

from 59 ± 4.3 % to 78 ± 2.9 % for the o-ring straight-through FFF linac compared with the standard c-arm linac with flattening filter.

Conclusion: The use of an o-ring straight-through linac with 6X FFF beams was associated with substantially greater superficial dose and may obviate the need for bolus in whole breast or chest wall irradiation.

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Simultaneously Integrated Boost and Variable Relative Biological Effectiveness Effects on Normal Tissue Complication Probability-Based Patient Selection for Proton Therapy



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Purpose/Objective(s): Patient selection for proton therapy is proposed to be based on the difference in normal tissue complication probability (NTCP) between photon and proton therapy ($\Delta NTCP = NTCP_{\text{photon}} - NTCP_{\text{proton}}$). This has been explored for homogeneous target doses, and a constant relative biological effectiveness (RBE) of 1.1. Due to the expected high conformity of the physical dose distribution, proton therapy, however, might be considered the modality of choice in case heterogeneous target doses are planned as simultaneously integrated boost (SIB). This study aims to investigate the patient selection in presence of dose escalation, and variable RBE models.

Materials/Methods: Volumetric modulated arc therapy (VMAT) plans, and robust intensity modulated proton therapy (IMPT) plans were generated for a head-and-neck (H&N) and a prostate case. A RBE-weighted dose (D_{RBE}) of 2 Gy (RBE) was planned in 35 and 39 fractions, respectively. The plans were optimized assuming RBE=1.1, while two LET_r and α/β -dependent variable RBE models were added for plan evaluation. Subsequently, virtual realistic boost volumes (25 cm³ for H&N, 5 cm³ for prostate) were positioned in three different locations within the primary target. For each location, SIB VMAT and robust IMPT plans were generated. A D_{RBE} of 77 Gy (RBE) and 95 Gy (RBE) was prescribed to the boost volumes for the H&N and prostate case, respectively. For each scenario, $\Delta NTCP$ s were calculated for several Grade 2 toxicities (G2), and one Grade 3 (G3). In accordance with the literature, $\Delta NTCP$ thresholds for selection of proton therapy were 5 percentage points (pp) for G3, 10 pp for G2, or 15 pp for the maximum sum of two G2 $\Delta NTCP$ s.

Results: The dose escalations had minor impact on the normal tissue doses for both modalities. The variable RBE models agreed well, and predicted lower $\Delta NTCP$ s than RBE=1.1. For the prostate case, no $\Delta NTCP$ threshold was reached. Several $\Delta NTCP$ s for G2 toxicities were around 0.0-2.5 pp. For the H&N case, both G2 and G3 thresholds were reached in all scenarios assuming RBE=1.1, whereas no thresholds were reached for the variable RBE models. The tube feeding G3, that was reached with RBE=1.1, was however close for all scenarios. The highest G2 $\Delta NTCP$ s were observed for larynx edema and decrease of parotid flow. Table 1 summaries the $\Delta NTCP$ evaluation.

Conclusion: This sample study indicates that realistic dose escalations not necessarily affect the prostate patient selection for proton therapy, whereas applying variable RBE models may degrade IMPT plans and affect the patient selection for H&N cases. Larger scale studies are needed to investigate these matter in further depth.

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Time Analysis in Magnetic Resonance Image-Guided Radiotherapy Workflow



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Purpose/Objective(s): Magnetic resonance (MR) image-guided radiotherapy (MRIgRT) has been recently implemented in routine clinical practice in our department. Treatment workflow for MRIgRT differs substantially from other radiotherapy systems and consists of set-up, MR imaging, re-contouring, re-optimization & plan QA and treatment delivery. We hypothesized that delivery of total on table treatment time will be less than 60 minutes for >75% of fractions.

Materials/Methods: Aforementioned treatment components were recorded in 44 patients (304 fractions), treated between September 2018 and January 2019 with our linear accelerator based MRIgRT. Effect of treatment parameters (treatment site, dose per fraction, being first or last fraction, being treated with adapted plan or not, using breath hold technique or not) on total treatment time were analyzed.

Results: Median age was 66 years (28-83). Upper abdomen (21 patients, 41.1%) and pelvic (17 patients, 33.3%) regions were most common sites treated. Most common diagnosis was prostate cancer (14 patients - 31.8%). Majority of patients (40 patients, 91%) were treated with stereotactic body radiotherapy (SBRT), with fraction number 8 or less. Twenty-nine patients (56.8 %) were treated with audio-visually coached breath-hold gating method. Median total dose was 36.25 Gy (24 – 70 Gy) and median fraction number is 5 (3 – 28). Median total treatment time for all fractions was 43.5 minutes (range, 21-125) with 85% of patients being treated in less than 1 hour. Median patient setup time was 10 minutes (range 5-31), contouring time was 8 minutes (range 1-45), re-optimization + QA time was 4,5 minutes (range 1-16). Median time lost due to technical problems

Abstract 3654; Table 1 Summary of the $\Delta NTCP$ s evaluation in percentage points.

Plan	Toxicity grade	Prostate case			H&N case		
		RBE=1.1	Wedenberg	McNamara	RBE=1.1	Wedenberg	McNamara
Original	G2 or G2 sum	1.4	0.9	0.9	17.3	5.3	5.5
	G3	0	0	0	6.5	4.3	4.1
SIB 1	G2 or G2 sum	1.4	0.9	0.9	10.4	6.0	6.2
	G3	0	0	0	7.2	4.8	4.7
SIB 2	G2 or G2 sum	1.4	0.9	0.9	17.1	5.3	5.6
	G3	0	0	0	7.3	4.8	4.6
SIB 3	G2 or G2 sum	2.6	1.2	1.2	10.1	6.0	6.3
	G3	0	0	0	7.0	4.7	4.5

was 7 minutes (range 2-49) and occurred in 86 fractions. The longest component of the workflow was found to be radiotherapy treatment delivery; median 18 minutes (range 8-76). There was correlation with the treatment site and the total treatment time ($p < 0.0001$) Median total treatment durations for upper abdomen, pelvis, thorax and spine were 48.3, 40.9, 42.2 and 53 minutes, respectively. As expected, lower fraction doses ($< vs > 6$ Gy) resulted in shorter treatment time (median 39.4 vs 47.2, $p < 0.0001$). Breath hold technique resulted in longer overall treatment time compared to non-breath hold techniques (median 41.7 vs. 45.1, $p = 0.01$). Similar difference was noticed in total treatment time between fractions treated with the original plan or the adapted plan (median 38.9 vs. 45.3, $p < 0.0001$). There was a gradual decrease in treatment time between the first and last fraction (median 51 vs 41.7, $p < 0.0001$). Total treatment time was found to be longer for SBRT compared with non-SBRT fractions (median 45 vs 40.5, $p = 0.001$).

Conclusion: MRIgRT can be easily delivered in less than 1 hour in 85% of fractions if appropriate precautions are taken. Radiotherapy delivery time remains the longest component of overall treatment. Optimization of the workflow and future hardware changes are expected to further reduce overall delivery times.

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Clinical Experience in Large-Sized Surface Treatments with High Dose Rate Brachytherapy (HDR)



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Purpose/Objective(s): Show an easy and reliable method to treat patients with large superficial lesions size. Carry out a dosimetric study of patients treated with H.A.M applicators with high dose rate Brachytherapy (HDR). Analyze the post-treatment cosmetic and control effects.

Materials/Methods: 15 patients receiving superficial high dose rate Brachytherapy with the H.A.M applicator were selected according to clinical and pathological criteria. of Ecker & Ziegler. The applicator was reconstructed three-dimensionally and planned with the planning system HDR plus 2.6.5 without the need for tomographic images. The treatment was delivered by means of a HDR Multisource charging equipment from Ecker & Ziegler with a Co-60 source, in 9 daily sessions of 7Gy each. The passage of the source is arranged in stops of 5mm and separated by 1cm, the depth of prescription depending on the lesion is prescribed in 3 to 5 mm of depth. Once the planning was completed, it was approved by a meeting between medical physicist and radiation oncologist. The plans were analyzed by observing the maximum surface dose of the applicator (contact with the skin) and prescribed dose at the requested depth. The uncertainty to perform surface treatments in large volumes with HDR was the distribution of doses, hot spots, so an OSL dosimeter placed in the center and at the ends of the treated area was used.

Results: A coverage between 90% and 100% of the surface to be treated was observed with maximum points of 150% of the prescribed dose evenly distributed over the surface of the applicator (0.5cm from the trajectories of the source). At the end of the treatments, superficial radiodermatitis was observed, which disappeared between 2 and 3 weeks after the last irradiation session. The cosmetic results were favorable compared to external irradiation with high-energy electrons (6MeV) Gap was not observed by union of fields, the treatment was carried out with the union of different sizes of applicators H.A.M. that covers the total surface to be treated The reading of the OSL dosimeters had a difference of 3% in the maximum points and in the center smaller 1%.

Conclusion: Large surface treatments can be performed with a high dose rate brachytherapy system with a Co-60 source. This treatment allows to obtain control of the disease with good cosmetic results appreciable in

fewer sessions than a treatment with high energy electrons (6MeV) An easy and objective dosimetric analysis that covers the needs of the treatment can be carried out.

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Optimizing Skin Dose for Post-Mastectomy Chestwall VMAT Radiation Therapy



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Purpose/Objective(s): To determine the optimal expansion of the PTV surface relative to the skin surface when planning post-mastectomy chestwall treatments using VMAT (Volumetric Modulated Arc Therapy) with the goal of delivering 100% of the prescription dose to the skin surface beneath 0.5 cm bolus.

Materials/Methods: CT simulation images of a thorax phantom were obtained and exported to the treatment planning system (TPS). Left chestwall organs at risk (OARs) and PTV (Planning Target Volume) ROIs (Regions of Interest) were contoured on the images. 0.5 cm bolus was added to the phantom surface in the TPS. The PTV ROI was modified near the skin surface so that the PTV surface was placed at the following locations with respect to the skin surface: (-) 1 mm, 0 mm, (+) 1 mm, (+) 2 mm where positive values indicate locations external to the patient surface and within the bolus. Using departmental planning objectives, a 6 MV VMAT plan was optimized for each PTV expansion with the goal of delivering 200 cGy per fraction to the PTV. The surface dose for each plan was calculated using a 1 mm thick "surface" ROI bounded by the PTV. Plans were exported to the Record and Verify System and plan specific QA (Quality Assurance) was completed. At the linear accelerator, the phantom was aligned to isocenter using image guidance. MOSFET (metal oxide semiconductor field effect transistor) dosimeters were placed on the phantom surface at four locations within the treatment area. 0.5 cm tissue equivalent bolus was also placed on the phantom surface. For each plan, four measurements were acquired at each of the four measurement locations (n=16). Measurements were compared for statistical significance ($\alpha = 0.05$) to one another, to TPS calculated doses, and to the prescription dose.

Results: Each plan passed QA using a 3%/2mm gamma passing criteria with passing rates from 97.2% to 98.8%. Analysis of Variation (ANOVA) indicated that the measurement results were affected by PTV surface expansion ($p < 0.0001$), but not significantly affected by measurement location ($p = 0.156$). Only the (-) 1 mm plan measurement was in statistical agreement with the TPS calculated dose ($p = 0.108$). The (-) 1 mm plan was in closest agreement to the prescription dose. (See Table 1).

Conclusion: The (-1) mm PTV expansion (PTV surface 1 mm inside the skin surface) plan measurement results were the closest to the prescription dose and in statistical agreement with the TPS calculated dose. We have implemented the use of a (-1) mm PTV expansion and will use in-vivo dosimetry to assess surface dose for post-mastectomy chestwall patients treated with VMAT.

Abstract 3657; Table 1 Comparison of Measurements to TPS Calculated Doses and Prescription Dose

PTV Expansion with Respect to Skin Surface	Comparison of Measurements to TPS Calculated Doses and Prescription Dose			
	(+) 2 mm	(+) 1 mm	0 mm	(-) 1 mm
MOSFET Average (cGy)	215.9	196.9	207.7	199.4
TPS Calculated Average (cGy)	207.0	206	203.5	201.2
Agreement (Measured/Calculated)	104.3%	95.6%	102.1%	99.1%
Measured to Calculated p value ($\alpha = 0.05$)	<0.00001	0.000012	0.0463	0.108
Agreement (Measured/Prescription)	107.9%	98.4%	103.9%	99.7%

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