

Patient-specific quality assurance of RapidArc treatments: Portal prediction dosimetry compared with phantom studies

Krishna Murthy K*

Krishna Institute of Medical Sciences, Secunderabad, AP, India.

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ABSTRACT

Purpose: To validate a locally fabricated phantom of Imatrixx-2D Array by comparing its results with ArcCheck phantom and comparing portal dosimetry measurements with the two phantom studies.

Materials and Methods: Electronic Portal Imaging Devices and Epiqa software were used for portal dosimetry. An Imatrixx-2D array with a locally fabricated phantom and ArcCheck cylindrical phantom were used for phantom studies. Eclipse-TPS with RapidArc treatment planning and portal dose prediction software was used for planar dose calculations. Three verification plans were created for each of the 15 patient plans of various sites, making a total of 45 plans to be delivered on 3 QA systems as above. Fifteen plans each with 2 arcs were delivered on the EPIDs of the Linacs, on Imatrixx-2D array phantom and on ArcCheck cylindrical phantom respectively. The planar dose matrices were analysed using global Gamma Index criteria of 3mm DTA and 3% dose difference.

Results: The maximum deviations of percentage in dose points, in which $\gamma > 1$, are 1.94, 1.89 and 1.5 in Imatrixx phantom, ArcCheck phantom and Portal dosimetry, respectively. Similarly, the mean deviations and SD values are less in portal dosimetry than that of phantom studies. The smaller deviations in portal dosimetry are attributed to closely embedded chambers in the EPID compared to the distance between the detectors placed in the phantom measurements.

Conclusion: After carrying out the comparison of results, the locally fabricated phantom has been validated and accepted for the dosimetric studies. The conclusion is that all the three dosimetric QA systems are suitable for the patient-specific QA of RapidArc treatments. © 2012 Biomedical Imaging and Intervention Journal. All rights reserved.

Keywords: Quality assurance, RapidArc, Portal dosimetry, Gamma index, Inclinator.

INTRODUCTION

Verification of RapidArc treatment delivery plays an essential role in clinical practice to assess the quality of radiotherapy given to patients. Implementation of a comprehensive quality assurance (QA) programme for

patient treatment verification is an important aspect of radiotherapy. The objective of such a QA programme is to evaluate the accuracy in machine delivery as per tolerance limits so as to ensure that adequate level of quality treatment is delivered to patients. RapidArc, which is also known as volumetric modulated arc therapy (VMAT), is an advanced form of intensity modulated radiotherapy treatment (IMRT). In this novel technique, the treatment is delivered with a single or multiple arc rotations of a linear accelerator gantry, during which the MLCs move dynamically while the

* Corresponding author. Address: Chief Medical Physicist & RSO, Advanced Cancer Center, Krishna Institute of Medical Sciences, Secunderabad, AP, India-500 003. E-mail: kammarikm@yahoo.co.in (K. Krishna Murthy)

dose rate and gantry speed vary continuously [1]. In the Varian RapidArc technique, the variables are optimised in 177 control points along the arc using single optimisation and soft dose-volume constraints [2, 3]. RapidArc treatment enables the faster delivery of a highly precise image-guided treatment with less “beam on” time, using fewer monitor units, and yet more conformal dose to the shape and size of a targeted tumour without compromising treatment quality. In view of the potential sources of errors as well as inaccuracies involved in various stages of its implementation, it is emphasised that there is a need for a standard quality assurance protocol for the RapidArc treatment as existing for IMRT [4, 5].

The systematic quality assurances for undetermined long periods are important to evaluate the errors in rapid adaptation of newly emerging modern treatment techniques. The investigations of these errors facilitate the improvement of existing QA procedures to minimise or avert future treatment errors. The complex nature of RapidArc delivery needs a precise patient-specific QA to verify whether the intended dose is delivered as planned in each treatment and ensure accurate treatment. The commissioning details of RapidArc treatment is explained clearly in many publications [6, 7]. The quality assurance procedures of RapidArc treatment delivery are reported by various authors [8–11]. The patient-specific QA procedures with 2D Array and phantoms are investigated by various methods, as reported in many papers [12–17], and the results obtained by EPID associated with portal dose prediction and Epiqa software are described in papers [18–20].

In this paper the RapidArc clinical setup used three different dosimetric QA equipment to carry out pre-treatment patient-specific QA for a retrospective study. In this study, measurements were performed using: 1) Linac mounted EPIDs (aS-1000) with Portal dose prediction and Epiqa (GLAAs) software; 2) Imatrixx-2D array (IBA Dosimetry GmbH, Germany) with locally fabricated acrylic phantom and Omnipro ImRT software; and 3) ArcCheck cylindrical phantom (Sun Nuclear Corporation, FL, USA) along with its software. In the initial stage, portal dose prediction and Epiqa software were used to carry out QA of RapidArc treatments and Imatrixx-2D array system for other dosimetric purposes. The Imatrixx-2D array system contains only 3.0mm buildup material above the detector plane and it requires additional buildup material to carry out the QA of RapidArc treatments to measure the dose planes at different depths. In the absence of a commercial phantom, the authors locally fabricated an acrylic (Perspex) phantom and used it with Imatrixx-2D array system for the QA tests of RapidArc treatments. The purpose of this study was to validate the locally fabricated phantom, which is used with Imatrixx-2D Array, by comparing it with another commercially available ArcCheck phantom, and finally, comparing the results of portal dosimetry with the measurements obtained in two phantom studies. This paper highlights the QA procedures followed in the measurements. The QA results obtained from three

methods are evaluated and compared results are presented.

MATERIALS AND METHODS

In this retrospective study, 15 patients from various sites, treated by VMAT using 6MV photon beam, were selected. The VMAT plan for each patient consisted of two arcs (CW and CCW), and these plans were verified using three different dosimetric QA systems. Fifteen plans each with two arcs were delivered on the EPIDs of the Linacs, on the Imatrixx-2D array embedded phantom and on the ArcCheck cylindrical phantom, respectively. Eclipse version 8.9.15 (Varian Medical Systems Inc, Palo Alto, CA) with inverse planning, RapidArc optimisation (PRO algorithm), forward dose calculation (AAA) and portal dose prediction software were used for the preparation of verification plans. The ARIA networking system was used for the transfer of plans, while recording and verification was done on 4DITC of Linacs. The verification plans were delivered using Varian Clinac-ix and Novalis-Tx linear accelerators mounted with amorphous silicon (aS1000) portal imaging devices (EPIDs). The details of dosimetric QA equipment and procedures for measurements are described in the following sections.

A) Portal dose prediction with EPID: Initially, 15 verification plans each with 2 arcs were created using portal dose prediction software. These plans were verified using the Electronic Portal Imaging Device (EPID) mounted on the Linac. The EPID is a flat panel detector with 1024×768 amorphous silicon detectors of size 0.39×0.39mm². The active area of the detector is 40×30cm². During the measurement, the EPID was kept at calibrated distance and operated at integrated image acquisition mode when the gantry was rotating, to deliver the two arcs (CW and CCW). The setup of arc treatment delivery on EPID without any phantom in between is shown in Figure 1. The portal dose prediction software of Eclipse TPS system converts the PV images into dose matrices. The calculated planar dose matrices of verification plan and EPID measured dose matrices of each arc were exported from the TPS and imported into a dosimetric computer system in which Epiqa (GLAAs) software was loaded. The calculated and measured planar dose matrices were analysed with Epiqa software and the results were compared.

B) Imatrixx Evolution-2D array with locally fabricated phantom: In the absence of a commercial phantom to carry out the QA of the RapidArc treatments with available Imatrixx Evaluation-2D array, an acrylic (Perspex) phantom was fabricated locally in two blocks. The dimensions of the upper block were 32cm(L)×36cm(W) and 10.5cm of thickness. Similarly the lower block had the same dimensions of length and width but a thickness of 11.5cm, in which a 30cm(L)×32cm(W) and 3.8cm depth groove was made to insert the Imatrixx-2D array system in the phantom during the measurements. The purpose of this locally fabricated phantom is to validate and use it as an

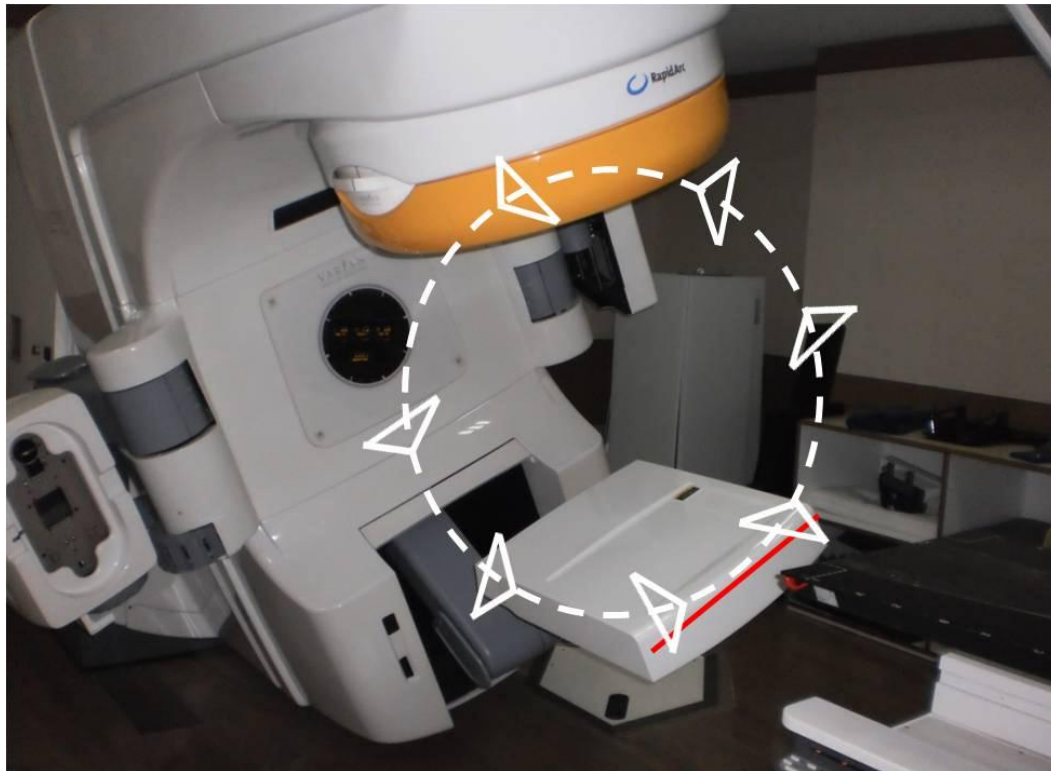


Figure 1 RapidArc verification plan delivery method on EPID in Portal dosimetry.

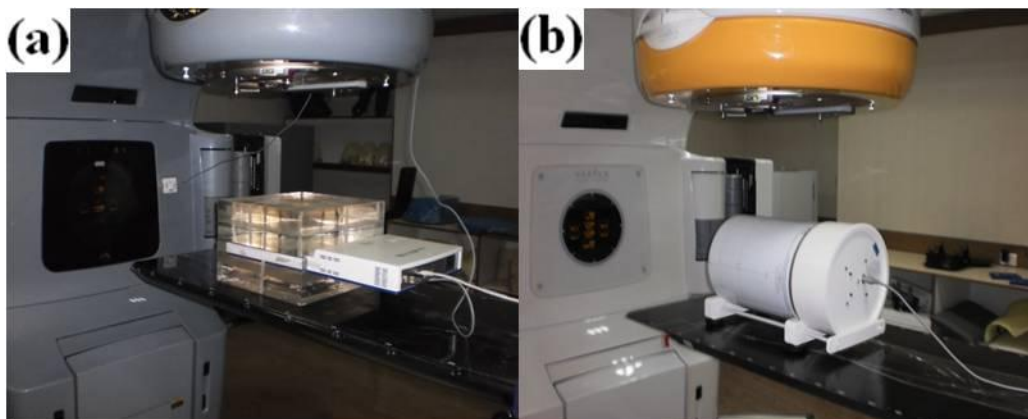


Figure 2 Setup arrangement of phantom measurements for: (a) ImaTrixx-2D array with locally fabricated phantom and (b) ArcCheck cylindrical phantom.

alternate phantom in the absence of a commercial phantom. The IBA-Imatrixx-2D array contained 1,024 air-vented pixel ionisation chambers measuring 4.5(dia)×5(h)mm, with a volume of 0.08cm³. The chambers were embedded in a RW3 phantom material spreading them over an active area of 24×24cm² with a spacing of 7.62mm in between. The 2D array system was calibrated for the absolute dose measurements. Fifteen verification plans, each with two arcs of the same patients, were generated on the CT images of the ImaTrixx-2D array acrylic phantom. An inclinometer, a gantry rotation sensor supplied along the 2D array, was attached to the accelerator gantry and connected to the 2D array. This device provides independent information about the gantry angle and angular calibration/correction during the arc delivery to compensate for the angular dependence of planar measurement devices. The two

(CW and CCW) arcs of each verification plan were delivered on the ImaTrixx-2D array phantom as planned. The setup of arc treatment delivery on the ImaTrixx-2D array phantom is shown in Figure 2(a). Omnipro ImRT software was used to compare and analyse the TPS calculated and phantom measured dose planes.

C) ArcCheck cylindrical detector array Phantom:

Fifteen verification plans, each with two arcs of the same patients, were generated on the CT images of the Sun nuclear ArcCheck phantom for comparison between planned and measured planar dose. The phantom contained 1,386 point diode detectors embedded along the cylindrical surface area of 21cm diameter PMMA material with a spacing of 1cm in between. The inherent buildup of detectors was 3.2g/cm² and the phantom provided 3.2g/cm² back scatter to the detectors. The cylindrical phantom used in the study did not have any

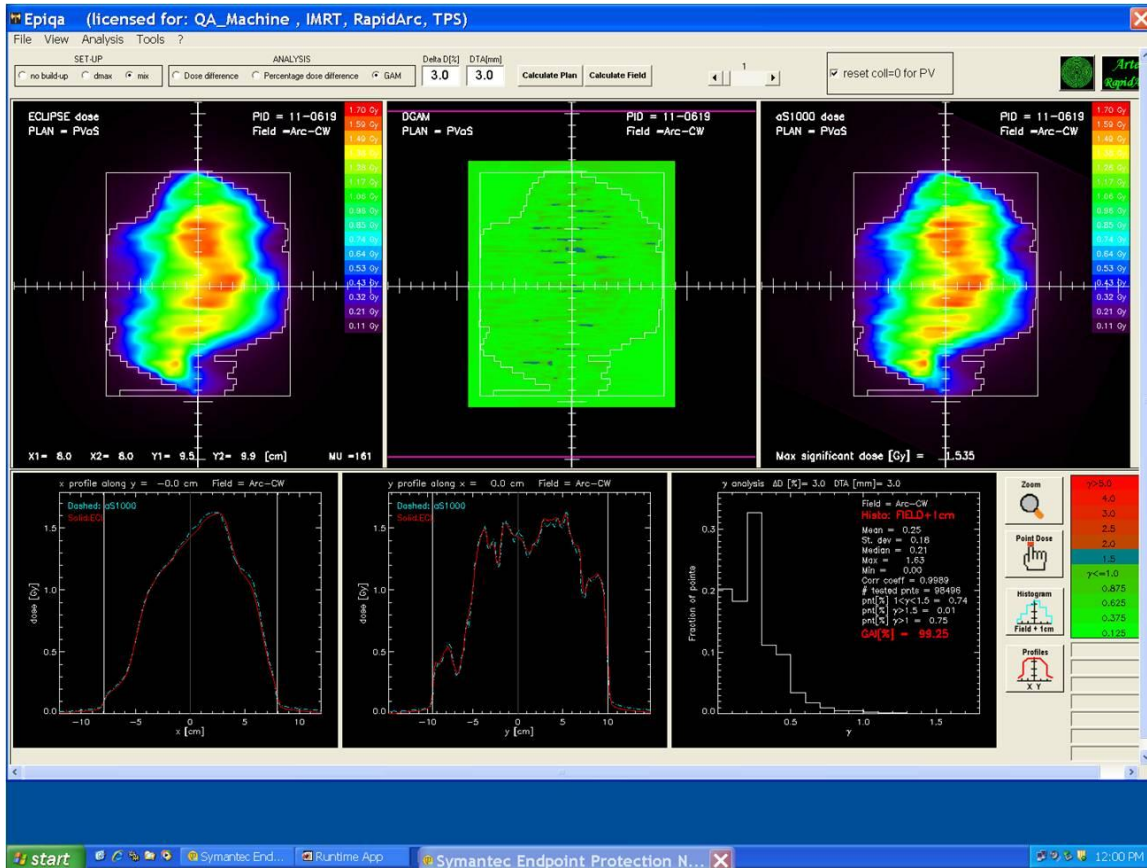


Figure 3 Comparison of calculated and measured planar dose distributions of a typical RapidArc plan with portal dosimetry and Epiqa software.

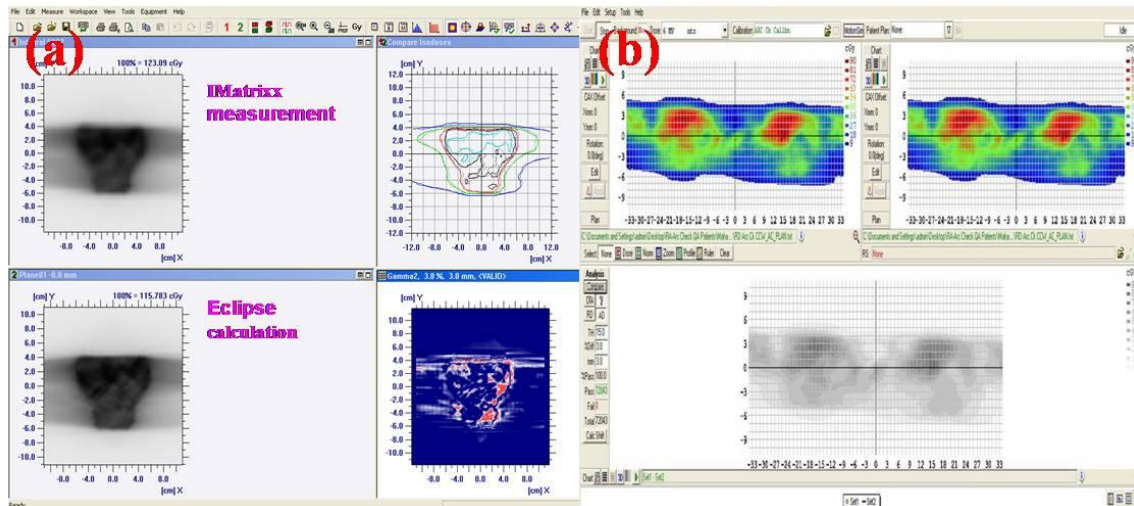


Figure 4 Comparison of calculated and measured planar dose distributions of a typical RapidArc plan with: a) Imatrixx-2D array phantom and (b) ArcCheck Phantom.

insert/multiplug inside the hollow space. The ArcCheck phantom is calibrated as per manufacturer’s guidelines. The two (CW and CCW) arcs of each verification plan were delivered on the ArcCheck cylindrical detector array phantom as planned. The setup of arc delivery on the cylindrical phantom is shown in Figure 2(b). The calculated dose planes were exported from the Eclipse TPS system and imported into the ArcCheck software (DICOM RT Format), which was used to analyse and compare the results.

RESULTS

The calculated and measured planar relative dose distributions and absolute CAX point doses were compared with profiles/isodose matching methods using their respective software. The 3mm DTA and 3% dose difference for the global Gamma Index ($\gamma \leq 1$), as well as 97% data pass criteria was used for the analysis and the results obtained from the three methods were compared. The planar dose evaluation of a typical RapidArc plan

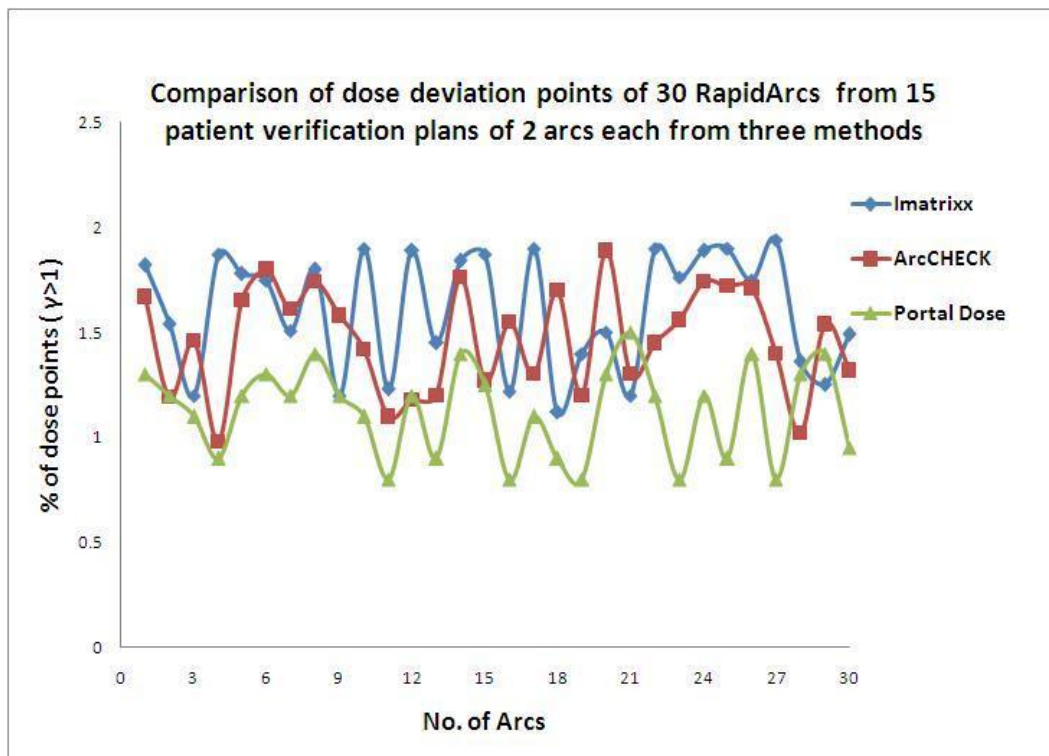


Figure 5 Percentage of dose point deviations ($\gamma > 1$) in measurements with Imatrixx, ArcCheck and portal dosimetry.

with portal dose prediction and Epiqa software is shown in Figure 3. The evaluation of planar dose matrix of another typical RapidArc plan done with Imatrixx-2D array phantom and Omnipro Imrt software is shown in Figure 4(a). A similar planar dose comparison result of the same plan analysed with cylindrical ArcCheck phantom and corresponding software is shown in Figure 4(b).

The percentage of points falling outside the passing criteria (3% & 3mm), which is defined by $\gamma > 1$ of 15 patients, along with maximum, mean and SD values obtained from three different methods is shown in table.1. The graphical representations of the percentage of deviations of dose points from the three methods are shown in Figure 5. All the CAX absolute point doses measured with three methods were well in agreement with the TPS calculations and the observed maximum deviation is less than 3%. The results calculated using 2mm DTA and 2% dose difference show that the percentage of errors in Portal dosimetry are comparable with ArcCheck system, and more in Imatrixx-2D array system.

DISCUSSION

A retrospective investigation on technical and QA data from the 15 patients using RapidArc treatment technique were performed to provide evidence about RapidArc delivery features, planning accuracy and machine performance. All the 15 patient plans created for the study, which were delivered on three dosimetric QA systems, have passed the gamma evaluation criteria. The results show that, on overall, minimal differences

exist between the three methods. The portal dose prediction with EPID and Epiqa software method is a less time- and material-consuming system and yet given minimal deviations. This may be due to the greater number of closely placed detectors and accuracy of the EPID setup during the treatment delivery. Though it is possible to convert the RapidArc beam into collapsed beam by making the gantry angle zero and delivering it on the EPID without gantry rotation in the portal dose prediction method, in this study the Arc beams were delivered on EPID with gantry rotation which is similar to the clinical situation to measure the doses under exact treatment conditions. The drawback of the portal dosimetry is that it does not provide any gantry angle information and requires individual analysis of each arc.

In phantom studies, the Imatrixx-2D Array phantom method requires gantry correction device- inclinometer, since it is an angular dependence system in RapidArc patient-specific QA, as reported by earlier authors [21, 22]. The density effect of locally fabricated acrylic phantom was not considered since the plan is both created and verified with the same phantom, which makes the interpretation of results quite straightforward. The ArcCheck system does not use any gantry correction device and it takes less set-up time. This may be due to the usage of point size detectors embedded in a cylindrical shape phantom and the beam incident perpendicularly on the system from every gantry angle during the measurement.

All the methods used for the measurements taken were subject to similar set-up uncertainties. The 2.5mm grid size was used in all verification plan calculations for uniformity in comparisons. The mean value deviations are lower in the portal dosimetry compared to that of

Table 1 Percentage of dose points with $\gamma > 1$ for 30 arcs each of three dosimetric systems.

Verification Plan No.	Imatrixx-2D array Phantom		ArcCheck Phantom		Portal Dosimetry with EPID	
	% of dose points ($\gamma > 1$)		% of dose points ($\gamma > 1$)		% of dose points ($\gamma > 1$)	
	Arc-1	Arc-2	Arc-1	Arc-2	Arc-1	Arc-2
1	1.82	1.22	1.67	1.55	1.3	0.8
2	1.54	1.9	1.19	1.3	1.2	1.1
3	1.2	1.12	1.46	1.7	1.1	0.9
4	1.87	1.4	0.98	1.2	0.9	0.8
5	1.78	1.5	1.65	1.89	1.2	1.3
6	1.75	1.2	1.8	1.3	1.3	1.5
7	1.51	1.9	1.61	1.45	1.2	1.2
8	1.8	1.76	1.74	1.56	1.4	0.8
9	1.2	1.89	1.58	1.74	1.2	1.2
10	1.9	1.9	1.42	1.72	1.1	0.9
11	1.23	1.75	1.1	1.71	0.8	1.4
12	1.89	1.94	1.18	1.4	1.2	0.8
13	1.45	1.36	1.2	1.02	0.9	1.3
14	1.84	1.25	1.76	1.54	1.4	1.4
15	1.87	1.49	1.27	1.32	1.25	0.95
Maximum	1.94		1.89		1.5	
Mean	1.6076		1.4670		1.1226	
SD	0.2819		0.2510		0.2184	

phantom studies. The measured absolute dose values at the central axis point of all the plans with the three methods were well in agreement with the TPS predicted values and the maximum deviation found was $< 3\%$.

The number of plans in which $\gamma > 1$ values are less in portal dosimetry than that of phantom studies are shown in Table 1. The graphs shown in Figure 5 clearly indicate the varying trends of the percentage of deviations of dose points for all the RapidArcs treatments from the three methods. The present results of our portal dosimetry are comparable with the earlier reported values by others [20]. All the deviations are slightly larger in Imatrixx when compared with ArcCheck measurements. This may be due to the changes in their phantom shapes and directional dependency of the detectors of the two systems. The authors anticipate that other reasons for the lower deviations in the ArcCheck phantom may be due to the rigorous calibration procedure needed for its installation. The present phantom studies dosimetric QA results are similar to the summaries provided by other groups using different phantoms and independent dosimetric tools [23, 24]. It was observed that, in the Imatrixx 2D array system, the results have shown consistent dose differences of about 4–6%, with and without the use of inclinometer, which gives gantry rotation corrections for the planar measurement devices. The fewer deviations in portal dosimetry are attributed to closely embedded chambers in the EPID compared to that of the distance between the chambers placed in Imatrixx 2D-Array and diode detectors in cylindrical

ArcCheck systems. The deviations observed in the percentage of errors in the three methods may be due to the difference in their dose reconstruction methods. The Portal dosimetry uses transmission, while Imatrixx system uses single dose plane and ArcCheck uses reconstruction from entry/exit dose. In this study, the locally fabricated acrylic phantom has been validated and used for all the authors' dosimetric purposes, since the Imatrixx-2D Array phantom measurements are comparable with the ArcCheck phantom and other phantom-based studies. However it is believed that more measurement data is needed for further evaluation.

CONCLUSIONS

The retrospective study on patient-specific quality assurance has shown the probable uncertainties and errors in dose delivery of RapidArc treatments. The study confirmed that the observed deviations were well within the limits of international standards and ensured the accuracy and quality of the treatments delivered at the authors' oncology centre. The locally fabricated acrylic phantom used in the Imatrixx-2D Array system was validated and accepted for the dosimetric purpose, since all the measurements carried out with it passed the gamma index criteria and the deviations were well within the acceptable limits. The results revealed that all the three dosimetric QA methods are suitable for the patient-specific QA of RapidArc treatment. This study concludes

that, depending on the machine time available, any dosimetric system of these three methods can be used interchangeably for routine patient-specific QA. The study helped to enhance understanding of various QA procedures and gave ideas to improve the work practices of the department. The study helps the staff involved to update their knowledge in QA procedures and explore the optimal QA methods needed for the RapidArc treatments.

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