Radiotherapy and Oncology xxx (2016) xxx–xxx

Contents lists available at ScienceDirect

Radiotherapy and Oncology

journal homepage: www.thegreenjournal.com

Patient-specific online dose verification based on transmission detector measurements

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ARTICLE INFO

Article history:
Received 11 September 2015
Received in revised form 23 March 2016
Accepted 2 April 2016
Available online xxxx

Keywords:
Quality assurance
Transmission detector
Online dose verification

ABSTRACT

Background and purpose: Since IMRT-techniques lead to an increasingly complicated environment, a patient specific IMRT-plan verification is recommended. Furthermore, verifications during patient irradiation and 3D dose reconstruction have the potential to improve treatment delivery, accuracy and safety. This study provides a detailed investigation of the new transmission detector (DTD) Dolphin (IBA Dosimetry, Germany) for online dosimetry.

Materials and methods: The clinical performance of the DTD was tested by dosimetric plan verification in 2D and 3D for 18 IMRT-sequences. In 2D, DTD measurements were compared to a pre-treatment verification method and a treatment planning system by gamma index and dose difference evaluations. In 3D, dose–volume-histogram (DVH) indices and gamma analysis were evaluated. Furthermore, the error detection ability was tested with leaf position uncertainties and deviations in the linear accelerator (LINAC) output.

Results: The DTD measurements were in excellent agreement to reference measurements in both 2D ($\gamma_{3\%,3mm}$ = (99.7 ± 0.6)% <1, $\Delta D_{\pm 5\%}$ = (99.5 ± 0.5)%) and 3D. Only a small dose underestimation (<2%) within the target volume was observed when analyzing DVH-indices. Positional errors of the leaf banks larger than 1 mm and errors in LINAC output larger than 2% were identified with the DTD.

Conclusions: The DTD measures the delivered dose with sufficient accuracy and is therefore suitable for clinical routine.

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Intensity modulated radiotherapy (IMRT) requires a comprehensive quality assurance (QA) program in general and puts considerable demands for the verification of dose delivery in particular [1]. IMRT-techniques are increasingly forcing a sophisticated dose delivery sequence with various degrees of freedom in delivering high doses to the target. Furthermore, possible errors could result in serious consequences for patients. Thus, a patient specific IMRT-QA is recommended [2]. Depending on national guidelines the beam model in the treatment planning system (TPS) as well as the correct radiation delivery for individual patients is supposed to be verified in IMRT-QA. Therefore, 2D detector arrays equipped with ionization chambers or semiconductor detectors as well as EPID dosimetry play a major role to ensure that an IMRT-plan is accurately delivered. Different 3D dose reconstruction models have been discussed in the literature [3–5]. These methods can reconstruct the 3D dose distribution inside the CT-dataset of a patient based on machine log files (Mobius 3D, Mobius Medical Systems), radiochromic film, 2D array (Delta4, ScandiDos; ArcCheck/3DVH, Sun Nuclear), or EPID measurements. However, a major goal in modern radiotherapy is the integration of an adaptive radiotherapy approach whereby independent plan verifications during patient irradiation are required. Therefore, various methods based on EPID dosimetry or transmission detectors placed in the beam between the treatment head and the patient are available [5–9]. In this study, the clinical performance of a new verification platform based on transmission measurements (COMPASS and Dolphin, IBA Dosimetry, Germany) was investigated. Dosimetric plan verification in 2D and 3D was performed and the error detection ability of the new system was evaluated.

Materials and methods

COMPASS and Dolphin

The verification platform COMPASS is a 3D anatomy based quality assurance system that provides different ways to verify treatment plans: (i) model-based dose computation,

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http://dx.doi.org/10.1016/j.radonc.2016.04.003
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Please cite this article in press as: Thoelking J et al. Patient-specific online dose verification based on transmission detector measurements. Radiother Oncol (2016), http://dx.doi.org/10.1016/j.radonc.2016.04.003

(ii) measurement-based dose reconstruction using MatriXX detector for pre-treatment plan verification and (iii) measurement-based dose reconstruction based on transmission measurements with the Dolphin transmission detector (DTD) for plan verification during patient treatment. For the dose computation the patient's DICOM information from the TPS is imported into COMPASS and, based on a collapsed cone algorithm, the dose distribution is computed as an independent secondary TPS verification in order to cross-check the TPS dose calculation. The purpose of the dose reconstruction is to provide information about the actual dose that is being delivered to the patient and to take the linear accelerator (LINAC) behavior into account. When performing measurement based dose reconstruction, the measured detector response is compared to the predicted detector response for each segment. A possible difference between them is considered in the final dose reconstruction using a correction kernel [10]. In this study, all measurements in COMPASS were performed with the DTD since COMPASS in combination with MatriXX has already been reported to be an accurate pre-treatment QA tool [10,11]. With the DTD mounted onto the treatment head, the detector response can be measured during patient irradiation. The DTD is a 2D array of 1513 air-vented plane parallel chambers that cover an active area of $(240 \times 240)\,mm^2$ which projects to a $(400 \times 400)\,mm^2$ field in isocenter distance when measuring at SDD 60 cm. The center to center distances of the chambers are ranging from 5 mm to 10 mm. The diameter of each chamber is 3.2 mm and the height is 2 mm.

Linear accelerator and treatment planning system

The treatment plans were generated by inverse optimization in Monaco (v.3.2, Elekta AB, Sweden) based on the Monte Carlo dose calculation algorithm XVMC. The dose grid was set to 3 mm and the standard deviation of the dose to 1% per plan. In total, 18 IMRT-sequences were randomly selected from the clinical database. Plan details are presented in Table 1. An Elekta Synergy LINAC equipped with an MLCi2 multi leaf collimator (MLC) and a nominal acceleration potential of 6 MV was used for the calculations and measurements.

Evaluation of the dosimetric performance of COMPASS and Dolphin transmission detector

To evaluate the clinical performance of the verification platform COMPASS using DTD, dosimetric plan comparisons in 2D based on a QA-phantom CT-dataset and in 3D based on patient CT-datasets were performed. Furthermore, the error detection abilities were investigated.

2D evaluation

Since planar IMRT-QA in 2D is widespread in many departments for the clinical routine, the COMPASS dose computation (CC) and reconstruction (CR) of various IMRT-sequences were compared to a conventional 2D pre-treatment verification method and TPS. For the pre-treatment verification method, OmniPro I'mRT (IBA Dosimetry) together with MatriXX detector (Mxx) was utilized, as it was investigated in different studies and used in our department for patient-specific IMRT-QA [12,13]. For comparisons of Mxx, CC, CR and TPS hybrid QA-plans of 18 IMRT-sequences (Table 1) were generated in the TPS. In our clinical workflow the QA-phantom is in general attached to the gantry with a holder for the pre-treatment verification based on Mxx. Therefore, the measurements were performed with original gantry angles but the detector is still orientated constantly perpendicular to the central axis of the beam. To generate a suitable QA-plan, the patient plans were transferred to the QA-phantom (Mxx with 4 cm build-up) with collapsing all beams to 0° gantry angle. However, for the 2D analysis all IMRT-sequences were measured with 0° gantry angle, as the DTD has an inclinometer and the actual gantry angle during the measurement is taken into account for CR which would prevent a comparison with the 0° QA-plans. Therefore, all 9 VMAT-plans were converted to dMLC-plans in the TPS with 0° gantry angle. All hybrid-plans were measured with Mxx as well as DTD. For the evaluations between CC, CR and TPS, Mxx was set as reference for dose difference (ΔD) and global gamma index calculations as these evaluations were commonly used for IMRT-QA [14]. For the acceptance criteria, the tolerances $\gamma_{2\%,2mm}$ (the percentage of points passing the gamma criteria dose difference 2% and distance to agreement 2 mm) and $\gamma_{3\%,3mm}$ were chosen (global gamma evaluation with a dose threshold of 20%).

3D evaluation of reconstructed dose distribution inside the patient

The COMPASS platform enables the 3D dose reconstruction based on the patient anatomy. In addition to the 2D verification, the 3D dose distribution for the pure recalculation and reconstruction based on DTD measurements was investigated. Therefore, the fluence distributions with original treatment angles of all 18 IMRT-plans were measured with DTD placed in the path of the beam. The dose distribution was computed as well as reconstructed in

Table 1
Detailed plan information for investigated IMRT-cases.

Plan ID	No. of beams/360° arcs	No. of segments/control points	No. of MU	Field size in (cm^2)
Head&neck-Step&Shoot-1	9	116	740	20 × 18
Head&neck-Step&Shoot-2	9	151	791	22 × 18
Head&neck-Step&Shoot-3	9	124	593	21 × 21
Thorax-Step&Shoot-1	8	75	650	15 × 20
Thorax-Step&Shoot-2	9	55	692	11 × 12
Thorax-Step&Shoot-3	8	88	496	15 × 24
Prostate-Step&Shoot-1	9	75	752	14 × 10
Prostate-Step&Shoot-2	9	74	1065	13 × 21
Prostate-Step&Shoot-3	7	44	605	20 × 15
Head&neck-VMAT-1	1	130	374.5	10 × 10
Head&neck-VMAT-2	1	168	484	6 × 10
Head&neck-VMAT-3	2	273	490.9	12 × 10
Thorax-VMAT-1	1	184	1058.1	12 × 20
Thorax-VMAT-2	1	179	715.7	12 × 14
Thorax-VMAT-3	1	51	309.9	14 × 13
Prostate-VMAT-1	1	96	729.8	11 × 5
Prostate-VMAT-2	1	122	665.3	14 × 14
Prostate-VMAT-3	1	192	733.7	13 × 12

Abbreviations: VMAT = volumetric modulated arc therapy, No = Number, MU = Monitor Units.

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