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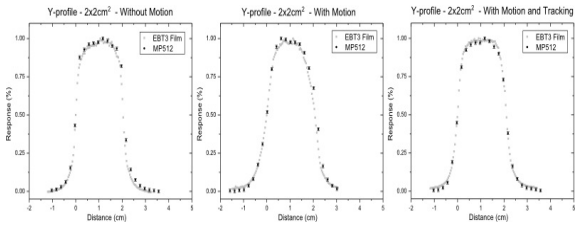
Purpose/Objective: Real-time adaptive radiotherapy aims to improve radiation treatment through re-optimisation of treatment delivery based on patient-specific changes in anatomy and biology during treatments. MLC tracking is one real-time adaptive strategy that applies real-time tumour localisation to adapt the MLC shape during treatment. MLC tracking has been shown to be feasible for prostate cancer treatment on a standard linac, leading to improved tumour dose conformity, reduced rectal dose and improved fidelity of the planned treatment compared to standard delivery. Patient specific quality assurance of MLC tracking treatment is complex due to daily variation in tumour motion track creating new adaptations each day. We propose a high temporal and spatial resolution dosimetry system to verify the performance of MLC tracking.

Materials and Methods: A monolithic silicon detector, known as MagicPlate-512 (MP512), has been developed and comprises 512 pixels arranged in a square array with sensitive volume 0.5x0.5x0.1mm^3 and pitch 2mm. The array allows high resolution dose mapping and dose profiling in 2D. The MP512 is read out by a data acquisition system (DAS) synchronised with the electron gun pulses of the linac for pulse by pulse resolution of the dose delivered by the treatment beam. The detector is embedded in a solid water phantom and installed on a movable platform. The platform is supplied with a patient-specific motion pattern to replicate tumour motion. An electromagnetic positioning system provides real time position information to the MLC tracking software. The dose delivered by a static gantry with MLC defined square fields of sizes 1x1, 2x2 and 3x3cm^2 is measured by MP512 and compared to EBT3 film for cases without motion, with motion and with motion and MLC tracking enabled. The DAS enables verification of dose variation pulse by pulse for each pixel, providing an insight into beam delivery for optimisation or debugging of a plan.

Results: The beam profiles along the y-axis of the detector are compared to the EBT3 film for the three motion cases for the 2x2cm^2 MLC defined field.



The penumbral width (80-20%) and full-width at half-maximum is measured for each profile for the field sizes and motion cases, the results benchmarked by EBT3 film.

	Square Field size (cm^2)	FWHM (cm) +/- 0.01 cm		Penumbral Width (PW) (cm) +/- 0.01	
		MP512	*EBT3*	*MP512*	*EBT3*
without Motion	1	1.17	1.14	0.25	0.26
	2	2.10	2.04	0.30	0.27
	3	3.16	3.06	0.29	0.30
with Motion	1	1.21	1.16	0.51	0.50
	2	2.15	2.07	0.56	0.54
	3	3.15	3.10	0.57	0.53
with Motion and MLC tracking	1	1.14	1.10	0.37	0.35
	2	2.10	2.10	0.38	0.34
	3	3.12	3.10	0.39	0.35

Conclusions: The results measured by the MP512 show excellent agreement with EBT3 film. The motion is observed to smear the profile of the beam. MP512 and EBT3 are able to reconstruct the distortion within 0.2mm; with MLC tracking enabled the smearing is reduced with a good agreement between no-motion and motion-tracking. The MP512 detector has proven to be an effective tool for pre-treatment verification of real-time adaptive deliveries with both high spatial resolution for dose profiling and high temporal resolution for pulse by pulse reconstruction.

Proffered Papers: Physics 10: Dose measurements challenges

OC-0552

First direct comparison of measured kQ values for FFF and FF clinical photon beams

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Purpose/Objective: The objective of this study was to directly measure and compare k_Q factors [1] of reference type ionization chambers in flattening-filter (FF) and flattening-filter-free (FFF) clinical photon beams with nominal energies of 6 and 10 MV.

Materials and Methods: Eight Baldwin-Farmer type ionization chambers (2×PTW 30013, 3×NE 2571, 3×PTW 30012) were calibrated in terms of absorbed-dose-to-water, D_w, in ^{60}Co at VSL and in four clinical photon beams of 6 and 10 MV, both FF and FFF of an Elekta Versa HD at the Netherlands Cancer Institute. The absorbed-dose-to water was determined with the new VSL water calorimeter, designed for on-site measurements in clinical teletherapy beams (see Figure). Two waterproof ionization chambers (PTW 30013) were directly calibrated inside the water calorimeter thermostat. The other six ionization chambers (not waterproof) were cross-calibrated in a reference phantom against the PTW 30013 chambers. Both the calorimeter and chamber measurements were performed against an external transmission monitor, placed on the accelerator tray. Measurements were corrected for radial non-uniformity due to the lateral beam profile with respect to the measurement point in the water calorimeter and the measurement volume of the ionization chamber.

The FF and FFF beams of the same nominal energy were matched with respect to *pdd*(10). Based on *pdd*(10) the measured k_Q factors in the two FFF beams were compared directly with the FF beams of the same nominal energy. Additionally a comparison between k_Q factors in FFF and FF beams based on quality index $TPR_{20,10}$ for both beams was

made using an existing code of practice for non-FFF beams, NCS-18 [1]. Therefore k_Q values were obtained provided by the code of practice. The differences of the NCS-18 k_Q values between FFF and FF beams were compared with the measured differences.

Results: The average k_Q of the six NCS-18 recommended chambers (i.e. the not waterproof types) are presented in the Table. Comparison between FFF and FF beams of the same nominal energy and *pdd*(10) show negligible differences of -0.001 (8) and 0.000 (9) for 6 and 10 MV respectively. Based on NCS-18, using quality index $TPR_{20,10}$ the differences in k_Q also show negligible deviations of respectively -0.002 (8) and -0.003 (9). The uncertainties, represented as the last significant digit between brackets, are reported with a coverage factor, k = 2.

				k_Q in FFF vs FF	
beam	*pdd*(10)	$TPR_{20,10}$	$k_{Q,measured}$	based on *pdd*(10)	based on $TPR_{20,10}$
6 FF	67.5	0.680	0.988 (7)	-0.001 (8)	-0.002 (8)
6 FFF		0.675	0.987 (8)		
10 FF	73.0	0.735	0.979 (7)	0.000 (9)	-0.003 (9)
10 FFF		0.720	0.979 (8)		

Conclusions: The differences between FFF and FF clinical photon beams of 6 and 10 MV for measured k_Q values of six reference type ionization chambers with the same value for the beam quality index *pdd*(10) are negligible (< 0.001). Application of a $TPR_{20,10}$ based protocol results in slightly higher differences (< 0.003). All differences are within the reported uncertainties.

References

[1] NCS 2008 Report 18: Code of Practice for the Absorbed Dose Determination in High Energy Photon and Electron Beams (Delft: Nederlands Commissie voor Stralingsdosimetrie)

OC-0553

Dosimetry using the PTW Farmer, 2611 and A1SL ionization chambers, and alanine pellets in an MR-linac beam

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Purpose/Objective: The combined simultaneous use of MRI and MV photon irradiations is one of the most promising innovations of cancer radiotherapy as it offers the capability of using non-ionizing radiation for high quality imaging with tissue selectivity to drive the delivery of therapeutic doses of ionizing radiation to tumour volumes. Clinical application of such facilities presents new dosimetric and radiobiological challenges.

The aim of this work was to use 4 different chamber types and alanine dosimeters to determine correction factors and optimum set up for ionization chamber based dosimetry in an MR-linac.

Materials and Methods: Measurements were made in the UMC Utrecht MR-linac facility (Elekta). Absorbed dose was measured at the isocentre in a static vertical beam, with the detector axis perpendicular to both the beam and magnetic field. A 10 cm x 10 cm field was set at the isocentre and measurements were made at 5cm depth in a water-equivalent full scatter phantom. The chambers used were a PTW Farmer-type chamber (TW30012-1), a PTW waterproof Farmer-type chamber (TW30013), a 2611-type chamber and an Exradin A1SL chamber. Alanine pellets were used in a Farmer-shaped PEEK holder.

Measurements were made in the conventional way to determine the corrections required for the effects due to both polarity and ion recombination. To investigate machine linearity, 500 – 5000MU were delivered to alanine pellets.

Results: The alanine dosimeters used in the UMC-Utrecht MR-linac were used to calibrate the MR-linac output. This was determined in terms of cGy / MU, using machine monitor units as the reference, as well as in terms of cGy / monitor chamber nC. The machine calibration was used to determine the dose delivered to each ionization chamber. For the same beams, each chamber also measured the total dose delivered. These results are shown in table 1.

Dose measured in MR-linac beam (cGy)					
Chamber type	(using chamber calibration factor)	(using alanine calibration of linac in terms of cGy/MU)	% diff	(using alanine calibration of side-by-side chamber)	% diff
2611	47.757	47.859	-0.2	47.946	-0.4
TW30013-1	49.019	47.859	2.6	48.154	1.9
TW30013	48.421	47.859	1.2	47.636	1.7
A1SL	46.862	47.859	-2.1	47.814	-2.0

Table 1. The dose as measured by each of four ionisation chambers compared to the dose determined via calibration of the MR-linac output using alanine.

Conclusions: The two Farmer chamber calibrations deviate from the alanine based calibration by 1.9% and measure a greater dose than the alanine. The 2611 chamber differs from the alanine measurement by 0.3% and measures a smaller dose than the alanine. The A1SL chamber differs by 2% from the alanine, measuring a smaller dose for the same conditions.

The effect of a 1.5 T field on the polarity and ion recombination corrections was expected to be small (Smit et al. 2013) and the results of this work agree with this for all chamber types. Within uncertainty, the dose response of alanine and the 2611 monitor ionization chamber was linear with delivered monitor units.

The correction for the effect of the magnetic field will be determined by measurements on a theratron cobalt-60 facility which has just had a 1.5T magnet installed.

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OC-0554

A novel, generally applicable method for EPID-based sub-arc dose QA of VMAT

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