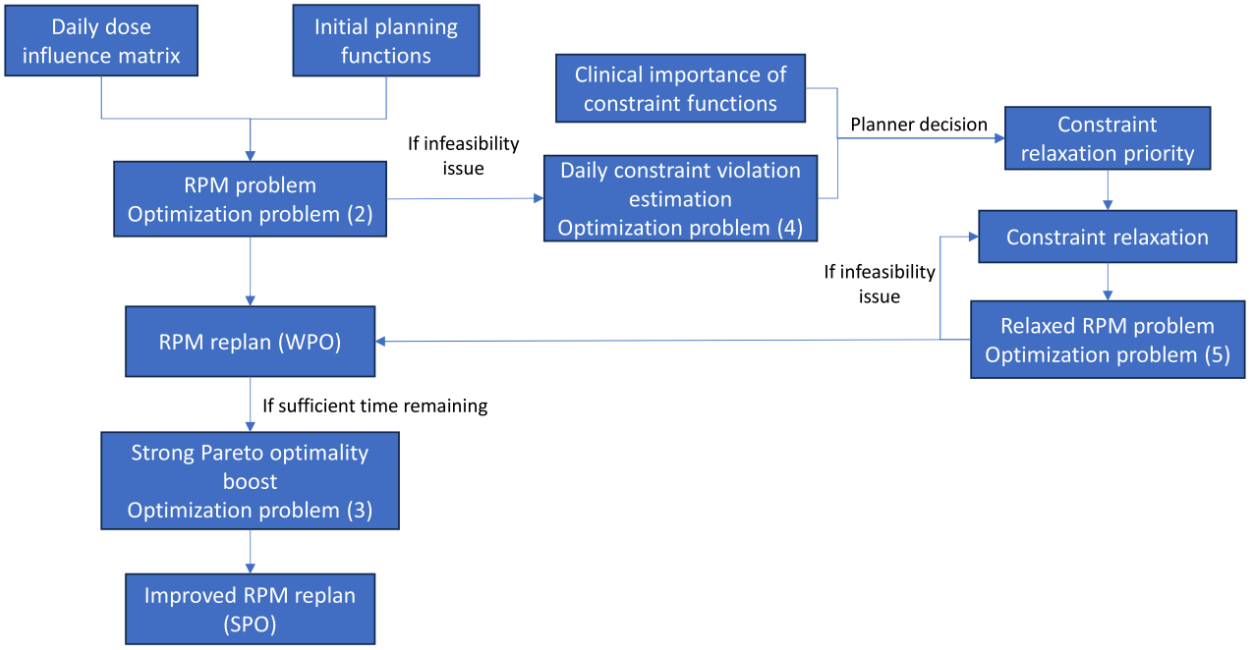




**Figure 1.** Workflow schematic of the proposed RPM-based daily plan re-optimization strategy. WPO and SPO stand for weakly and strong Pareto optimal.

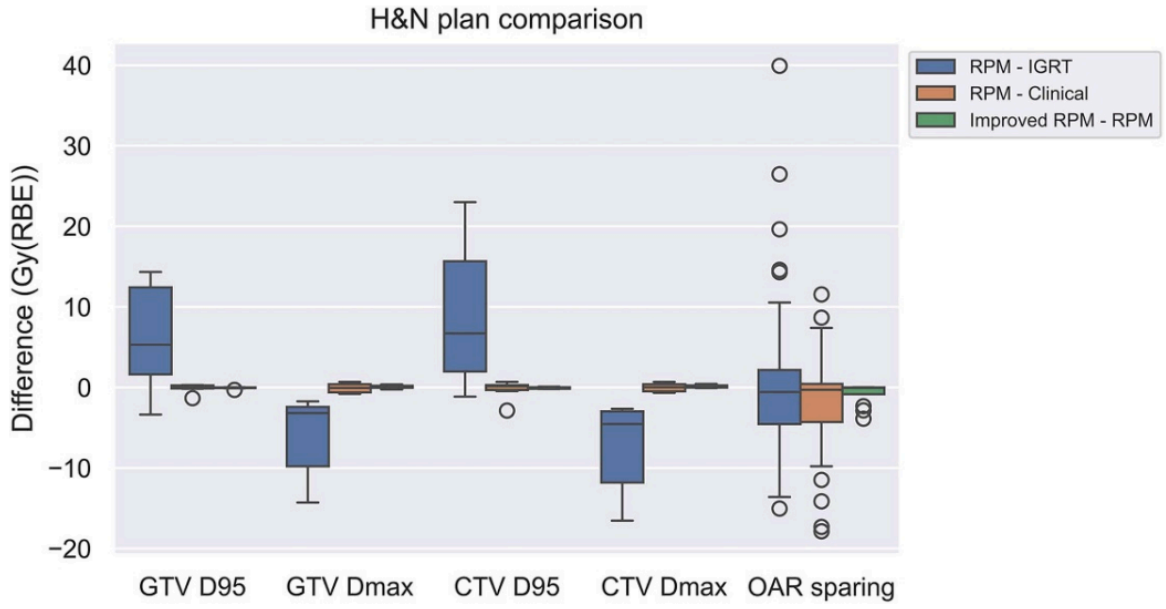



**Figure 2.** Plan key DVH parameter comparison of H&N cases.

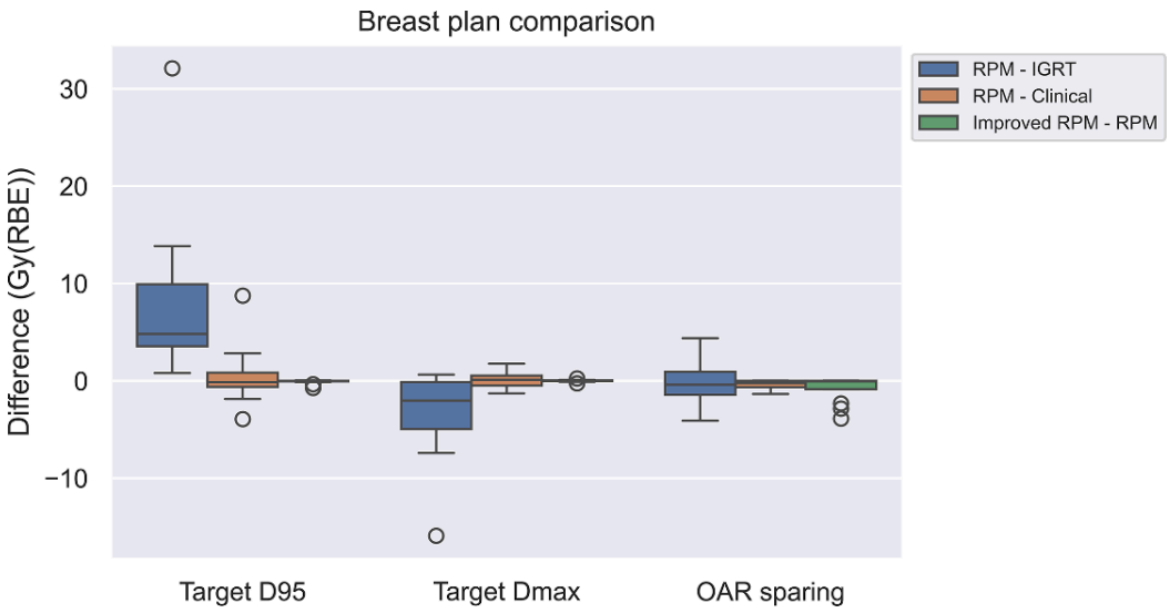



**Figure 3.** Plan key DVH parameter comparison of breast cases.

# Multi-institution investigations of online daily adaptive proton strategies for head and neck cancer patients*

**ESR10: Evangelia Choulilitsa, Center for Proton Therapy, Paul Scherrer Institute, Switzerland**

**Supervisors: Francesca Albertini, Tony Lomax**

**Background and Aim :** In recent years, adaptation in proton radiotherapy has gained prominence. Numerous studies have addressed uncertainties in patient positioning and anatomical changes, though significant changes often require offline replanning. Daily adaptation tailors treatment plans to daily anatomy, optimizing target coverage and minimizing toxicity.

Several studies have explored online daily adaptation strategies, including dose restoration, reoptimization, plan libraries, and online re-planning. At PSI, a full daily plan reoptimization is implemented, using a daily CT image to create a new spot list with the same constraints and field arrangement as the approved plan. Fast reoptimization is crucial, with PSI's raycasting dose algorithm enabling rapid adaptation. Other institutions have also developed methods to speed up this process, though some exceed clinically meaningful times.

These approaches have yet to be clinically implemented or experimentally validated. This study aims to compare the dose restoration approach from Massachusetts General Hospital with PSI's online adaptive workflow and conduct a multi-institutional retrospective investigation of daily online reoptimization workflows.

**Materials and Methods:** 10 H&N patients (PSI: 5, MGH: 5) with daily CBCTs were included. Synthetic CTs were created by deforming the planning CT to each CBCT. Targets and OARs were deformably propagated on daily images. Three daily adaptive treatment strategies were explored: a dose restoration approach modifying the fluence of i) 20% of pencil beams contributing to at least 50% of the total weight (MGH); ii) 100% of pencil beams (MGH); and iii) full plan reoptimization (PSI), modifying both fluence and position of all pencil beams.

**Results:** Despite significant anatomical changes, all three daily adaptive approaches ensure daily target coverage without compromising OAR sparing. Our data suggests a 20% dose restoration suffices, providing comparable results to full reoptimization with only a marginal time increase.

**Discussion and Conclusions:** This multi-institutional investigation of different reoptimization approaches is the first in silico investigation of the dose restoration approach proposed by MGH, with the clinically implemented full reoptimization approach of PSI. Even with notable anatomical changes, the three daily adaptive methods maintain daily target coverage while sparing OARs. Our findings indicate that a 20% dose restoration is effective, offering outcomes comparable to complete reoptimization with only a slight increase in time. For optimal daily adaptive strategies, the full reoptimization alternative is favored.

*This work has been presented at PTCOG62 (Oral talk), and a manuscript is under preparation.


**Figure 1.** The figure shows the simulated workflows. Each patient has a no-adaptation workflow where the daily plan is recalculated on the daily image. In addition, for each patient, a full reoptimization (DAPT) was simulated, and two other adaptation strategies where 20% and 100% of the beamlets were changed without changing the spot placement.

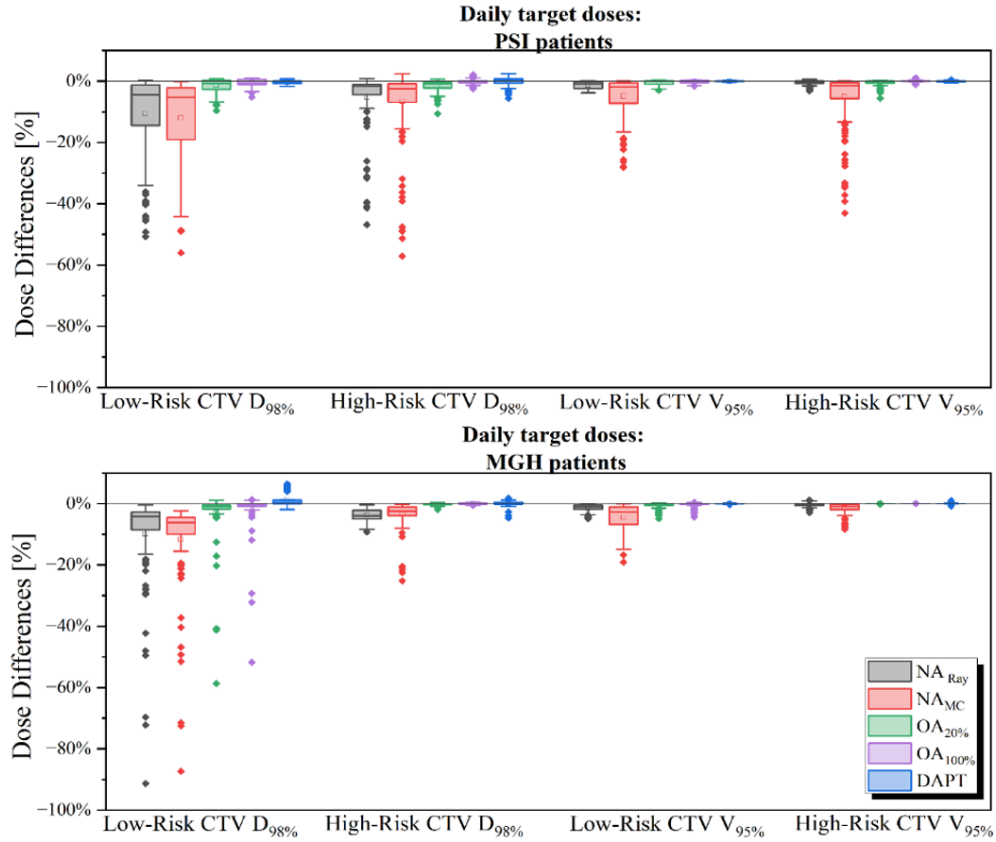



**Figure 2.** Summary of the dosimetric differences for both D98% and V95% of the daily target doses and the respective approved treatment plans for both patient cohorts for the two non-adapted scenarios (NARay and NAMC) and the three reoptimization approaches (OA20%, OA100%, and DAPT).

# 4D robust planning based on dose mimicking for adaptive intensity modulated proton therapy

**ESR11: Suryakant Kaushik, RaySearch Laboratories AB, Sweden**

**Supervisors: Albin Fredriksson, Iuliana Toma-Dasu, Jakob Ödén**

**Background and Aim:** 4D-robust planning is employed when addressing substantial tumour motion. However, it is computationally demanding, so for adaptive planning, an automated planning method that avoids manual trial-and-error would be beneficial. Here, an innovative adaptive planning technique based on dose mimicking is presented and evaluated in terms of target coverage and organ at risk (OAR) sparing.

**Materials and Methods:** The initial plans for 4D-robust IMPT were created on an average CT (avgCT) of each of the four patients with clinical target volume (CTV) in lung, oesophagus, or pancreas. These plans were robustly optimized using three phases of 4DCT (min, max and mid amplitude), accounting for setup variations (3.0-4.0 mm) and density uncertainties (4.5-5.0%). Weekly 4DCTs were used for adaptive replanning, using a constant relative biological effectiveness (cRBE) of 1.1. Two methods were used: (1) template-based-adaptive plan, which used the same optimization functions, weights, and robustness settings as the initial plan; (2) dose-mimicking-based-adaptive plan with min and max CTV dose functions and reference dose functions on CTVs and OARs to mimic the deformed dose from the initial plans to weekly avgCTs, while maintaining other settings similar to template-based-adaptive plan. Non-adapted plans were created by recalculating the initial plans on weekly 4DCTs. Furthermore, McNamara and Wedenberg models were used to calculate the variable RBE (vRBE) weighted doses, and biologically consistent dose accumulation was evaluated.

**Results:** Dose parameters of individual plans are shown in Figure 1. The accumulated dose in the CTV of non-adapted plans with cRBE has D98 ≥97.4% (except P4). Average accumulated dose in the CTV was maximum in the dose-mimicking-based-adaptive plan for all patients. For all OARs, the average dose and D2 after dose accumulation resulted in dose-mimicking-based-adaptive plan dose less than or equal to template-based-adaptive plan dose, except small bowel in P4 (Figure 2). The McNamara and Wedenberg models produce vRBE-weighted doses with an average difference of -2.0% and -2.6% in the CTV compared to cRBE.

**Discussion and conclusions:** Dose-mimicking-based-adaptive plan and template-based-adaptive plan achieved good target coverage, with dose-mimicking-based-adaptive plan performing slightly better than non-adapted plans and template-based-adaptive plan. Dose-mimicking-based-adaptive plan demonstrated superior performance in terms of average dose and D2 of OARs. These results indicate that the proposed dose-mimicking-based-adaptive plan technique offers improved plan quality and can be applied in clinical settings.

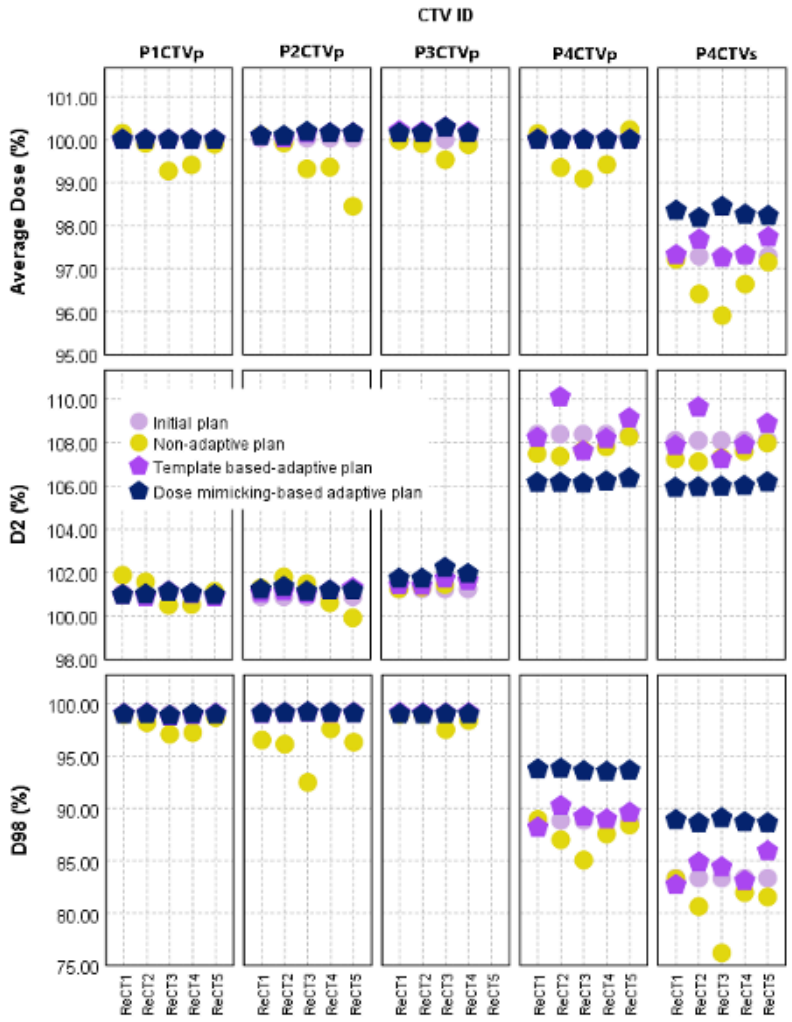



**Figure 1.** The dose parameters for the primary CTV (CTVp) and the secondary CTV (CTVs, which also includes CTVp) represent both non-adaptive and two adaptive plans on the ReCTs (weekly average CT). Dx refers to the minimum dose received by x% of the volume. All percentages were calculated with respect to the prescribed dose for CTVp.

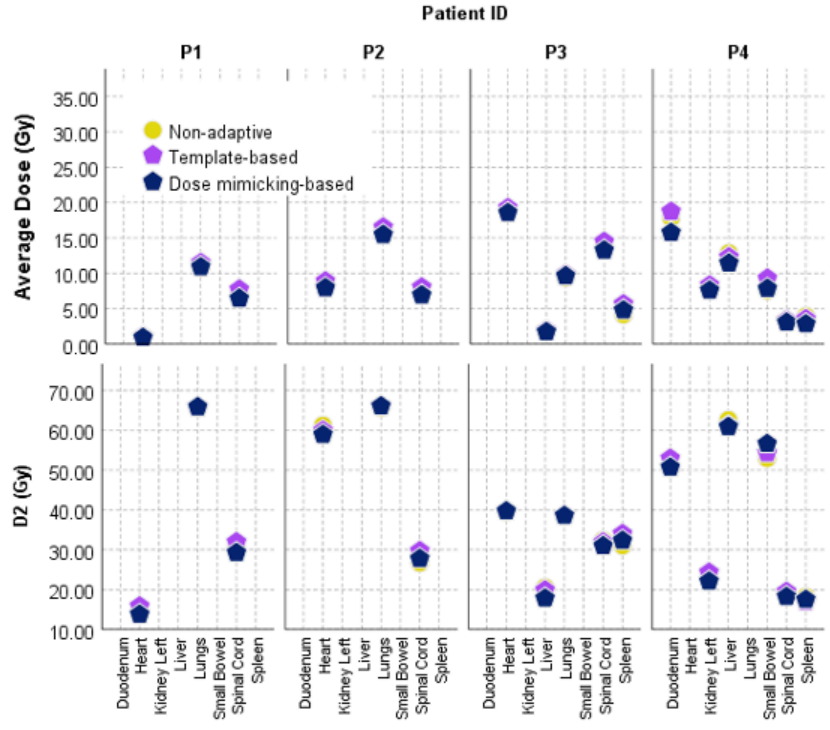



**Figure 2.** The average dose and D2 parameter for OARs dose accumulation for non-adaptive and adaptive plans.

## Conferences and Publications

1. Suryakant K., Kristin S., Jakob Ö., Albin F., Iuliana T. “4D robust planning based on dose mimicking for adaptive intensity modulated proton therapy” – PTCOG 2024
2. Kaushik S, Ödén J, Sharma DS, Fredriksson A, Toma-Dasu I. “Generation and evaluation of anatomy-preserving virtual CT for online adaptive proton therapy” Med Phys. 2024 Mar;51(3):1536-1546.
3. Kaushik S, Ödén J, Sharma DS, Fredriksson A, Toma-Dasu I. “Anatomy-preserving virtual CT for online adaptive proton therapy” – PTCOG 2023
4. Kaushik S, Fredriksson A, Ödén J, Toma-Dasu I. “The effect of different optimization function templates on daily online adaptive proton planning” – ESTRO 2023

## Secondments

1. Oncoray, Germany, April 2023, 3 months – 4D robust planning based on dose mimicking for adaptive intensity modulated proton therapy.
2. UMCG, Netherland, October 2023, 3 weeks – Uncertainty quantification from variable relative biological effectiveness models for protons.

# Real-time 4D-dose calculation to assess the efficacy of motion mitigation strategies

**ESR8: Cosimo Galeone, GSI Helmholtzzentrum für Schwerionenforschung GmbH, Germany**

**Supervisors: Christian Graeff, Marco Durante**

**Background and Aim:** Evaluating the delivered dose for moving targets is crucial in particle therapy, assessing the impact of motion and the effectiveness of motion mitigation strategies. To maximize the accuracy of carbon ion treatments, we extended the INFN-RIDOS system to calculate the delivered dose in real-time accounting for variable motion. Irregular motion was integrated into the RIDOS system for 4D-dose calculations, based on real-time reported motion detection data.

**Materials and Methods:** RIDOS was interfaced with the next generation of the CNAO Dose Delivery System (DDS). The system receives spot parameters (number of particles and position) measured by the beam monitors and motion parameters (respiratory phase and 1D-amplitude), detected by the Optical Tracking System. In detail, the 1D-amplitude is exploited by the adopted motion model (Fig. 1) to provide, intrafractionally, an instantaneous phase and amplitude to estimate a new CT volume. The algorithm reconstructs the delivered and planned 4D-doses and, after each iso-energy layer, the results are displayed on a Graphical User Interface by the end of the spill pause of the synchrotron.

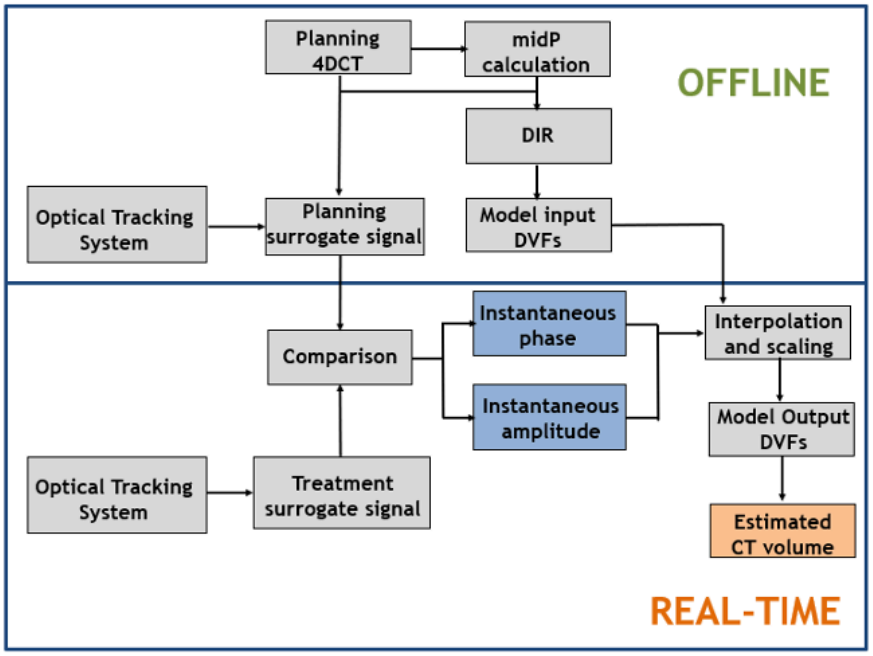



**Figure 1.** Schematic representation of the adopted motion model, based on A. Fassi et al., "Surrogate-driven deformable motion model for organ motion tracking in particle radiation therapy", 2015. The two main boxes depict the operations to be performed offline, and the ones happening during the delivery (real-time).
The procedure starts with the generation of a mid position (midP) CT, which is a time-averaged anatomy based on the planning 4DCT breathing cycle. The midP is then registered to the planning 4DCT, generating the model input vectors.
During the planning 4DCT and the treatment, the Optical Tracking System acquires the motion traces. Out of the comparison of these signals, the model during the delivery outputs an instantaneous phase and amplitude, used to interpolate and scale the model input vector fields, generating the output vector fields. The latter are used to warp the midP, resulting in a new estimate CT volume.

**Results:** The system was tested in the simulated mode at CNAO, delivering a static plan for a virtual XCAT 4DCT (Fig. 2). The plan was optimized on the reference phase (end-exhale). The patient's motion was mimicked by a 1D-regular moving phantom (Anzai, AZ-7332). The generation of new CTs was performed on average in 3.2 ms, while the delivered and planned doses were reconstructed in about 0.25 ms per spot. The accuracy of the reconstructed doses by RIDOS was previously benchmarked against experimental data with an average gamma passing rate of 98.3% (3%/3mm).

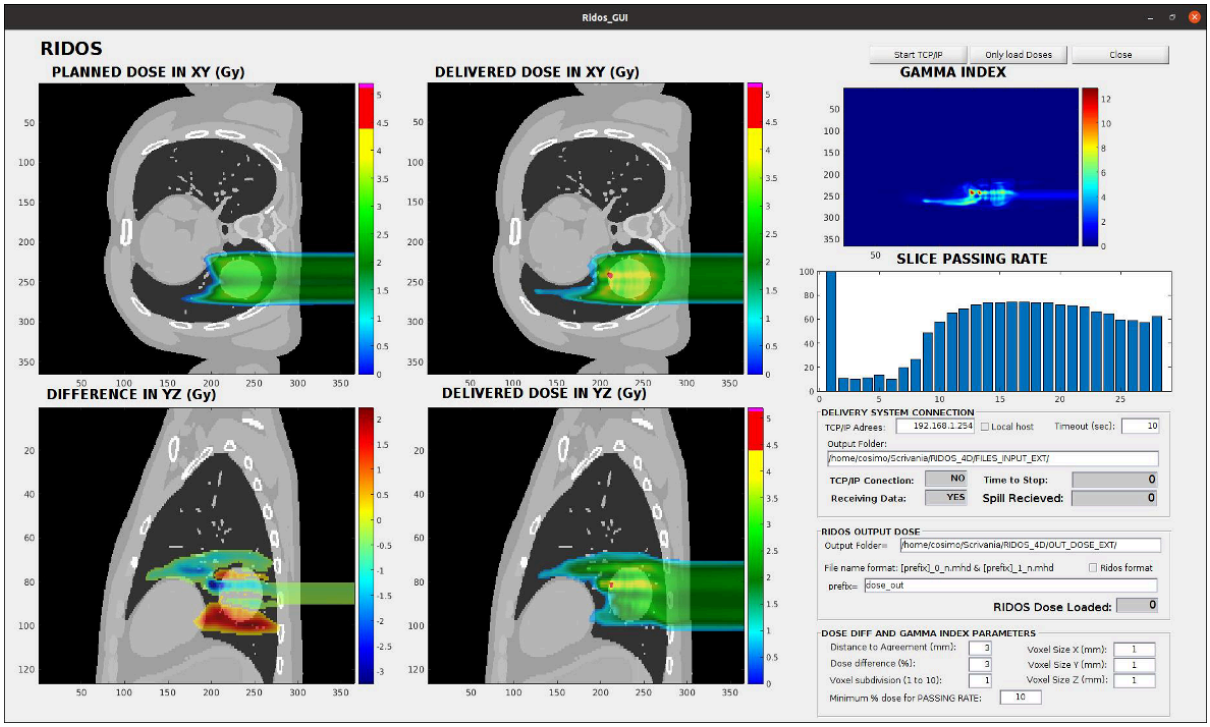



**Figure 2.** RIDOS Graphical User Interface (GUI) interface at the end of a simulated delivery. There are six figures displaying the accuracy of the treatment. In detail, planned and delivered doses in XY plane in the upper section. Below, delivered dose and difference between planned and delivered doses in YZ plane. On the right, gamma-map in the same XY plane, and right below the gamma-index passing rate of all the energy slices delivered during the treatment. The GUI is updated at the end of each energy slice.

The motion model was tested by varying the 1D-amplitude signals, simulating an irregular respiratory pattern. The results of this study are reported in Fig. 3. All the reconstructed phases exhibit a value of average boundary Hausdorff Distance smaller than 2 mm (max 0.63 mm). The maximum target center of mass distance between nominal and generated CTs is 1.05 mm (Fig. 3).

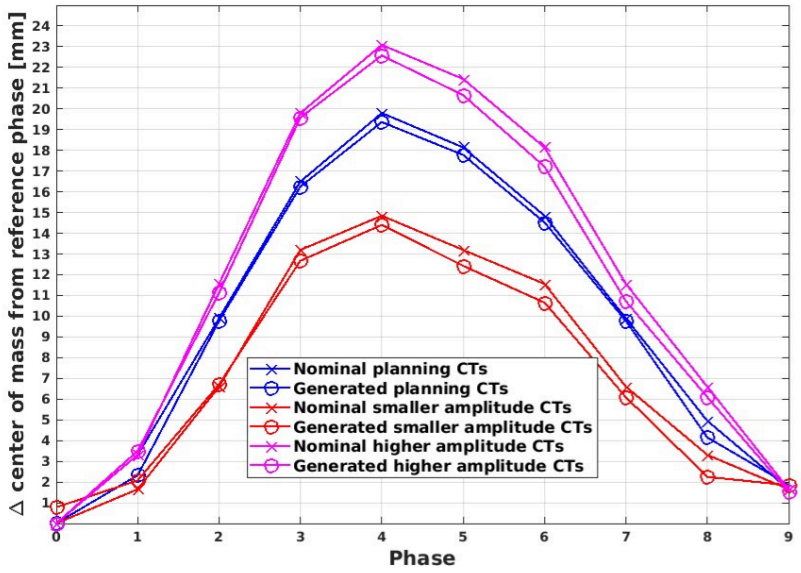



**Figure 3.** Target center of mass distance between nominal and generated CTs for three different scenarios.

**Discussion and conclusion:** We extended the 4D-capabilities of RIDOS to interface with a clinical motion detection system and to handle irregular motion, as expected in clinical reality. The preliminary tests show excellent speed and satisfactory dosimetric results. Thus, the next steps will involve experimental measurements with an irregular moving phantom at CNAO, as well as consideration of different motion models for the generation of new CTs.

**Conferences and publications**

C.Galeone et al. 2024, Real-time delivered dose assessment in carbon ion therapy of moving targets, *Submitted to: Physics in Medicine and Biology*

**Secondment**

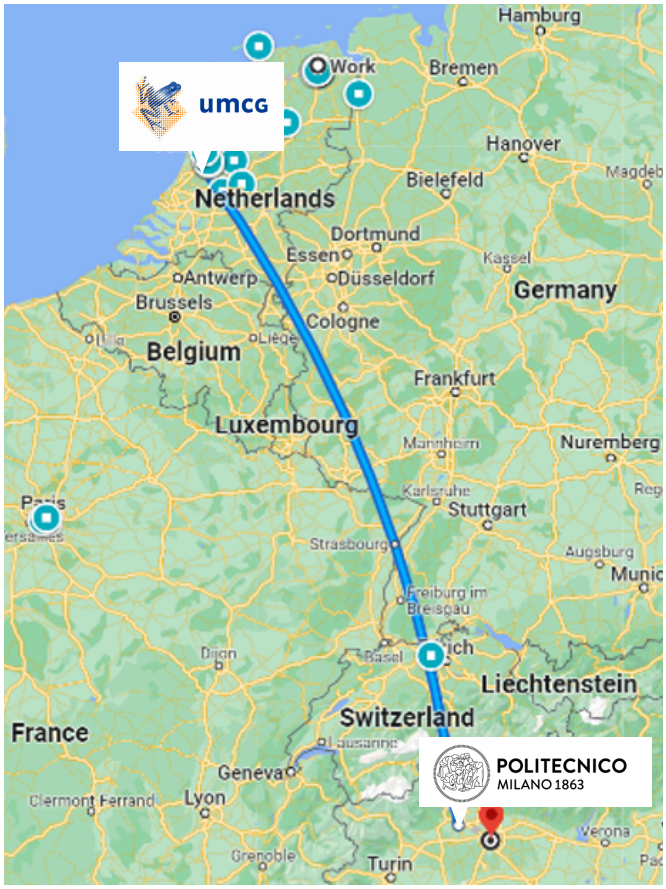
INFN, Turin (Italy), 2 months, March and May 2024, Beamtime preparation.

# *Secondment reports*

**Arthur Galapon**, University Medical Center Groningen

**Who:** Arthur Galapon collaborating with Chiara Paganeli and Anestis Nakas
**Where:** Politecnico di Milano, Milan, Italy
**When:** October 15 – December 23, 2023 (10 weeks)
**Why:** Comparison of deep learning-based sCT models for carbon ion therapy and deep learning-based prediction of radionecrosis in skull-based chordoma

My secondment at POLIMI offered me a fresh perspective and the chance to work on a unique deep learning-based project, diverging from my usual focus. This secondment allowed me to broaden my skills and gain experience in various AI applications. Our goal is to develop an AI model that can predict radionecrosis for skull-based chordoma, utilizing a range of MRI images, quantitative images, and available clinical information.




Milan is a city that can be explored in a day, but don't let that deter you. This city serves as an excellent starting point for discovering the rest of Italy. Every weekend presents a new travel opportunity, whether you head north to Lake Como, south to Rome and Naples, east to Verona and Venice, or west to Turin. Overall, my time in Milan has been an enriching blend of professional growth and cultural exploration. The city's vibrant lifestyle, combined with the opportunity to work on groundbreaking AI research, has made this secondment a truly memorable experience.

**How would you describe your secondment in one word?**
*Fresh*

**What did you take home from your secondment?**
*Lots of pasta and guanciale, pasta-making skill*

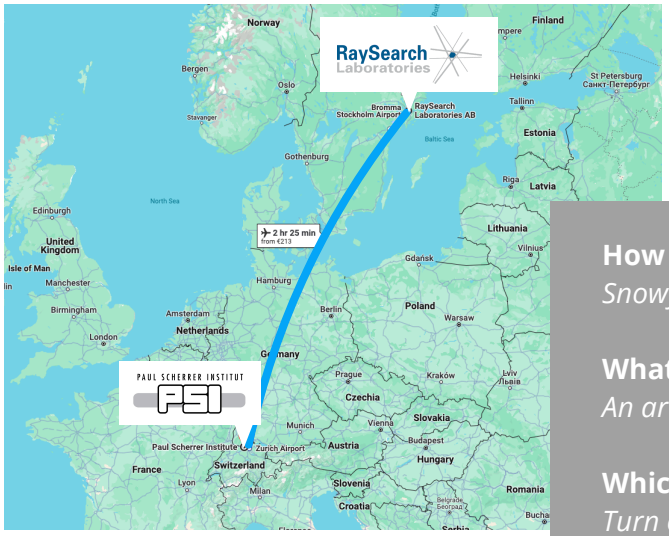
**Which song describes your secondment best?**
*White Toyota by Sunkissed Lola*

**Andreas Smolders**, Paul Scherrer Institute

**Who:** Andreas Smolders, collaborating with Ivar Bengtsson and Albin Fredriksson
**Where:** Raysearch Laboratories, Stockholm, Sweden
**When:** September-December 2023
**Why:** to develop robust optimization techniques against contour uncertainties

Stockholm in Autumn is probably not the most attractive destination for a secondment. And it is true: the lack of light is a downside compared to southern Europe. That said, Stockholm has so much to offer, and is well prepared for the dark period. The city quickly gets a cosy, christmassy vibe, with many interesting events. The coming of the snow, this year already early November, certainly adds to it.

Raysearch also offered a very warm welcome, integrating me in the team with many interesting (and tasty) lunch break discussions. When coming from an academic environment, doing a secondment in a company is definitely beneficial, to understand better the reality of radiation oncology, and also the business perspective behind it. Nevertheless, Raysearch's focus on research is remarkable, with a very large team that is fully dedicated to improve their software. In a time where competition is scarce, at least for particle therapy planning systems, such an effort is commendable.





From my personal research experience, it was especially interesting to get firsthand experience with an advanced treatment planning system, and to implement new features into a very large codebase. Thoroughly helped by Ivar Bengtsson, my local host and collaborator, this went reasonably smooth, and we managed to get interesting results. The good thing is that we both brought unique capabilities to the table, doing a research project that neither of us could have done independently.

**How would you describe your secondment in one word?**
*Snowy*

**What did you take home from your secondment?**
*An article to finish*

**Which song describes your secondment best?**
*Turn of the lights – Fred Again*

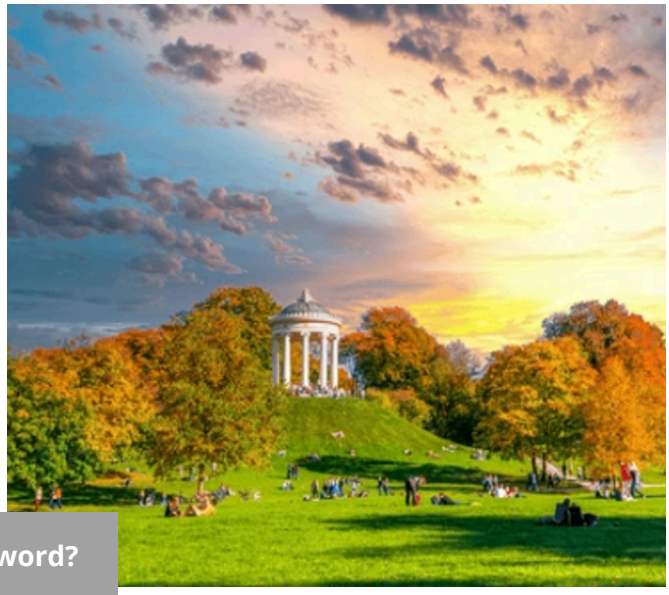
**Francesco Russo**, *medPhoton GmbH*

**Who:** Francesco Russo, Philipp Steininger, Katia Parodi, Guyue Hu
**Where:** Ludwig-Maximilians-Universität München (LMU) – LMU klinikum, Munich, Germany
**When:** February – April 2024
**Why:** Gathering clinical data for sCT improvement and dual energy CBCT data with phantoms not available at home institute

After spending my first year in Salzburg, visiting a large German city was an exciting change. I loved spending my free time relaxing in the Englischer Garten and interacting with locals to improve my German skills. Socially, it was a vibrant experience that offered much more than my home city.

Professionally, the secondment was incredibly inspiring. Witnessing the clinicians' work firsthand was enlightening. With the clinic staff's assistance, I quickly gathered the necessary clinical data. Additionally, supporting the ImagingRing of medPhoton while collecting clinical data provided invaluable insights into clinical workflows and system requirements. Working at the university allowed me more time to explore research ideas, particularly in dual energy imaging. Engaging with the LMU faculty broadened my knowledge on various RAPTOR-related topics, including proton radiography, detector mechanisms, and dual energy imaging.

Overall, this secondment was a rewarding experience that enhanced my social and professional skills significantly, contributing to my PhD journey in a meaningful way.

**How would you describe your secondment in one word?**
Instructive

**What did you take home from your secondment?**
*Much data to work with*

**Which song describes your secondment best?**
*Have you ever seen the rain - CCR*

**Jacob Brunner,** *MedUni Wien*

**Who:** Jacob Brunner, collaborating with Gabriel Guterres Marmitt, Dirk Wagenaar, Stefan Both, Arthur Galapon and Giuliano Perotti Bernardini
**Where:** University Medical Center Groningen (UMCG), Groningen (NL)
**When:** September – October 2022
**Why:** Trial run of adaptive phantom irradiation at another institute

Although the Netherlands is a direct neighbor of my home country Germany, I had never visited prior to my Secondment. I was excited to meet new people and visit a country where water has had such an impact on…everything. When traveling through the country via train there's canals and bodies of water everywhere! I was very warmly welcomed by the colleagues at UMCG, they happily answered my questions about work and helped my out whenever I needed something. On a more personal level I also couldn't have been better off. We had discussions about the Dutch and their relationship with rules, went to bars, went to Korean BBQ (group picture) and were invited to a colleagues house in Friesland (a northern province) and stayed for a Dutch tent party.

Research-wise the stay was very productive. Thanks to our colleagues at UMCG I could get beam time at their clinical machine to test out a mock-adaptive workflow on my phantom prototype including anatomical modifications. Since work at the clinic always takes priority, we had to reschedule once. It all worked out in the end, thanks to everyone at the facility helping me to have a working setup ready in time. The future plan for my project is to visit the treatment centers participating in RAPTOR and conducting end-to-end tests there. From A to Z all steps in a possible adaptive proton therapy workflow will be tested and dosimetrically verified. The time before, during and after the Secondment taught me a lot of lessons about what to look out for in future visits. I am looking forward to seeing everyone again, next time with the final version of my phantom and an adaptive workflow in my luggage!


**How would you describe your secondment in one word?**
*Warmhearted*

**What did you take home from your secondment?**
*Copious amounts of cheese*

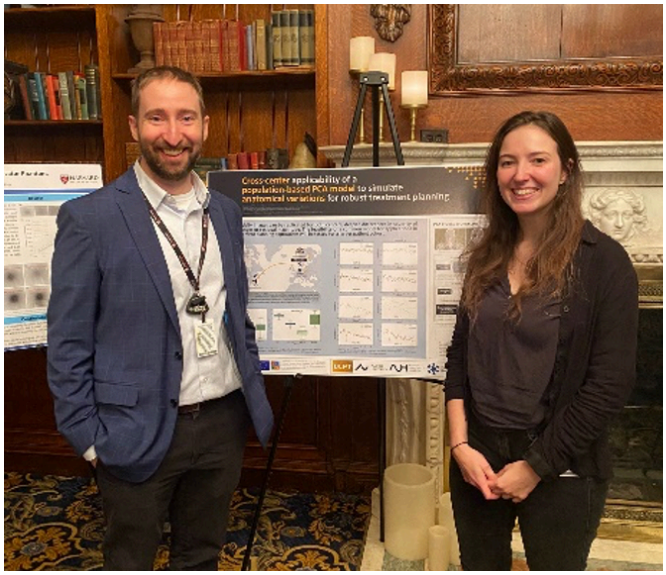
**Which song describes your secondment best?**
*Mart Hoogkamer - Ik Ga Zwemmen*

**Nadine Vatterodt**, *Aarhus University*

**Who:** Nadine Vatterodt collaborating with Brian Winey
**Where:** MGH, Boston, United States
**When:** 20th September - 17th November 2023
**Why:** Assessment of cross-center applicability of a population-based anatomical PCA model

My secondment at MGH was raising my nervosity to a new level. Going to such a prestigious institution, affiliated with Harvard and sitting in meetings with pioneers of our field felt surreal. Once there I had a short moment of victory over my high school physics teacher, who had once told me to polish my nails instead of listening to the next lectures, as they would be too difficult for me anyhow. In contrast, Brian is super supportive and his perspectives as a medical physicist from another leading center are of high value for our study.

Having only been to the US once before for PTCOG in Miami Beach, I was pleasantly surprised by Boston's charming character. It was easy to feel at home, especially with Eva and Zihang being there at the same time as I was. I loved the apple picking with Brian's family and Eva and the weekend trip to Vermont with Zihang and others from MGH.



However, I must admit that I also greatly enjoyed my stay in San Diego for ASTRO2023 – finally, a warm place! The two coasts differ quite a lot, not only in architecture and nature but also in overall vibe. One thing that remained constant throughout the US, though, was the condition of the homeless which was particularly emotionally challenging for me.
Overall, I am super grateful for the experience during this secondment, which complimented my stay at RaySearch in Sweden perfectly.


**How would you describe your secondment in one word?**
*Ambivalent*

**What did you take home from your secondment?**
*A Boston Bruins centennial shirt*

**Which song describes your secondment best?**
*Under pressure – David Bowie & Queen*

*Listed in alphabetical order.

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