Conclusion: A novel approach for liver SBRT at a linear accelerator was developed. The basis of the treatment is a fast VMAT plan, supplemented with a few (1-4) computer-optimized non-coplanar IMRT beams. In terms of achievable tumor BED within the clinical OAR constraints, this approach is equivalent to time-consuming, fully non-coplanar treatment. The technique is currently also explored for other treatment sites.

OC-0264

Fast biological RBE modeling for carbon ion therapy using the repair-misrepair-fixation (RMF) model

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Purpose or Objective: The physical and biological advantages of carbon ion beams over conventional x-rays have not been fully exploited in particle therapy and may result in higher levels of local tumor control and improvements in normal tissue sparing. Treatment planning must account for physical properties of the beam as well as differences in the relative biological effectiveness (RBE) of ions compared to photons. In this work, we present a fast RBE calculation approach, based on the decoupling of physical properties and the (α/ß)x. The (α/ß)x ratio is commonly used to describe the radiosensitivity of irradiated cells or organs. The decoupling is accomplished within the framework of the repair-misrepair-fixation (RMF) model.

Material and Methods: Carbon ion treatment planning was implemented by optimizing the RBE-weighted dose (RWD) distribution. Biological modeling was performed with the RMF and Monte Carlo Damage Simulation (MCDS) models. The RBE predictions are implemented efficiently by a decoupling approach which allows fast arbitrary changes in (α/ß)x by introducing two decoupling variables c1 and c2. Dose-weighted radiosensitivity parameters of the ion field are calculated as (Fig 1). This decoupling can be used during and after the optimization.

$$\alpha_D = \alpha_X \cdot c_1 + \beta_X \cdot c_2 \text{ and } \beta_D = \beta_X \cdot c_1^2 \text{ resulting in}$$
$$RBE_{RMF}(c_1, c_2, (\alpha/\beta)_X, d) = \left(-(\alpha/\beta)_X + \sqrt{(\alpha/\beta)_X^2 + 4d\left(c_1(\alpha/\beta)_X + c_2 + c_1^2 d\right)}\right)/2d$$

Carbon ion treatment plans were optimized for several patient cases. Predicted trends in RBE are compared to published cell survival data. A comparison of the RMF model predictions with the clinically used Local Effect Model (LEM1 and 4) is performed on patient cases.

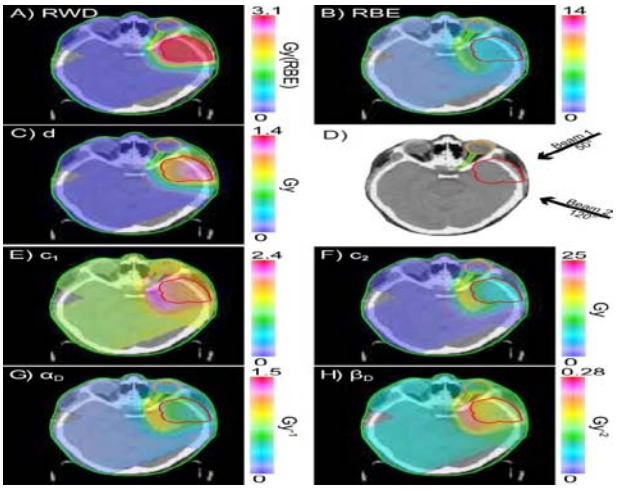

Figure 1: Axial CT slice of a treatment plan using the RMF model. The astrocytoma plan with two carbon ion fields was optimized on 3 Gy(RBE) using a spatially constant (α/ß)x = 2 Gy (αx = 0.1 Gy^-1, ßx = 0.05 Gy^-2). The PTV is shown in red, along with 3 organs at risk: left optic nerve (green), left eye (orange) and left lens (brown). The panels show A) RWD, B) RBE, C) physical dose d and the beam geometry in D. The two decoupling variables c1 and c2 are shown in panels E and F, along with αD and ßD in panels G and H.

Results: The presented implementation of the RMF model is very fast, allowing online changes of the (α/ß)x including a voxel-wise recalculation of the RBE. For example, a change of the (α/ß)x including a complete biological modeling and a recalculation of RBE and RWD for 290000 voxels took 4 ms on a 4 CPU, 3.2 GHz workstation. Changing the (α/ß)x of a single structure, e.g. a planning target volume (PTV) of 270 cm^3 (35000 voxels), takes 1 ms in the same computational environment. The RMF model showed reasonable agreement with published data and similar trends as the LEM4.

Conclusion: The RMF model is suitable for radiobiological modeling in carbon ion therapy and was successfully validated against published cell data. The derived decoupling within the RMF model allows extremely fast changes in (α/ß)x, facilitating online adaption by the user. This provides new options for radiation oncologists, facilitating online variations of the RBE during treatment plan evaluation.

OC-0265

Efficient implementation of random errors in robust optimization for proton therapy with Monte Carlo

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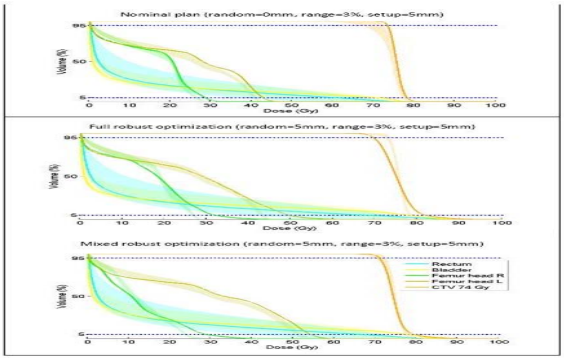
Purpose or Objective: In treatment planning for proton therapy, robust optimizers typically limit their scope to systematic setup and proton range errors. Treatment execution errors (patient and organ motion or breathing) are seldom included. In analytical dose calculation methods as pencil beam algorithms, the only way to simulate motion errors is to sample random shifts from a probability distribution, which increases the computation time for each simulated shift. However, the stochastic nature of Monte Carlo methods allows random errors to be simulated in a single dose calculation.

Material and Methods: An in-house treatment planning system, based on worst-case scenario optimization, was used to create the plans. The optimizer is coupled with a super-fast Monte Carlo (MC) dose calculation engine that enables computing beamlets for optimization, as well as final dose distributions (less than one minute for final dose). Two strategies are presented to account for random errors: 1) Full robust optimization with beamlets that already include the effect of random errors and 2) Mixed robust optimization, where the nominal beamlets are involved but a correction term C modifies the prescription. Starting from C=0, the method alternates optimization of the spot weights with the nominal beamlets and updates of C, with C = Drandom – Dnominal and where Drandom results from a regular MC computation (without pre-computed beamlets) that simulates random errors. Updates of C can be triggered as often as necessary by running the MC engine with the last corrected values for the spot weights as input. MC simulates random errors by shifting randomly the starting point of each particle, according to the distribution of random errors. Such strategy assumes a sufficient number of treatment fractions. The method was applied to lung and prostate cases. For both patients the range error was set to 3%, systematic setup error to 5mm and standard deviation for random errors to 5 mm. Comparison between full robust optimization and the mixed strategy (with 3 updates of C) is presented.

Results: Target coverage was far below the clinical constraints (D95 > 95% of the prescribed dose) for plans where random errors were not simulated, especially for lung case. However, by using full robust or mixed optimization strategies, the plans achieved good target coverage (above

clinical constraints) and overdose comparable to the nominal case. Doses to organs at risk were similar for the three plans in both patients.

		$CTV_{prostate}$ 74 Gy	CTV_{lung} 60 Gy
worst D_{95}	Nominal plan	67.1	38.2
	Full robust optimization	73.3	59.8
	Mixed robust optimization	70.2	56.4
worst D_5	Nominal plan	77.8	62.4
	Full robust optimization	78.9	62.6
	Mixed robust optimization	78.2	69.9



Conclusion: The proposed strategies achieved robust plans in term of target coverage without increasing the dose to the CTV nor to the organs at risk. Full robust optimization gives better results than the mixed strategy, but the latter can be useful in cases where a MC engine is not available or too computationally intensive for beamlets calculation.

OC-0266

Automated treatment plan generation for advanced stage NSCLC patients

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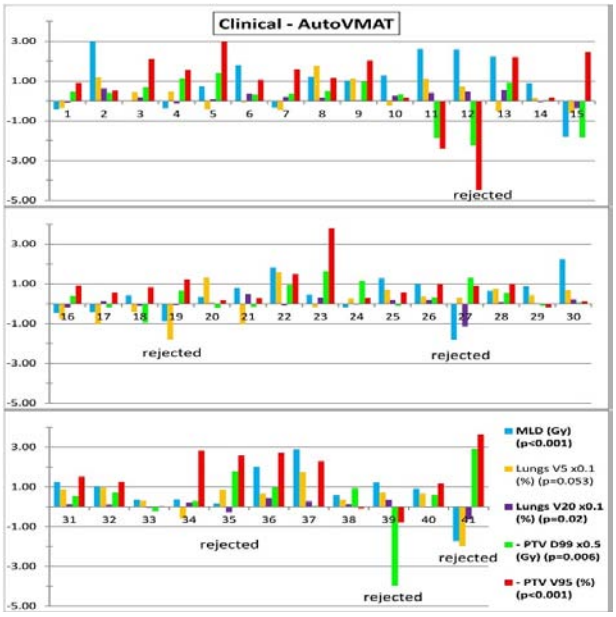
Purpose or Objective: The aim of the study was to develop a fully automated treatment planning procedure to generate VMAT plans for stage III/IV non-small cell lung cancer (NSCLC) patients, treated with curative intent, and to compare them with manually generated plans.

Material and Methods: Based on treatment plans of 7 previously treated patients, the clinical protocol, and physician's treatment goals and priorities, our in-house developed system for fully automated, multi-criterial plan generation was configured to generate VMAT plans for advanced stage NSCLC patients without human interaction. For 41 independent patients, treated between January and August 2015, automatic plan generation was then compared with manual plan generation, as performed in clinical routine. Differences in PTV coverage, dose conformality R50 (the ratio between the total volume receiving at least 50% of the prescribed dose and the PTV volume) and sparing of organs at risk were quantified, and their statistical significance was assessed using a Wilcoxon test.

Results: For 35 out of 41 patients (85%), the automatically generated VMAT plans were clinically acceptable as judged by two physicians. Compared to the manually generated plans, they considered the quality of automatically generated plans superior for at least 67% of patients, due to a combination of better PTV coverage, dose conformality and sparing of lungs, heart and oesophagus (positive values in figure). For the other acceptable plans plan quality was considered equivalent. On average, PTV coverage (V95) was improved by 1.1 % ($p<0.001$), the near-minimum dose in the PTV (D99) by 0.55 Gy ($p=0.006$) and the R50 by 12.4% ($p<0.001$). The mean lung dose was reduced by 0.86 Gy (4.6%, $p<0.001$), and the V20 of the lungs by 1.3 % ($p=0.001$). For some patients it was possible to improve PTV V95 by 3.8%, D99 by 3.3 Gy, to reduce mean lung dose by 3.0 Gy and V20 by 6.2%. All plans fulfilled the planning constraints for the spinal cord, heart and plexus.

For the 6 automated VMAT plans that were initially not acceptable, it took a dosimetrist less than 10 minutes hands-on time to manually fine-tune the VMAT plan in our TPS to make it acceptable. In contrast, to generate a VMAT plan from scratch 3-4 hours were required.

For 5 out of 10 patients with a PTV prescription dose of less than 66 Gy in the manual plan, we were able to escalate the tumour dose using automated planning. For two patients dose escalation from 60 Gy to 66 Gy was possible, for other patients from 60.5 Gy to 66 Gy, 45 Gy to 57.75 Gy, and 55 Gy to 60.5 Gy, respectively.



Conclusion: Using our fully automated treatment planning procedure, clinically deliverable, high quality VMAT plans for advanced stage NSCLC patients may be generated without human interaction for the far majority of patients. When manual adjustments were required, they took very little hands-on time only. With automated planning, a higher tumour dose could be achieved for a subgroup of patients. Clinical introduction has been started.

OC-0267

Fully automated planning for non-coplanar CyberKnife prostate SBRT - comparison with automatic VMAT

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Purpose or Objective: In stereotactic body radiation therapy, high accuracy is required to deliver high fraction doses with steep dose gradients. Non-coplanar beam setups may improve plan quality. This can be realized with a robotic CyberKnife (CK, Accuray Inc, Sunnyvale, USA). Due to its tumor tracking features, CTV-PTV margins may be reduced compared to linac treatment. In previous works we have built and validated a system for fully automated, multi-criterial VMAT plan generation (iCycle/Monaco). Recently, we have extended the system with an option for fully automated plan generation for the CK (iCycle/Multiplan). In this study we have used fully automated plan generation for un-biased comparison of non-coplanar CK with coplanar VMAT at a linac, for prostate SBRT.

Material and Methods: Our in-house iCycle system was first coupled to the Multiplan TPS that comes with the CK treatment unit. The iCycle/Multiplan and iCyle/Monaco systems were then configured for automated prostate SBRT plan generation for CK and linac-VMAT, respectively. Plans were then generated for 10 prostate SBRT patients, delivering 38 Gy in 4 fractions. Three clinically deliverable