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Scientific Session

Topic: Hadrontherapy

Chair: Kevin Souris (UCLouvain)

Saturday 30/04/2022 09h00-10h10

Auditorium 2000

Healthy tissue sparing in proton therapy of lung tumors using statistically sound robust planning

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ABSTRACT – To ensure safe delivery, proton treatment plans must be robust to all sources of uncertainty. One of the most common approaches, robust optimization, directly incorporates treatment errors in the optimization process. This approach can be limited by overly conservative scenario selection and a lack of consistently calculated confidence levels. We explore the clinical benefit of using scenario selection tools with improved statistical foundations for robust optimization and evaluation in the form of their impact on target coverage and organs-at-risk sparing.

KEY WORDS – proton therapy, robust optimization, robust evaluation, IMPT

Introduction

Robust planning is essential in proton therapy for ensuring adequate treatment delivery in the presence of uncertainties. For both robust optimization and evaluation, commonly-used techniques can be overly conservative by generating error scenarios from combinations of only maximum error values of each uncertainty source and they lack in providing quantified confidence levels [1]. In this study, we explore whether a clinical benefit can be expected using scenario selection tools with improved statistical foundations, both at the level of robust optimization and evaluation.

Materials and methods

Thirteen lung cancer patients were planned. Two robust optimization methods were used: scenario selection from marginal probabilities (SSMP) based on using maximum setup and range error values and scenario selection from joint probabilities (SSJP) that selects errors on a predefined 90% hypersurface [2]. Two robust evaluation methods were used: conventional evaluation (CE) based on generating error scenarios from combinations of maximum errors of each uncertainty source and statistical evaluation (SE) via the Monte Carlo dose engine MCsquare [3]

which considers scenario probabilities. During evaluation we report for the target coverage the D_{98} (Gy) nominal and worst-case values as well as D_{mean} (Gy) and V_{30} (%) for heart and lungs-GTV and D_2 (Gy) for spinal cord and esophagus.

Results

Plans optimized using SSJP had, on average, 0.5 Gy lower dose in CTV $D_{98(worst\text{-}case)}$ than SSMP-optimized plans. This was expected as the SSJP tool aims at securing robustness at a predefined 90% confidence level with the aim of achieving a level of target robustness situated at the limit of clinical acceptability (i.e., adequate coverage for at least 90% of patients). When evaluated using CE only 76.9% of SSMP patients and 46.2% of SSJP patients passed our clinical threshold. Evaluating with SE, 92.3% of patients passed our clinical threshold in both optimization methods highlighting the impact of evaluating in a statistically consistent manner. Average gains in OAR sparing were recorded when transitioning from SSMP to SSJP in all metrics: esophagus (0.6 Gy $D_{2(nominal)}$, 0.9 Gy $D_{2(worst\text{-}case)}$), spinal cord (3.9 Gy $D_{2(nominal)}$, 4.1 Gy $D_{2(worst\text{-}case)}$) heart (1.1 Gy D_{mean}, 1.9% V_{30}), lungs-GTV (1.0 Gy D_{mean}, 1.9% V_{30}). The reduction of the target margin to the bare minimum is the main drive that enables substantial and consistent OAR sparing.

Conclusion

Establishing a proper robust optimization and evaluation workflow is essential to realize the potential of proton therapy. Optimization using SSJP yielded significant OAR sparing in all recorded metrics with a target robustness within our clinical objectives, provided that a more statistically sound robustness evaluation method was used. This highlights the importance of using both advanced optimization and evaluation tools when we aim at ensuring a quantified level of robustness.

References

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Fetal dose comparison during photon and proton treatment of a brain tumor

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ABSTRACT – In this study, we describe the case of a pregnant woman with a brain tumor undergoing photon therapy during pregnancy and compare the fetal dose between photon and proton therapy. We showed a 30-fold reduction in fetal dose when using PBS proton therapy compared to photon therapy, showing the immense potential of proton therapy for treating pregnant cancer patients.

KEY WORDS – Pregnancy, Proton therapy, photon therapy, fetal dose

Introduction

About 1 out of 1000 pregnancies are complicated by cancer. With growing evidence on the safety of chemotherapeutic treatment during pregnancy, approximately 69% of these patients are now being treated during their pregnancy. Although guidelines indicate that radiotherapy is feasible when the fetal dose is kept below 100 mSv, only 1-3% of pregnant cancer patients receive radiotherapy[1]. In this study, we describe the case of a pregnant woman with a brain tumor undergoing photon therapy during pregnancy and compare the fetal dose between photon and proton therapy.

Materials and methods

At 7 weeks of pregnancy our patient presented with a recurrent astrocytoma (grade III) for which radiotherapy was indicated. At 13 weeks of gestation the patient started radiotherapeutic treatment, consisting of 45 Gy, delivered in 25 fractions, and a consecutive boost of 14.4Gy in 8 fractions to the prophylactic volume. The estimated distance between the isocenter and the fetus was estimated to be 60 cm.

The IMRT photon therapy plan was optimized to minimize the fetal radiation dose. This included the use of 7.7cm frontal and 5cm left lead shielding, minimization of the MU=239/240 (resp. main/boost) and the use of a low energy, 6 MV, treatment beam[2]. As the tumor was left lateralized, the head was fixated sideways, looking at the right, to avoid treatment angles not covered by shielding. For both the main and boost plans, three treatment angles were used at 55, 110 and 325°, with a

couch rotation of 10°. The fetal dose was estimated using an ionization chamber (Farmer type, 345), at 60 cm from the isocenter. The head, shoulders and abdomen of the patient were modelled using solid water plates and in-house built water phantoms. The photon therapy was delivered using a Varian Truebeam STX with HD MLC.

A comparative pencil beam scanning proton therapy plan was made for the ProteusONE (IBA) proton beam at UZ Leuven. A two-beam set-up was used for the main plan at gantry angles of 80 and 170°, and similarly for the boost plan at gantry angles of 60 and 120°. No table rotations were used. A range shifter was used for both angles of the main plan with minimal air gap. The fetal dose was estimated using a FHT 762 Wendi-2 detector, placed with its center at 60cm from the isocenter. The patient geometry was modelled using CIRS PT head and shoulder phantoms, 3D printed breasts and SP34 solid water plates.

Results

The estimated total fetal doses during photon and proton therapy were respectively 15mSv and 0.48 mSv (Table 1), including both the fetal dose from the main (45Gy) and boost (14.4Gy) plans.

Table 1: Estimated fetal dose during the photon and proton therapy plans

		Fetal dose per fraction [µSv]		**Fetal dose all fractions [mSv]**		
		Main	Boost	Main	Boost	**Sum**
Photon therapy	**No shielding**	710	490	17.75	3.92	**21.67**
	With shielding	500	320	12.5	2.56	**15.06**
	PBS proton	18.7	1.26	0.47	0.01	**0.48**

Conclusion

This case study observed a 30-fold reduction in fetal dose when using PBS proton therapy compared to photon therapy. Future work should generalize these results for other tumors and improve the accuracy of the fetal neutron dose estimation during proton therapy, leading to guidelines and standardization on the use of proton therapy during pregnancy.

References

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Validation of a Monte Carlo framework for out-of-field dose calculations in proton therapy

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KEY WORDS – Proton therapy, TOPAS, Monte Carlo simulation, out-of-field dosimetry, TLD, bubble detector

ABSTRACT

Introduction: Proton therapy (PT) enables to deliver highly conformed dose distributions owing to the characteristic Bragg peak and the finite range of protons. However, during proton therapy secondary neutrons are created which can travel a long distance and deposit dose out-of-field. This out-of-field absorbed dose needs to be considered for radiation-induced secondary cancers which are particularly relevant in the case of pediatric treatments. Unfortunately, no method exists in clinical routine for the computation of the out-of-field dose distributions in proton therapy. To help overcome this limitation a computational tool was developed based on the

Monte Carlo code TOPAS. The purpose of this work is to evaluate the accuracy of this tool by comparison to experimental data obtained from an anthropomorphic phantom irradiation.

Materials and methods: An anthropomorphic phantom of a 5-year-old child (ATOM, CIRS) was irradiated for a brain tumor treatment in an IBA Proteus Plus facility using a pencil beam dedicated nozzle. Thermoluminescent detectors (TLD), namely Li-7 enriched LiF:Mg, Ti (MTS-7) type, were irradiated in 180 positions. Moreover, Li-6 enriched LiF:Mg,Cu,P (MCP-6) in combination with Li-7 enriched MCP-7 to quantify thermal neutrons. Additionally, bubble detectors (BD-PND) were used for measuring neutrons (< 50 keV). The treatment consisted of three pencil beam scanning fields employing a lucite The Monte Carlo code TOPAS (version 3.6) was run using a phase-space file containing $1x10^{10}$ histories reaching an average standard statistical uncertainty of less than 0.1% (coverage factor k=1) on all voxels scoring more than 50% of the maximum dose. The primary beam was modeled following a Fermi-Eyges description of the spot envelope fitted to measurements. For the Monte Carlo simulation the chemical composition of the tissues represented in ATOM was employed. Dose was tallied as dose-to-water.

Results: Out-of-the-field doses showed absorbed dose that were 5 to 6 orders of magnitude lower than the target dose. The discrepancy between the central values of the TLDs located in the out-of-the-field region and the corresponding scored values in the Monte Carlo calculations involving proton and gamma doses was on average 18%. The comparison between the neutron equivalent doses between the Monte Carlo simulation and the measured neutron doses was on average 8%.

Conclusions

The proposed computational method for routine calculation of the out-of-the-field dose in proton therapy produces results that are compatible with the experimental data.

Real-time treatment of mobile tumors in proton therapy by a library of treatment plans

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ABSTRACT – We propose an approach based on a library of treatment plans optimized on each breathing phase of a 4DCT and delivered in real-time during treatment based on the current anatomy. A comparison between a 4D-robust treatment plan and our method is done by simulating the treatment on a continuous sequence of synthetic CTs generated from an MRI sequence of a liver patient. We show that our approach outperforms the 4D-robust plan on both target coverage and OARs sparing.

KEY WORDS – Proton therapy, mobile tumors, real-time, Treatment plans library

Introduction

Today, treating mobile tumors in proton therapy is usually carried for low motion amplitude with offline techniques such as 4D robust optimization, rescanning or with online techniques such as gating or abdominal compression for higher motion amplitudes. Those techniques show disadvantages such as an increased dose to the organs at risk in case of 4D robust optimization or an increased treatment time in case of gating. A real-time adapted method which selects precomputed plans based on the current anatomy has the ability to give a more conformal dose to the target and decrease the dose to surrounding organs due to the absence of margins.

Materials and methods

A library of 3D plans is constructed where each plan is independently optimized to cover the CTV for each phase of a planning 4DCT, similarly to the 4D-rescanning method in [1]. The anatomy's motion of a liver patient was recorded during several minutes using cine-MRI and transformed into a sequence of 3DCTs using the method of Dasnoy et al. [2] that follows the breathing pattern of a patient in 3D. The treatment is then delivered according to the workflow depicted in Figure 1. A distance is computed between the current CT and the planning 3DCTs. The phases respecting a distance threshold are selected and the spots in the corresponding plans are delivered until the next CT from the continuous sequence is obtained. The treatment continues until all spots of the library of plans are delivered.

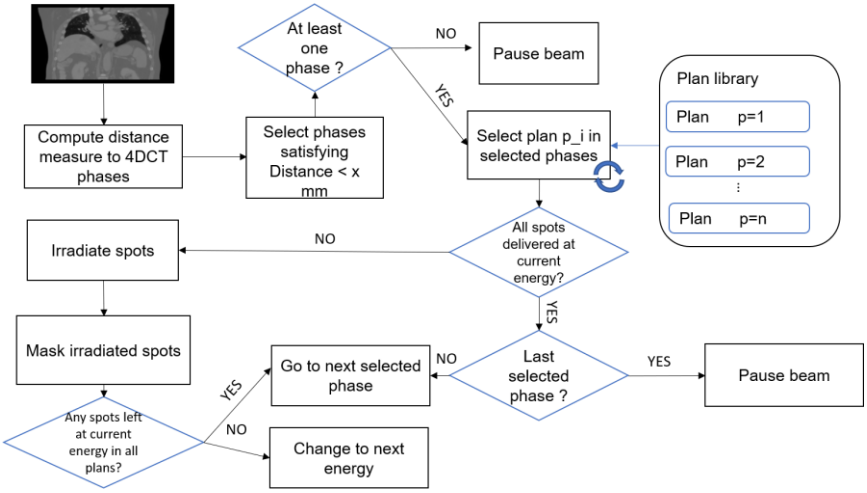

Figure 1: Real-time treatment delivery workflow

Results

Results of a simulation on the continuous sequence of CTs are shown in Table 1 for a 60Gy prescription. The 4D robust plan is not able to achieve a conformal dose to the target while our method does and the dose to the surrounding OAR is 40% higher on average than in our method.

	4D-robust plan	**Our method**
CTV D95 – D5	54.2 – 66.5	59.1 – 61.1
Liver-CTV (Dmean – D5)	3.10 – 26.8	2.20 – 15.8
Lung R (Dmean – D5)	5.40 – 29.7	4.10 – 26.8
Treatment time (sec)	182.8	225

Table 1: Comparison of 4D-robust plan and library of treatment plans

Conclusion

Treating mobile tumors in proton therapy based on real-time anatomy information with a library of treatment plans optimized on each breathing phase of a planning 4DCT helps to drastically reduce the dose to the surrounding OARs and results in a more conformal dose to the target while only moderately increasing the treatment time.

References

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Ion recombination correction factor simulations in Carbon Ion beams at conventional and high dose rates

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ABSTRACT – Ion recombination collection factor remains issue for non-standard radiotherapy modalities (heavy ions and high dose rates) where general and initial recombination are significant and cannot be neglected. In this work, simulations with carbon ion beams at conventional and ultra high dose rates were carried out in order to improve the understanding of the recombination effect and predict ion recombination correction factors for different ionization chambers and non-conventional radiotherapy modalities.

KEY WORDS – Recombination, Simulation, Correction factor, High dose rates, Carbon Ions

Introduction

In the last years there has been an increasing interest in non-standard radiotherapy modalities such as high LET particles like carbon ions and ultra-high dose rates, the latter being used to reach FLASH effect conditions. In these modalities, the standard correction methods for the recombination provided by international reference dosimetry protocols such as TRS-398[1] and TG-91[2] are not valid as suggested by S. Rossomme et al.[3] and their dosimetry remains an issue.

There are two types of recombination: initial and volume. Initial recombination occurs when there is recombination between charge carriers liberated from the same particle, this happens with high LET particles and also depends on the ion track structure. The volume recombination takes place between charge carriers of different particles, this depends heavily on the dose rate.

Materials and methods

In this work, general and initial recombination were simulated for conventional and ultra-high dose rates for a scanned carbon ion beam with a plane parallel ionization chamber using the software *IonTracks*[4]. This code is based in the resolution of an equation that governs the movement of charge carriers inside an ionization chamber under the influence of an electric field using numerical calculations based on the finite differences method.

The simulations carried out were based on the work done by S. Rossome et al.[5], where experimental data for a 62 MeV/n carbon ion beam measured with a PPC40 situated at a 4-5 cm depth in water (on the plateau before the Bragg peak) were available. The simulations were carried out at various voltages: 50, 60, 80, 100, 132, 150, 200, 250, 400 and 800 V. Three conventional dose rates: 1.25, 2.3 and 5.8 Gy/min. And three ultra-high dose rates: 2400, 6000 and 12000 Gy/min.

Results

The simulations were in accordance with the experimental data at high voltages as well as the Jaffe theoretical values for the initial recombination, which is dominant for high LET particles (see figure 1). At low voltages we observe a disagreement between the experimental, theoretical and the simulations data, that for now can be solved by fine tuning some free parameters, as suggested by S. Rossomme et al.[5] With this adjustment on the simulation we have a better agreement between experimental and theoretical results as we see in figure 2. The origin of this discrepancy is under investigation.

The conventional dose rates have almost similar plots as we see in figure 3, this is something expected and in accordance with S. Rossome et al.[5] data because at low dose rates with high LET particles the dominant effect is the initial recombination.

Regarding the ultra-high dose rates plotted in figure 3 we can see an increase of the correction factor with the dose rate. This result is expected because volume recombination becomes dominant when the dose rate increases. This occurs mainly at lower voltages, when the time to collect the charges is greater than the one at higher voltages. It was not possible to compare either with experimental data or with Boag's theory for volume recombination. Boag's theory is only valid when no new pulses enter the chamber before the previous one has been collected. Ultra high dose rates do not fulfill this last condition.

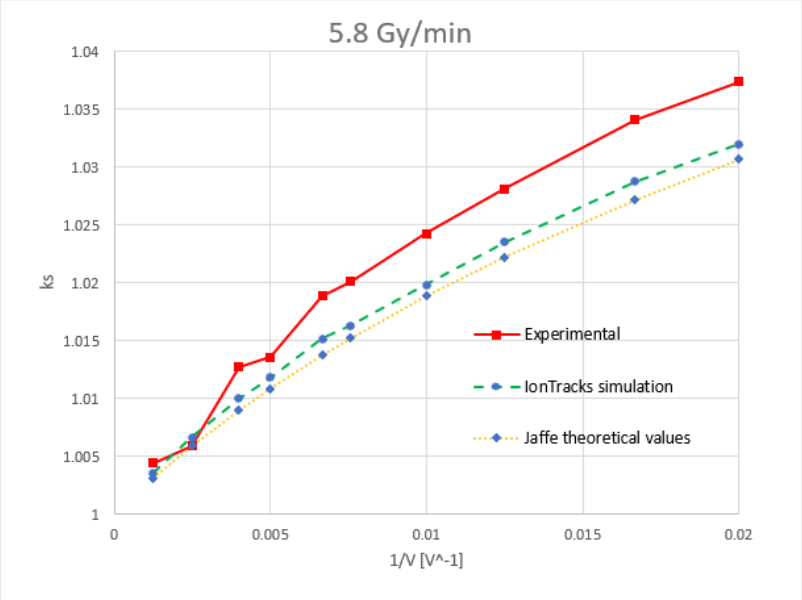

Figure 1: Comparison between experimental data, IonTracks simulations and Jaffe theoretical values for a 5.8 Gy/min dose rate.

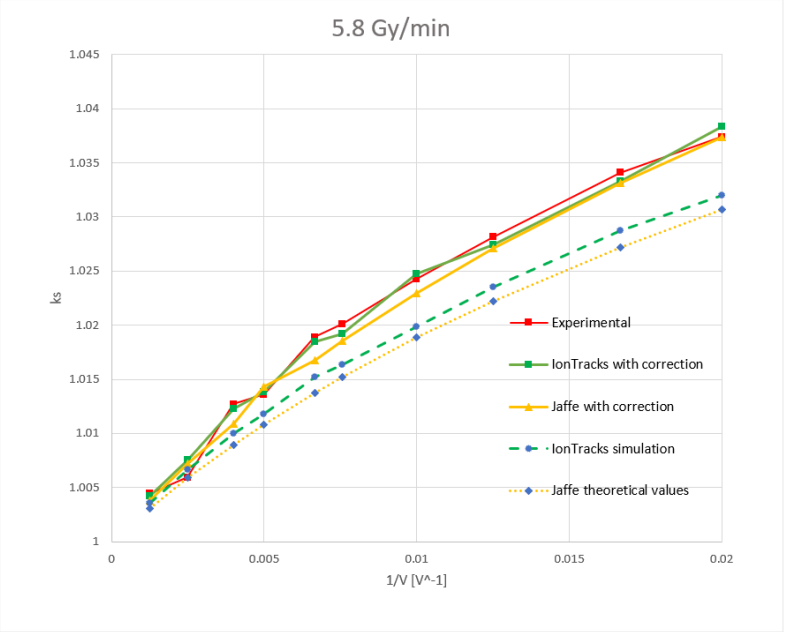

Figure 2: Comparison between experimental data, IonTracks simulations and Jaffe theoretical values with the tuned (solid lines) and non-tuned (dotted lines) free parameters for a 5.8 Gy/min dose rate.

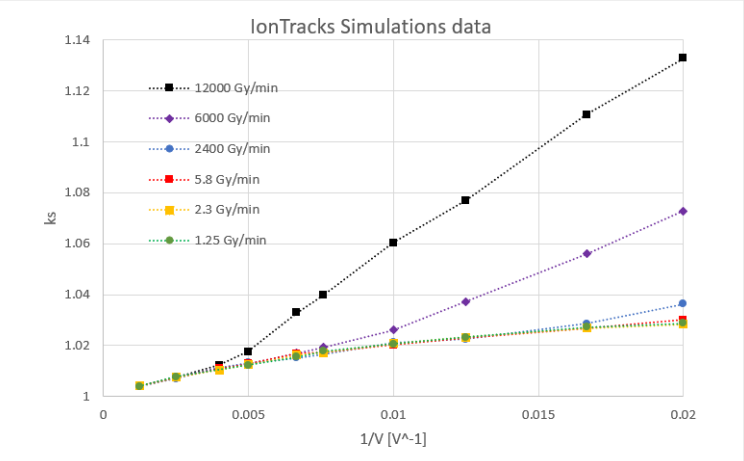

Figure 4: IonTracks simulation data for conventional dose rates (from 1.25 to 5.8 Gy/min) and ultra high dose rates (from 2400 Gy/min to 12000 Gy/min).

Conclusion

Based on the accordance between the simulation results and the experimental data, this simulation tool could be useful to face the challenge of obtaining and designing ionization chambers that can correct properly for ion recombination. Even though the data for high dose rates were not compared with any experimental or theoretical values, the results obtained with IonTracks have a similar tendency as the results obtained on Carbon Ion beams for different dose rates by S. Rossome[3].

References

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Treatment plan optimization algorithm for proton arc therapy

H. Ozan[1], M. C. Vera[1], S. Wuyckens[1], A. C. Wéra[1], G. Janssens[2], J. A. Lee[1], E. Sterpin[1], K. Souris[1]
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ABSTRACT – Arc proton therapy (ArcPT) has gained interest recently as it could help resolve some of the challenges of proton therapy. This work presents a script (spARCling) developed to produce ArcPT plans. SpARCling treatment plans were computed with pencil beam scanning dose algorithm in a clinically reasonable time. In comparison to IMRT and IMPT, spARCling plans can improve plan quality. This approach could allow having a fast beam delivery time once the mechanical features of treatment unit are improved.

KEY WORDS – proton, arc, treatment planning, delivery time

Introduction

Proton therapy has improved over the past years with the introduction of Intensity Modulated Proton Therapy (IMPT) based on pencil beam scanning techniques. IMPT improves dose conformity but faces challenges due to its sensitivity to uncertainties related to motion, patient set-up or proton range. Moreover, the number of beams used is usually limited to two or three as the delivery time can increase substantially. ArcPT delivery is a promising approach to answer some of these challenges, notably in mitigating the impact of uncertainties, improving dose conformation, and reducing integral dose as well as decreasing the treatment delivery time. However, using regular IMPT optimization techniques would require massive computation resources due to the large number of beams that compose ArcPT plans. Moreover, the number of energy layers (EL) should be minimized during the optimization process because of its prominent impact on beam delivery time (BDT). The group of Beaumont Health proton therapy center initially proposed the SPArc algorithm to address these issues [1]. Based on their work, we implemented a RayStation script (spARCling) to efficiently optimize ArcPT plans combining fast pencil beam (FPB) and more accurate Monte Carlo (MC) dose calculations. The algorithm is applied to two patient cases of esophagus cancer and is compared to IMRT and IMPT results.

Materials and methods

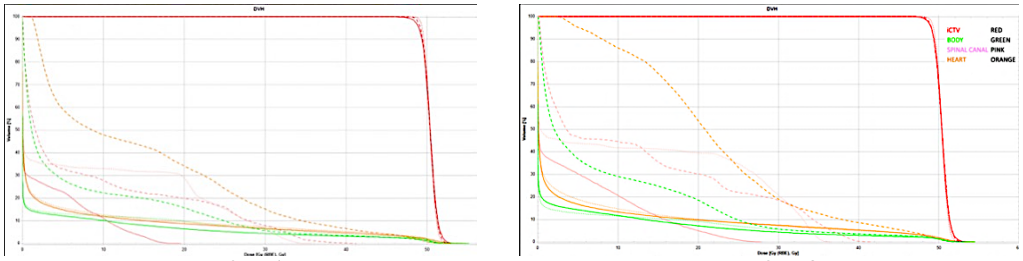
A spARCling plan is initialized with only a few IMPT beams. The number of beams is then progressively increased by iteratively splitting the existing beams and redistributing the energy layers to the beams hence newly created. The total number of energy layers remains thus constant in order to keep the computation resources tractable during optimization and to maintain a reasonable delivery time of the final plan. When the desired angular separation is achieved, ELs are then further reduced by iteratively removing the least important layers until every beam contain just 1 EL. Finally, the beams are sorted according to their gantry angle.

Treatment plans for two esophagus cancer patients with 50.40Gy prescribed dose were created using RayStation version 10B TPS. Plans were generated for IMRT (7 beams), IMPT (2 beams) and spARCling (48 beams). During ArcPT planning, the repeated

optimizations of the spARCling method were performed with FPB algorithm along with a final optimization round with MC algorithm at the end of the process. BDT was calculated using an in-house developed platform (OpenTPS).

Results

The results showed that spARCling plans achieved similar target coverage as IMPT and IMRT plans. Proton plans led to strong decrease in spinal canal and heart doses. A slight dose reduction was observed with ArcPT compared to IMPT. The BDT were comparable for IMPT and ArcPT, but the beam transition time for IMPT was not considered. That condition would be in favor of ArcPT.



patient-1 *patient-2*

Figure 1: *DVH comparing the treatment plans created with spARCling script (solid lines), IMPT (dotted lines) and IMRT (dashed lines) technique*

	Patient 1			Patient 2		
	IMRT	**IMPT**	**ArcPT**	**IMRT**	**IMPT**	**ArcPT**
iCTV: 95% prescribed dose (%)	99.96	99.90	99.26	99.99	99.97	99.94
Body: D_{mean} *(Gy)*	7.10	4.10	3.20	8.50	3.80	3.60
Spinal Canal: $D_{0.05cm^3}$ *(Gy)*	40.66	34.56	18.20	41.10	36.03	27.03
Heart: D_{mean} *(Gy)*	14.76	4.73	4.39	22.10	5.15	4.92
Beam Delivery Time *(s)*	-	194	195	-	203	185

Table 1: *Comparison of dosimetric results for spARCling, IMPT and IMRT plans*

Conclusion

As results showed, ArcPT could help exploit the full potential of proton therapy with an increased plan conformity and normal tissue sparing, reduced integral dose and optimized delivery time. Technical development and improvement of optimization algorithms are still needed considering the computation time, but the first prototype of a dynamic spot-scanning proton arc treatment on a ProteusOne in Beaumont showed that ArcPT was successfully performed within clinical requirements.

References

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Dosimetric comparison of a VMAT, IMPT and ArcPT treatment plans for a brain tumor

B. Rollus[1], M. Chocan Vera[1], H. Ozan[1], S. Wuyckens[1], A. Wéra[1], E. Sterpin[1,2], K. Souris[1]
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[2]KU Leuven, Department of Oncology, Leuven, Belgium

ABSTRACT – The aim of this work is to study the limitations and benefits of the new Arc proton therapy (ArcPT) delivery modality by comparing dosimetric and robustness metrics with VMAT and IMPT plans for a brain case.

KEY WORDS – ArcPT– proton therapy – robustness – brain tumor

Introduction

Similarly to VMAT in conventional radiotherapy with photons, Arc proton therapy (ArcPT) is a new proton therapy delivery modality that enables to deliver protons while the gantry is continuously rotating. Besides reducing the treatment delivery time compared to an IMPT plan, there is also a potential to reduce the integral dose and improve organ sparing. In order to study the dosimetric outcome of ArcPT, it is compared to a VMAT and IMPT plans for the case of a brain tumor.

Materials and methods

In order to provide a fair comparison, all three plans have been generated in the RayStation using robust optimization. A setup error of 3 mm was used in all cases and a range uncertainty of 2.6% was used for both proton therapy plans. For ArcPT plan optimization the SPArc algorithm initially proposed by X. Ding et al [1] was reimplemented with RayStation scripting (more details in the BHPA 2022 abstract of H. Ozan).

Beam arrangement was selected for each modality to provide the best plan quality, avoiding as much as possible the brainstem and optic chiasm. All plans were normalized with the dose prescription (65Gy) at the target D50.

A robustness evaluation was then performed for the 3 plans to assess and compare their dosimetric performance. In addition, the LET distribution was calculated for both proton therapy plans using OpenTPS and MCsquare.

We use clinical standards goals for a brain tumor proposed by G. Noël et al [2] as criteria of comparison whilst keeping as a main objective, a CTV coverage of 99% of the volume at 95% of the prescribed dose. We pay attention to the nominal result, the worst scenario and the number of scenarios which pass the clinical goal.

Results

Dosimetric results are shown in the Table 1. Each metric is reported for the nominal and worst case scenarios. The percentage of acceptable scenarios is also reported for each clinical objective. A more detailed comparison of IMPT and ArcPT plans is shown in Figure 1.

We observe that the VMAT plan offers the best robustness in terms of target coverage. However, it is also the modality that provides the worst organ sparing. Both proton modalities offer very similar dosimetric results. The ArcPT led to a slightly lower integral dose in the brain and body volumes. Moreover, ArcPT provided a little bit better flexibility to reduce the dose to organs surrounding the tumor. We also observe that ArcPT reduces LET values in the brainstem, thus potentially better protecting organs compared to IMPT. The delivery time was estimated to **119,2** sec for ArcPT, compared to **27,8** sec for IMPT without taking in account the waiting time between each IMPT beams, estimated at **55** sec. In our case, with only 2 beams for IMPT and because the volume of the target is low (8,98 cm^3), the ArcPT plan is not interesting for the beam delivery time.

Prescription : Median dose of 65 Gy to the CTV Robust evaluation : 0,3 cm of setup error and 2,6% of range uncertainty for protons										
ROI	Clinical Goals	VMAT			IMPT - 2 beams			Double ArcPT		
		Pass	Nominal result	Worst scenario	Pass	Nominal result	Worst scenario	Pass	Nominal result	Worst scenario
CTV	D99 > 61,75 Gy	100%	100%	99,99%	100%	100%	99,93%	100%	100%	99,60%
CTV	D98		64,27 Gy	63,57 Gy		63,56 Gy	62,91 Gy		63,90 Gy	62,88 Gy
CTV	D95		64,47 Gy	63,89 Gy		63,82 Gy	63,46 Gy		64,10 Gy	63,49 Gy
BrainStem	D0,03cc<54Gy	0%	61,61 Gy	64,09 Gy	14%	60,44 Gy	65,78 Gy	19%	59,65 Gy	65,42 Gy
Chiasm	D0,03cc<54Gy	21%	59,45 Gy	63,74 Gy	26%	58,57 Gy	64,83 Gy	21%	58,72 Gy	64,08 Gy
Eye_L	D0,03cc<50Gy	100%	9,22 Gy	10,04 Gy	100%	0,02 Gy	0,03 Gy	100%	0,02 Gy	0,07 Gy
Eye_R	D0,03cc<50Gy	100%	7,48 Gy	8,29 Gy	100%	0,03 Gy	0,03 Gy	100%	0,01Gy	0,02 Gy
Lens_L	D0,03cc<10Gy	100%	4,72 Gy	5,02 Gy	100%	0,0 Gy	0,00 Gy	100%	0,00 Gy	0,00 Gy
Lens_R	D0,03cc<10Gy	100%	4,86 Gy	5,16 Gy	100%	0,0 Gy	0,00 Gy	100%	0,00 Gy	0,00 Gy
LON	D0,03cc<54Gy	100%	41,57 Gy	52,11 Gy	100%	24,59Gy	40,95 Gy	100%	24,09 Gy	39,73 Gy
RON	D0,03cc<54Gy	100%	32,12 Gy	39,83 Gy	100%	19,40Gy	39,88 Gy	100%	20,66 Gy	35,12 Gy
Brain	V60Gy < 33 %	100%	1,69%	1,81%	100%	1,69%	1,93%	100%	1,55%	1,69%
Brain	Mean Dose		8,23 Gy	8,63 Gy		3,91 Gy	4,30 Gy		3,74 Gy	4,13 Gy
Body	Mean Dose		3,41 Gy	3,41 Gy		1,40 Gy	1,44 Gy		1,34 Gy	1,38 Gy

Best plan in worst scenario
Best plan in nominal result

Table 1: Comparison of dosimetric results between VMAT, IMPT and SPArc therapy plan

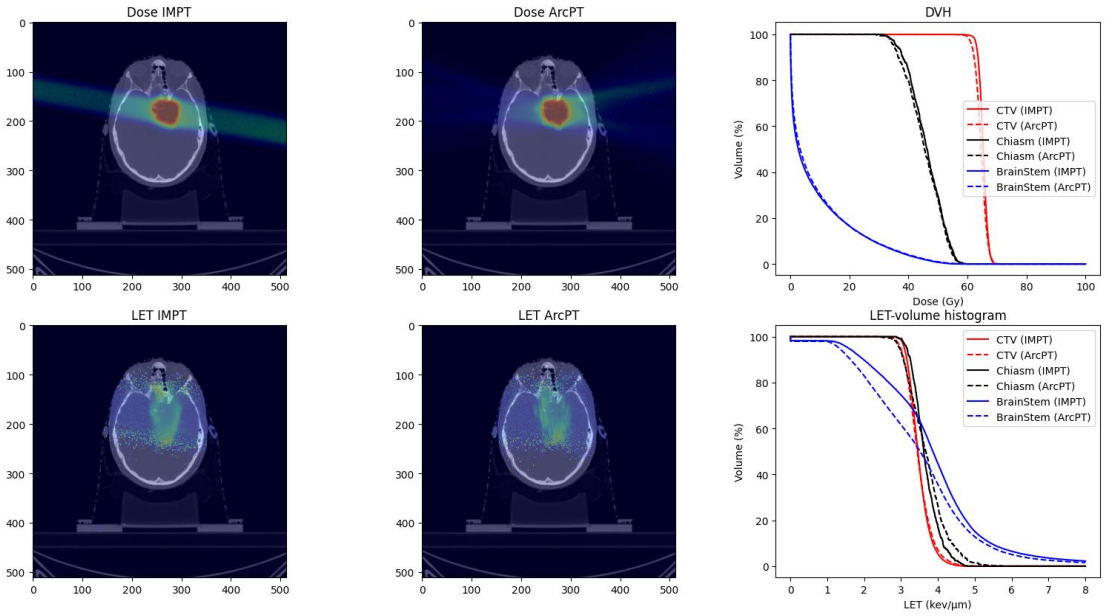

Figure 1: DVH and LET volume histogram comparison for both proton plans

Conclusion

This preliminary study compared dosimetric, LET and robustness performances of VMAT, IMPT, and ArcPT plans for the treatment of a brain tumor. Additional patients will be required to conclude on the advantages and limitations of the new ArcPT modality. Moreover, the plan quality will probably continue to improve with the future innovations in ArcPT optimization algorithms. However, we can already see a potential interest in ArcPT to reduce the treatment delivery time and improve the LET distribution.

References

[1] Ding, X., Li, X., Zhang, J. M., Kabolizadeh, P., Stevens, C., & Yan, D. (2016). Spot-scanning proton arc (SPArc) therapy: the first robust and delivery-efficient spot-scanning proton arc therapy. International Journal of Radiation Oncology* Biology* Physics, 96(5), 1107-1116.

[2] Noël, G., Antoni, D., Barillot, I., & Chauvet, B. (2016). Délinéation des organes à risque et contraintes dosimétriques. Cancer radiotherapie: journal de la Societe francaise de radiotherapie oncologique, 20 Suppl, S36-60.