Detecting VMAT delivery errors: A study on the sensitivity of the ArcCHECK-3D electronic dosimeter

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Abstract. The sensitivity of the ArcCHECK 3D dosimeter in detecting VMAT delivery errors has been investigated. Dose and leaf positional errors of different magnitudes were introduced to whole arc and individual control points (CPs) of a simple open arc VMAT plan. The error introduced and error free plans were delivered and measured using the ArcCHECK device. The measured doses were compared against the treatment planning system calculated doses using gamma (γ) criteria with 2%/2mm and 3%/3mm tolerance levels. ArcCHECK effectively detected the dose errors resulting from MLC leaf positioning errors in limited CPs and Whole arc. For errors introduced to MU, ArcCHECK effectively detected the MU delivery errors in whole arc but not the MU errors introduced to CPs in integrated dose comparison.

1. Introduction

Modern radiotherapy techniques are highly complex in both planning and treatment delivery. The Volumetric Modulated Arc Therapy (VMAT) technique has been recently introduced and follows this trend [1, 2]. The complexity involved in the planning and delivery stages of VMAT necessitates the need for pretreatment plan specific dose verification using 3D dose measurements [3].

Gel dosimeters offer high resolution 3D dose measurements, but at present they are not in widespread clinical use due to various factors such as their high sensitivity to variations in chemical composition, limitations in readout methods, limited commercial availability and lack of user experience [4]. In recent years at least two electronic dosimeters, which enable semi 3D dose measurements, have been commercially introduced [5, 6]. ArcCHECK is one such device which uses semiconductor diode detectors arranged in a helical pattern in a cylindrical phantom. Feygelman et al [6] studied the characteristics of the ArcCHECK device extensively and reported its suitability and limitations for VMAT dose verification. However, to our knowledge, there is little evidence in the literature about the ability of the ArcCHECK to detect errors in a VMAT delivery. Yang et al studied the sensitivity of ArcCHECK in detecting systematic MLC leaf positioning error in Intensity Modulated Radiation Therapy (IMRT) and VMAT delivery by introducing errors to IMRT beams and VMAT arc [7] . In this work we have investigated the sensitivity of ArcCHECK in detecting MLC leaf

positional and Monitor Units (MU) delivery errors in VMAT at both whole arc and individual control-point (CP) levels.

2. Materials and Methods

The Pinnacle Treatment Planning System (TPS), V9.0,(Philips Ltd, USA) was used to generate the VMAT plans considered in this study and described below. An Elekta-Synergy accelerator was used to deliver the VMAT plans using 6 MV photon beams and the ArcCHECK 3D dosimeter (Sun Nuclear Corporation, USA) was used for the dose verification. SNC Patient dose analysis software (Sun Nuclear Corporation, USA) was used to compare measured and planned dose matrices. The ArcCHECK dosimeter used in this study included the central cylindrical insert and all measurements were performed with the cylindrical insert in place. The absolute dose calibration procedure recommended by the manufacturer was followed to calibrate the device.

2.1. Simple VMAT plan

To study the sensitivity of ArcCHECK in detecting VMAT delivery errors, a treatment plan was generated on a digital CT representing ArcCHECK. The plan consisted of a single arc with gantry starting at 250^0 and ending at 110^0 and 111 CPs with 2^0 gantry spacing between them. The aperture size for each CP was set to 5 x 10 cm^2 and equal weights were assigned to all CPs. The ability of ArcCHECK to detect dosimetric errors was tested by introducing known errors of different magnitude to the planned VMAT arc in two steps:

In the first step, a range of dose errors 1%,-3%, 5%,-7% and -10% was introduced to the entire VMAT arc by changing the MU of the arc. Similarly a MLC leaf positional error was introduced by offsetting the MLC leaf banks by different magnitudes. The MLC leaves of both X1 and X2 banks were offset by 1 mm, -2 mm, 3 mm, -4 mm and 5 mm.

In the second step, dose and MLC leaf positional errors were introduced to two CPs of the arc. Two CPs at gantry angle 320^0 (Error ECP1) and 40^0 (ECP2) were chosen so that in the measurement of ECPI, the exit error would not be measured by ECP2. A dose error ranging in magnitude from 5% to 100 % was introduced to the weight of ECP1 and ECP2. Similarly an MLC error ranging in magnitude from 1 mm to 10 mm was introduced to the X1 and X2 leaf banks at ECP1 and ECP2 respectively. Dose and leaf position errors in the positive direction were introduced to ECP1 and in the negative direction were introduced to ECP2.

In both of the above mentioned steps the MLC leaf position and monitor unit weight errors were applied separately to the treatment field. The treatment field with no error and with the above mentioned errors was measured using ArcCHECK. The measured dose matrices were compared against the planned dose (with no error) to study the ability of ArcCHECK in detecting errors.

2.2. Dose matrix analysis

The calculated and measured dose matrices were analysed using gamma (γ) analysis [8] with a γ tolerance of 1. The γ analysis was performed with both 2%/2mm and 3%/3mm dose difference and distance to agreement tolerance levels. The percentage points passing γ criteria was analysed to assess the agreement between plan and measured dose matrices.

3. Results and Discussion

Table 1 shows the percentage points passing γ tolerance for the simple VMAT plan delivered with and without error. The ArcCHECK measurement showed good agreement with the calculated dose for the plan delivered without any error (96.5% and 100% of the points pass 2%/2mm and 3%/3mm tolerance levels respectively). For the plans delivered with MLC error to the whole arc, the pass rate decreased as the MLC error increased above tolerance level used in gamma analysis. This shows the ability of ArcCHECK to detect systematic errors in MLC leaf positions for VMAT delivery. Similarly the pass rate decreased as the magnitude of dose error introduced to the whole arc increased. However, the pass rate for delivery with positive dose errors was consistently reduced when compared to the negative

dose errors although the magnitude of the negative errors was higher (table 1). This can be explained by a detailed analysis of the measured dose for the delivery without error. Figure 1 shows the dose profile for the planned and measured dose along the X axis and % difference between them. The dose measured at the beam entry points (distance between -205 mm and 205 mm in figure 1) varies from -1.6 % to 1.2 % whereas the dose measured at the exit points (distances from -325 mm to -205 mm and 205 mm to 325 mm in figure 1) is always higher, on average 0.8%, compared to the plan dose. Our Pinnacle beam model commissioning data showed that the percentage depth dose (PDD) calculated by Pinnacle for depths between 20 cm and 30 cm (ArcCHECK exit dose measurements are at 24 cm) agreed within ± 0.3% with ion chamber measurements in water. The high exit dose in the ArcCHECK measurement could be attributed to the difference in diode characteristics for the exit beam [9]. This inherent error in exit dose further increases the difference in measurements with positive error in dose delivery and thus decreased the pass rate of measurement points [10]. For the delivery with negative dose errors the opposite occurs thus increasing the pass rate of the measurement points.

Table 1: % points passing γ tolerance for 'simple VMAT plan' delivered with and without error

		% points passing γ			% points passing γ	
		γ Criteria			γ Criteria	
Error Scenario	Dose error (%)	2%/2 mm	3%/3 mm	MLC error (mm)	2%/2 mm	3%/3 mm
	No error	96.5	100	No error	96.5	100
	1	85.2	100	1	96.6	100
	-3	96.9	100	2	92.9	100
Whole arc	5	21.8	49.8	3	83.3	96.5
	-7	60.1	65.4	4	79.2	95.0
	10	13.5	19.7	5	70.6	87.6
	5	96.2	100	1	96.5	100
	7	95.5	100	2	96.4	100
Control point	10	95.6	100	3	95.5	99.6
(CP)	20	94.5	100	4	94.8	100
	40	94.1	100	5	95.2	100
	70	94.1	100	7	90.2	99.6
	100	94.0	100	10	90.8	99.3

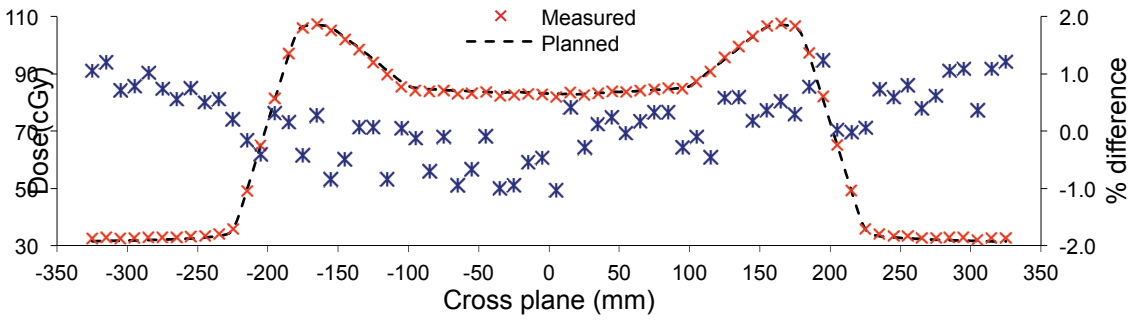

Figure1: Planned and measured dose profiles along the X direction for the simple plan delivered without error

For the plans with MLC errors introduced to CPs, the pass rate for the 2%/2 mm tolerance decreased only by 1.3 % between the plans delivered with no error and 5 mm error. As the error value increased further, larger changes (5.1% at 7 mm and 5.7 % at 10 mm) in the pass rate were observed (table 1). For the range of MU weight errors introduced to the CPs, only a very small change in the pass rate was observed. A decrease of 1.5% in the pass rate was observed between the plan with no error and the plan with a 100% weight error. Further, the pass rate for the 3%/3 mm tolerance was decreased only by 0.7% for the 10 mm error in MLC leaf position and no change in pass rate was observed for plans delivered with dose errors. The dose errors resulted from MLC leaf position and MU weight error are less than 3%, the tighter tolerance level detects these errors (table 1).

The delivery of clinical VMAT plans is far more complex than the simple plan investigated in this study. Further the accuracy of dose calculations performed by the TPS in VMAT calculations depends on the factors such as MLC leaf travel distance and gantry step size between CPs. Due to finite discretisation in arc calculations large MLC and gantry steps between CPs results in less accurate dose calculations [2, 6]. Feygelman et al [6] demonstrated the impact of the discretisation effect on the measurement plane of ArcCHECK and reported that ArcCHECK showed consistently low pass rate at the low tolerance levels compared to other detector systems. In this study we used 2^0 gantry spacing between CPs for the dose calculations of simple VMAT plan. In agreement with Feygelman et al we also observed that for measurement without delivery errors a high pass rate (100 %) was observed with 3%/3 mm tolerance and a relatively low pass rate (96.5 %) was observed with 2%/2 mm tolerance. In our study we simulated MLC leaf positions and MU delivery errors that likely to happen due to miscalibration and random misbehaviour of the treatment unit. ArcCHECK detected the MLC leaf position errors (table 1) but delivery errors resulting from errors in CP MU delivery was not detected by the device. One of the advantages of electronic 3D dosimeters over other integrated type 3D dosimeters is that electronic 3D dosimeters have high temporal resolution; enabling the verification of 3D doses measurements at individual CPs as well as integrated dose verification. In this study we investigated the ability of the ArcCHECK to detecting VMAT delivery errors using integrated dose measurements. In the next phase of this study we will investigate the ability of CP dose analysis to detect VMAT delivery errors and the impact of CP delivery errors on the dose delivered to clinical Regions of Interest (ROIs).

4. Conclusion

The ArcCHECK dosimeter was shown to effectively detect dose errors resulting from MLC leaf positioning errors. This included errors introduced to the whole arc and errors introduced only to two CPs of a simple single arc VMAT plan. For the simple single arc VMAT plan the ArcCHECK dosimeter only detected MU delivery errors occurring over the whole arc, not MU errors introduced to CPs using an integrated dose comparison. Future investigations will assess the effectiveness of individual CP dose analysis using ArcCHECK measurements for detecting these delivery errors and the impact of these errors on the dose to clinical ROIs.

5. References

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