combined with the use of an inverse optimization method, can be used to generate IMPT plans. These plans can be used in future dosimetric comparisons with IMRT, the MR Linac and conventional IMPT. Finally, it shows the dosimetric feasibility of IMPT in a 1.5 T magnetic field.

OC-0163

Does the clinical benefit of IMPT persist if plans are made robust against setup and range errors?

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Purpose/Objective: To compare the clinical benefit of robust optimized Intensity Modulated Proton Therapy (IMPT) with current photon radiotherapy (IMRT) and PTV-based IMPT for head and neck cancer (HNC) patients. The clinical benefit is quantified in terms of both Normal Tissue Complication Probability (NTCP) and target coverage in the case of setup and range errors.

Materials and Methods: For 10 HNC patients, PTV-based IMRT (7 fields), robust optimized (minimax) and PTV-based IMPT (2, 3, 4, 5 and 7 fields) plans were tested on robustness, meaning that at least 98% of the CTVs had to receive ≥ 95% of the prescribed dose in 90% of the possible systematic setup and range error scenarios. Robust optimized plans differed from PTV-based plans in that they target the CTV and penalize possible error scenarios, instead of using the static isotropic CTV-PTV margin. Perturbed dose distributions of all plans were acquired by simulating in total 8060 setup (+/-2.5mm) and range error (+/-3%) combinations. Furthermore, NTCP models for xerostomia and dysphagia were used to estimate the clinical benefit of IMPT versus IMRT.

Results: The robustness criterion was met in the IMRT and minimax IMPT plans in all error scenarios, but for PTV-based IMPT plans this was only the case in 4 out of 10 patients. The volumes receiving deficient dose were sometimes centrally situated in the CTV (Figure), indicating that expansion of the CTV-PTV margin would not solve the underdosage. Mean doses to the major salivary glands and swallowing related organs at risk (OAR) were generally lower with minimax than with PTV-based IMPT. Xerostomia and dysphagia NTCP values calculated for IMRT plans were reduced by 16.4% (95% CI; 10.1-22.7%) and 9.9% (95% CI; 4.9-14.9%) with minimax IMPT in the 5 patients with the largest NTCP reductions. In the other 5 patients the average NTCP reduction was smaller (xerostomia: 4.7% (95% CI; 1.0-8.3%) ; dysphagia: 3.0% (95% CI; -0.2-6.2%). Increasing the number of fields did not contribute to plan robustness, but improved organ sparing.

Conclusions: The clinical benefit in terms of NTCP of robust optimized (minimax) IMPT compared to IMRT is equal or even greater than that of PTV-based IMPT in head and neck patients. Furthermore, the target coverage of minimax IMPT plans in the presence of setup and range errors was comparable to that of current photon radiotherapy (IMRT) plans.

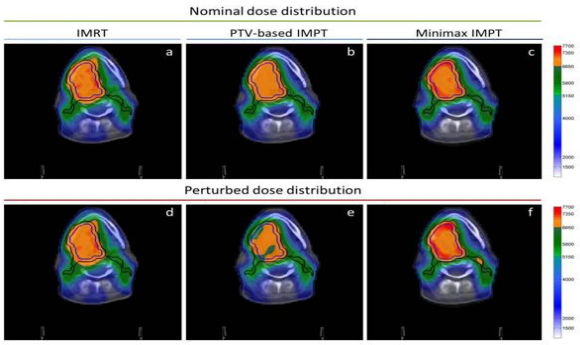

Figure. Dose distributions of IMRT (a,d), PTV-based IMPT (b,e) and minimax optimized IMPT plans (c,f) in nominal (a-c) and an error scenario (d-f) with a setup error of x=0.18;y=0;z=0.18cm and a range error of 3%. Both CTV_{70} (blue lines) and $CTV_{54.25}$ (black lines) are shown in all dose distributions.

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OC-0164

Calibration and validation of kV-CBCT in room imaging for dose calculation and adaptive radiotherapy

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Purpose/Objective: To investigate the accuracy of dose calculation on cone beam CT (CBCT) data sets after HU-RED calibration and validation in phantom studies and clinical patients.

Materials and Methods: Calibration of HU-RED curves for kV-CBCT were generated for three clinical protocols (H&N, thorax and pelvis) using a Gammex RMI phantom ® (Gammex RMI, Middleton, WI) with human tissue equivalent inserts and additional perspex blocks to account for patient scatter. Two calibration curves per clinical protocol were defined, one for the Varian Truebeam 2.0 and another for the OBI systems (Varian Medical Systems Inc., Palo Alto, USA). Differences in HU values with respect to the CT-calibration curve were evaluated for all the inserts.

Four radiotherapy plans (breast, prostate, H&N and lung) were produced on an anthropomorphic phantom (Alderson) to evaluate dose differences on the kV-CBCT with the new calibration curves with respect to the CT based dose calculation. Dose calculation was performed in Eclipse TPS using an anisotropic analytic dose calculation algorithm (AAA, Varian Medical Systems Inc.). Dose differences were evaluated according to the D2%, D98% and Dmean metrics extracted from the DVHs of the plans and g- evaluation (2%, 1mm) on the three planes at the isocenter for all plans. Clinical evaluation was performed on ten patients and dose differences were evaluated as in the phantom study.

Results: HU values on the kV-CBCT calibration curves exhibited deviations with respect to the CT-calibration curve on the low- (lung) and high-density (bone) inserts. These deviations were found to be ca. 250 HU. Differences between the Truebeam 2.0 and OBI-system for HU-RED curve were ca.14 %. Radiotherapy plans calculated on the anthropomorphic phantom showed very good agreement with the CT-based calculated plans (Table 1, Figure 1).

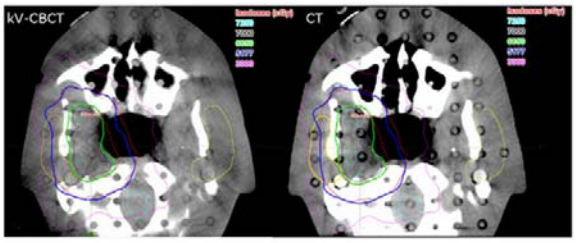

Figure 1. Head & Neck plan comparision in antropomorphic phantom. Dose calculation on kV-CBCT (left) is shown next to that on CT (right). PTVboost and PTVelective are shown in red. Isodoses 95% for both PTVs are shown in green and blue.

Prostate				Lung				Head & Neck			
	$D_{2\%}$	D_{mean}	$D_{98\%}$		$D_{2\%}$	D_{mean}	$D_{98\%}$		$D_{2\%}$	D_{mean}	$D_{98\%}$
PTV	-0.4	-0.2	0.6	PTV	1.2	2.2	4.0	PTVboost	-0.6	0.0	1.9
Rectum	-0.6	0.4	-0.9	GTV	1.3	1.5	0.9	PTVelec.	-0.6	-0.1	0.7
Bladder	-0.6	-0.6	-1.0	IL Lung	0.0	1.1	0.0	Brainstem	-2.1		
Hip Left	0.8	0.1	0.0	CL Lung	0.0	-1.2	0.0	Parotid L.	-0.7	0.3	8.3
Hip Right	0.4	0.1	0.7	Myelum	0.3			Parotid R.	-0.8	0.1	1.1

Table 1. Estimated dose differences (%) for dose calculations on kV-CBCT (Truebeam) from dose calculation on CT for a prostate, lung and head & neck plan on an antropomorphic phantom.

Only few structures for some specific metrics, such as Dmean rectum and D98% parotid glands exhibited deviations larger than 3%. g-analysis (2%, 1mm) on the three planes at isocenter showed a pass-rate higher than 98% for all cases. Clinical evaluation in ten patients showed very good agreement with the dose calculation on the CT as expressed by the D2%, D98% and Dmean of the delineated structures. Several drawbacks were also found: the limited FOV of the kV-CBCT, which impairs the dose evaluation of those structures in its vicinity and the difference in beam profile of the kV-CBCT with respect to the CT, reducing the accuracy of the dose estimation at nearby the surface of the patient.

Conclusions: The generation of three kV-CBCT specific HU-RED curves for the pelvis, thorax and H&N cases resulted in accurate dose calculation on kV-CBCT images. Very good agreement was found with the CT-based dose calculated plans according to DVH dose parameters and g-evaluation. Limitations of the kV-CBCT warrant some caution when evaluating dose differences for adaptive radiotherapy.

OC-0165

FSD measurements are obsolete when treating prostate IMRT and VMAT

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Purpose/Objective: Given the complexity of modulated fields, the validity of the traditional central axis FSD measurement is now being questioned. This study aims to quantify the impact a change in patient body contour, away from the central axis, has on target dose when treating dose escalated image guided IMRT and VMAT for definitive and post prostatectomy prostate cancer.

Materials and Methods: A total of 39 patients, 22 definitive and 17 post prostatectomy, were included in this retrospective dosimetric study. Both IMRT and VMAT plans were calculated with a prescription dose of 80Gy and 64Gy for definitive and post surgical cases respectively. The treatment plan was applied to each of the patients' weekly cone beam scans and all plans were recalculated with the homogeneity correction inactivated allowing for direct dosimetric comparison. FSDs were recorded for each IMRT field on each scan. The CTV D100, PTV D98, PTV D95, PTV D2, PTV mean and PTV median doses along with the 98% and 95% conformity indices and homogeneity index were recorded for all 712 plans analyzed. Statistical analysis included repeated measures ANOVA and Freidman's tests for the whole treatment course. Individual CBCT dependant variables were further analysed using paired samples T tests and Wilcoxon Signed Rank tests.

Results: A total of 712 plans were created, 6408 dependant variables analysed and 2502 FSD measurements recorded. Of the FSD measurements taken from CBCTs for the IMRT plans, 96.3% and 100% were within 1cm from the planned value for definitive and post prostatectomy patients respectively. For the definitive cohort, an increase in dose was observed across each metric measured ($p<0.05$). Subsequent analysis revealed 83.3% of individual measurements from CBCTs were significantly different ($p<0.05$) from the original planned value. For the post prostatectomy cohort only the IMRT homogeneity index ($p=0.000$) and the VMAT PTV D98 ($p=0.009$), 98% ($p=0.006$) and 95% ($p=0.002$) conformity indices and homogeneity index ($p=0.022$) were significantly different from the planned value based on measures of variance. Analysis of the individual CBCTs for this group revealed 88% and 71.4% of endpoints measured were statistically similar to the original plan for IMRT and VMAT respectively.

Conclusions: IMRT and VMAT beams are complex in nature. The endpoints analysed in this research indicate statistical differences to target doses despite the FSD measurements being within the nominal tolerance. The traditional central axis measurement is an insufficient indicator for dosimetric variation with modulated beams. As such a volumetric approach to contour variation, through the use of CBCT, is essential when treating with IMRT or VMAT.

OC-0166

The importance of creating an ITV with variable bladder filling status when using IMRT to treat cervical cancer

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Purpose/Objective: The use of IMRT for cervical cancer can significantly reduce dose to normal tissue. However, there is substantial uterine motion during treatment resulting from variation in bladder and rectal filling and this risk of a geographical miss has limited the implementation of IMRT. A population based CTV-PTV margin requires 15-30mm to ensure coverage throughout treatment but this encompasses large volumes of normal tissue. Daily online imaging with an adaptive approach may reduce margins but is very resource intensive. IMRT can still be safely introduced if internal motion throughout treatment can be accurately predicted to individualise volumes.

Our aim was to assess whether variable bladder filling scans can be used to predict uterine position during treatment and compare methods for generating the final PTV.

Materials and Methods: A retrospective analysis was performed of 11 patients treated with primary chemo-radiotherapy for cervical carcinoma. Patients underwent 'bladder full' radiotherapy planning scans and 'bladder empty' pre-treatment diagnostic imaging, with images co-registered on the treatment planning software. The uterus and cervix were contoured on the planning scan to generate the CTV_{uterus} and an isotropic 15mm expansion made to generate the unmodified PTV_{uterus}. A manually modified PTV was made by the clinician taking into account the change in uterine position between scans. CBCT verification was performed weekly during treatment. The unmodified and