Comparison of two patient-specific VMAT QA systems: Portal Dosimetry versus ArcCHECK phantom

การเปรียบเทียบการทวนสอบแผนการรักษาผู้ป่วยในเทคนิคการฉายรังสีแบบปรับความเข้มเชิงปริมาตรด้วยเครื่องมือวัดรังสีสองระบบ: เครื่องมือวัดรังสีระบบพอร์ทอลเปรียบเทียบกับเครื่องมือวัดรังสีอาร์คเช็ค

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Abstract

Background: Due to the complexity of VMAT dose distribution, the implementation of pre-treatment verification is an essential process in clinical practice to ensure that the accuracy of radiation dose is delivered to the patient as planned.

Objective: To compare the VMAT pre-treatment QA results for head and neck cancer and prostate cancer using Portal Dosimetry system (PDs) and ArcCHECK phantom with difference gamma evaluation criteria.

Materials and Methods: Thirty VMAT plans of head and neck site and prostate site were created and delivered on two different QA systems; PDs and ArcCHECK. The measured planar dose matrices were compared with planned dose and were analyzed using global gamma evaluation with the criteria of 3%/3 mm, 3%/2 mm and 2%/2 mm.

Results: The average passing rate of head and neck cases measured by PDs and ArcCHECK using 3%/3 mm was 97.9 $\pm$ 0.9% and 97.8 $\pm$ 0.8%, respectively. When using 3%/2 mm and 2%/2 mm, the average passing rate measured by PDs was 95.7 $\pm$ 0.8% and 76.5 $\pm$ 2.6%, while the results measured by ArcCHECK was 96.6 $\pm$ 0.8% and 79.8 $\pm$ 2.1%, respectively. Similar trend of the results was observed for prostate cases; however, the higher passing rate was detected due to lesser complexity in prostate plan. The average passing rate measured by PDs and ArcCHECK using 3%/3 mm was 99.1 $\pm$ 0.9% and 99.6 $\pm$ 0.5%, respectively. When using 3%/2 mm, the passing rate of 98.1 $\pm$ 1.0% and 98.7 $\pm$ 0.9% was observed for PDs and ArcCHECK, respectively. The passing rate decreased to 97.0 $\pm$ 0.9% for PDs and 97.4 $\pm$ 0.7% for ArcCHECK when 2%/2 mm was applied.

Conclusion: The gamma passing rates of PDs were comparable to those of the ArcCHECK measurements for all gamma criteria. The distinct differences were observed when the stringent gamma criteria were applied.

Keywords: ArcCHECK, Patient-specific QA, VMAT

บทคัดย่อ

หลักการและเหตุผล: เนื่องจากความซับซ้อนของการกระจายปริมาณรังสีในแผนการรักษาด้วยเทคนิคการฉายรังสีปรับความเข้มเชิงปริมาตร (VMAT) การทวนสอบแผนการรักษาก่อนการฉายรังสีจึงเป็นสิ่งจำเป็น เพื่อให้มั่นใจว่าผู้ป่วยจะได้รับปริมาณรังสีที่ถูกต้องตามแผนการรักษา

วัตถุประสงค์: เพื่อเปรียบเทียบผลการทวนสอบแผนการรักษา VMAT ในมะเร็งศีรษะและลำคอ และมะเร็งต่อมลูกหมากโดยใช้เครื่องมือวัดรังสีระบบพอร์ทอล (PDs) และเครื่องมือวัดรังสีอาร์คเช็ค (ArcCHECK) โดยทำการประเมินผลด้วยเกณฑ์แกมมาต่างๆ

วัสดุและวิธีการ: ทำการฉายรังสีแผนการทวนสอบ VMAT ของมะเร็งศีรษะและลำคอ และมะเร็งต่อมลูกหมากทั้งหมด 30 แผน ลงบนอุปกรณ์รับภาพอิเล็กทรอนิค (EPIDs) ของเครื่องฉายรังสีรุ่น และ ArcCHECK จากนั้นทำการเปรียบเทียบปริมาณรังสีที่ได้จากการวัดค่ารังสีในแนวระนาบเมทริกซ์ กับปริมาณรังสีจากแผนการรักษา และทำการวิเคราะห์ด้วยโกบอลแกมมา ที่เกณฑ์ 3%/3 มม, 3%/2 มม และ 2%/2 มม.

ผลการศึกษา: ค่าเฉลี่ยของ passing rate ในมะเร็งศีรษะและลำคอที่ทำการวัดโดย PDs และArcCHECK เมื่อใช้เกณฑ์ 3%/3 มม เท่ากับ 97.9 $\pm$ 0.9% และ 97.8 $\pm$ 0.8%, ตามลำดับ เมื่อใช้เกณฑ์ 3%/2 มม และ 2%/2mm, ค่าเฉลี่ยของ passing rate ที่ทำการวัดโดย PDs เท่ากับ 95.7 $\pm$ 0.8% และ 76.5 $\pm$ 2.6% ในขณะที่ค่าการวัดโดย ArcCHECK เท่ากับ 96.6 $\pm$ 0.8% และ 79.8 $\pm$ 2.1% ตามลำดับ ผลการศึกษาในมะเร็งต่อมลูกหมากมีแนวโน้มเป็นไปในแบบเดียวกันกับมะเร็งศีรษะและลำคอ แต่อย่างไรก็ตามพบว่ามีค่า passing rate ที่สูงกว่าเนื่องจากในมะเร็งต่อมลูกหมากมีความซับซ้อนน้อยกว่า ค่าเฉลี่ยของ passing rate ที่ทำการวัดโดย PDs และArcCHECK เมื่อใช้เกณฑ์ 3%/3 มม เท่ากับ 99.1 $\pm$ 0.9% และ 99.6 $\pm$ 0.5% ตามลำดับ เมื่อใช้เกณฑ์ 3%/2 มม ค่า passing rate เท่ากับ 98.1 $\pm$ 1.0% และ 98.7 $\pm$ 0.9% สำหรับการวัดโดย PDs และ ArcCHECK ตามลำดับ ค่า passing rate มีค่าลดลงเท่ากับ 97.0 $\pm$ 0.9% สำหรับ PDs และ 97.4 $\pm$ 0.7% สำหรับ ArcCHECK เมื่อทำการลดเกณฑ์ไปที่ 2%/2 มม.

ข้อสรุป: ค่า passing rates ของ PDs มีค่าเทียบเท่ากับค่า passing rate ของ ArcCHECK ในทุกๆ เกณฑ์แกมมา และจะพบค่าความแตกต่างอย่างชัดเจนเมื่อทำการลดค่าเกณฑ์แกมมา

คำสำคัญ: เครื่องมือวัดรังสีอาร์คเช็ค, การทวนสอบแผนการรักษา, เทคนิคการฉายรังสีปรับความเข้มเชิงปริมาตร

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Introduction:

Volumetric Modulated Arc Therapy (VMAT) provides highly conformal radiation dose distribution to the target while sparing the radiation dose to the organs at risk. It delivers radiation with dynamic dose rate, collimator angulation and gantry rotation[1]. Due to the complexity of the VMAT dose distribution, the implementation of pre-treatment verification or treatment planning quality assurance (QA) is an essential procedure in clinical practice to ensure that the accuracy of radiation dose is delivered to the patient as planned. The planning QA is also possible to detect the systematic errors which can lead to various side effects for the patients[2].

Several QA systems, such as 2D or 3D array of ionization chamber or diode, film and Electronic Portal Imaging Device based are available and widely used for VMAT QA[3-6]. The planning QA examines the concordance between planned dose distribution from the treatment planning system and the measured dose delivered by the linear accelerator. The analysis is generally performed with the

gamma evaluation method which is derived from the protocol regarding the choice of the deviation of % dose difference, distance to agreement and the gamma pass rate criterion[7].

The scope of this study covered the use of two dosimetry systems for VMAT QA: Portal dosimetry system (PDs) and ArcCHECK phantom which are available at our clinic. The aim was to understand and compared the gamma pass rate of those two dosimetry systems. Previous studies have reported the performance of ArcCHECK and PDs for VMAT QA. Li et al.[8] and Chaswal et al.[9] evaluated the use of ArcCHECK for VMAT plans verification. The studies showed very good gamma analysis for the simple plan verification. However, the correction for detector directional dependence was needed. Bailey et al.[10] performed pretreatment VMAT QA with PDs. It appeared good gamma passing rate but the detector inherent limitation due to gantry motion and detector sag should be concerned. Most of studies mentioned above performed the analysis using gamma criteria of 3%/3 mm which was recommended by AAPM TG119[11]. However, numbers of studies have discussed the acceptance criteria for VMAT QA. Hussein et al.[12] compared gamma analysis of ArcCHECK, EPID, Delta4 and EBT2 film. They found higher sensitivity of error detection when the gamma criteria of less than 3%/3 mm was applied. Vieillevigne et al.[13] compared ArcCHECK, 2D array 729 and EPID and studied the their sensitivity to delivery errors. The devices presented similar potential for VMAT QA even analyst with tight criteria of 2%/2 mm. Another purpose of this study was to study the detectors response on the gamma index passing rate when applied various acceptance criteria and developed the VMAT QA protocol for our center.

Materials and Methods:

A. Patient selection

Fifteen head-and-neck (HN) and fifteen prostate VMAT cases treated by 6 MV photon beams were retrospectively selected. Two arcs or three arcs were created with a dose rate of 400 MU/min for each patient. Eclipse treatment planning system version 13.6 (Varian Medical System, Palo Alto, CA) and analytical anisotropic algorithm (AAA) with 2.5 mm calculation grid size were used for patient plan calculating. For HN plans, the treatment plan consisted of 2-3 dose levels of 66-70 Gy (High risk CTV), 59.4 Gy (Intermediate risk CTV) and 54 Gy (Low risk CTV) with a dose fraction of 2-2.12 Gy. For prostate plans, the prescribed doses of 70-76 Gy with a dose fraction of 2 Gy were generated.

To create the treatment verification plans, the plans containing an actual fluence and calculated MLC leaf motion were exported to two QA systems; PDs and ArcCHECK. PDs generated the calculated portal images while ArcCHECK recalculated all parameters as a planned dose map. Then, the data were transferred to the Linac for dose delivery using ARIA information system. All measurements were performed using Varian Clinac iX (Varian Medical System, Palo Alto, CA) equipped with a Millennium 120 MLCs. A composited portal measured dose image from PDs and a measured

planar dose from ArcCHECK were compared with the calculated dose from TPS using gamma evaluation.

B. Patient-specific QA VMAT system

B.1 Portal Dosimetry system (PDs)

Portal Dosimetry system (Varian Medical System, Palo Alto, CA) acquired image with Varian Portal Vision and analyzed with Portal Dosimetry (version 13.6). The images were obtained with amorphous silicon EPID model aS1000 which was set statically at 105 cm source detector distance (SDD) respect to the rotated gantry with no additional build up. EPID has 40 ×30 cm^2 detecting surface size with a 1024 × 768 pixel of active area (0.39 mm resolution). It was attached directly to the Varian Clinac iX by a robotic Exact arm. The detector was calibrated follow the manufacturer's specifications[14], dark field and flood field calibration was performed each day before measurement. The detector dose calibration was performed monthly delivered by a 10 × 10 cm2 open field at 100 cm SDD. The dose scaling was calibrated to 1 Calibration Unit (CU) = 1 centigray (cGy)[10]. EPID sag was performed on the first time of machine installation. The average of detector sagging was within 2 mm for all tested. The treatment machine QA was performed monthly to ensure that the gantry sag was within ± 2 mm[15].

B.2 ArcCHECK cylindrical phantom

ArcCHECK (Sun Nuclear Inc, Melbourne, FL) combined with SNC patient software (version 8.1) is a 3D cylindrical detector. It consists of 1386 silicon diode detectors embedded on the cylindrical surface area of 21 cm diameter and 21 cm array length. The device has the inherent detector of 2.85 cm and 1 cm detector spacing. ArcCHECK dose calibration was performed follow the manufacturer's guidelines before each measurement session with a 10 × 10 cm^2 open field at 100 cm source axis distance (SAD) [16]. For plan verification measurements, ArcCHECK was set isocentrically (SAD = 86.3 cm) accommodate with a MultiPlug inserted inside in the center of the phantom (cavity diameter = 15 cm). All measurements recorded by ArcCHECK were corrected for background radiation, angular dependence, field size dependence and heterogeneity automatically. The correction factors were determined from manufacturer during initial calibration of the detector[9].

C. Evaluation protocol

Gamma evaluation or gamma index analysis developed by Low et al.[17] is a common quantitative method for assessment the agreement between measured dose and the TPS planned dose. The agreement between two point in dose spatial domain was calculated using two acceptance criteria: percentage dose difference (%DD); and distance to agreement (DTA). The gamma index value assigned to each individual points are satisfied the passing criterion by the condition value ≤ 1[18]. The gamma passing rate or the percentage of passing point can be calculated for different criteria or apply an action

level by the user[19]. This study used a global gamma evaluation method where the percent differences for every point was normalized to a globally used single value, usually the maximum planned dose[18].

The absolute gamma analysis with criteria of 3%/3 mm, 95% as an action level followed the AAPM TG 119 protocol was used [11] for PDs and ArcCHECK VMAT QA. Criteria of 3%/2 mm with a threshold of 95%, as suggested by AAPM No.218[7] and the criterion of 2%/2 mm with 90% pass rate recommended from previous studies[13,20] was also reported. These analyses included 10% dose threshold for all devices. The dose threshold corresponds to the detectors receiving doses less than 10% of the maximum dose were excluded from this analysis in order to minimize the effects of noise in low dose regions[11]. The significance of the differences between portal dosimetry system and the ArcCHECK measurements was examined with two tails paired t-test for all criteria.

Results

The example of the comparison between measured and calculated dose with PDs and ArcCHECK is shown in **Figure 1** and **Figure 2**, respectively. The mean value and standard deviation (SD) of % gamma passing rate for all gamma criteria of 30 VMAT plans using portal dosimetry system and ArcCHECK are presented in **Table 1** (head and neck) and **Table 2** (prostate), respectively. The summary of gamma passing rate comparison between measured and calculated dose of those two dosimeters are shown in **Table 3**. All head and neck plans measured by PDs and ArcCHECK had the average gamma passing rate using 3%/3 mm of 97.9$\pm$ 0.9% and 97.8 $\pm$ 0.8%, respectively. When 3%/2 mm and 2%/2 mm were applied, the average passing rate measured by PDs was 95.7 $\pm$ 0.8% and 76.5 $\pm$ 2.6% while the results measured by ArcCHECK was 96.6 $\pm$ 0.8% and 79.8 $\pm$ 2.1%, respectively. There were no significant different between ArcCHECK and PDs in planar dose measurements and TPS dose calculation (p-value = 0.760) when 3%/3 mm was selected. The result showed statistically significant differences when gamma criteria were reduced to 3%/2 mm (p-value = 0.003) and 2%/2 mm (p-value = 0.001).

For prostate plans, when 3%/3 mm criteria were applied the average gamma passing rate measured by PDs and ArcCHECK was 99.1 $\pm$ 0.9 % and 99.6 $\pm$ 0.5%, respectively. The results showed passing rate of 98.1 $\pm$ 1.0% for PDs and 98.7 $\pm$ 0.9% and for ArcCHECK when 3%/2 mm was used. For 2%/2 mm, the passing rate decreased to 97.0 $\pm$ 0.9% for PDs and 97.4 $\pm$ 0.7% for ArcCHECK. The prostate cases illustrated no statistically significant difference for all gamma criteria.

Discussion

Both PDs and ArcCHECK dosimetry currently have been operated at Lopburi Cancer Hospital. The detectors were tested and characterized before being used for clinical patient-specific VMAT QA. This study investigated the PDs results comparing to the ArcCHECK cylindrical phantom by utilizing various gamma criteria.

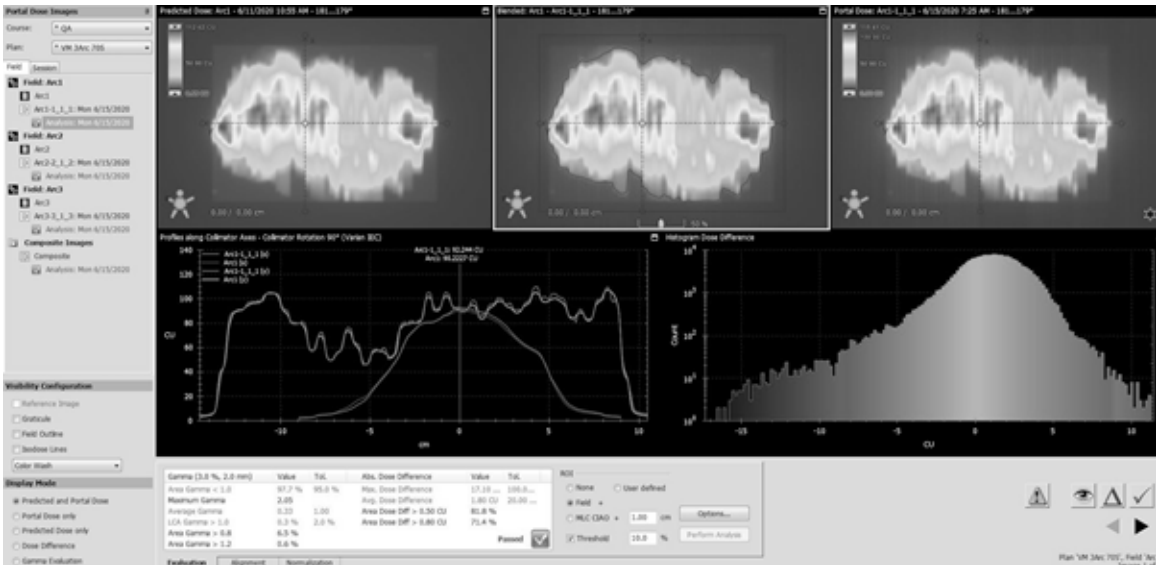

Figure 1 The comparison of PDs calculated (top left) and EPID measured planar dose distribution (top right) showing gamma analysis results (top middle) and line profile agreement (bottom).

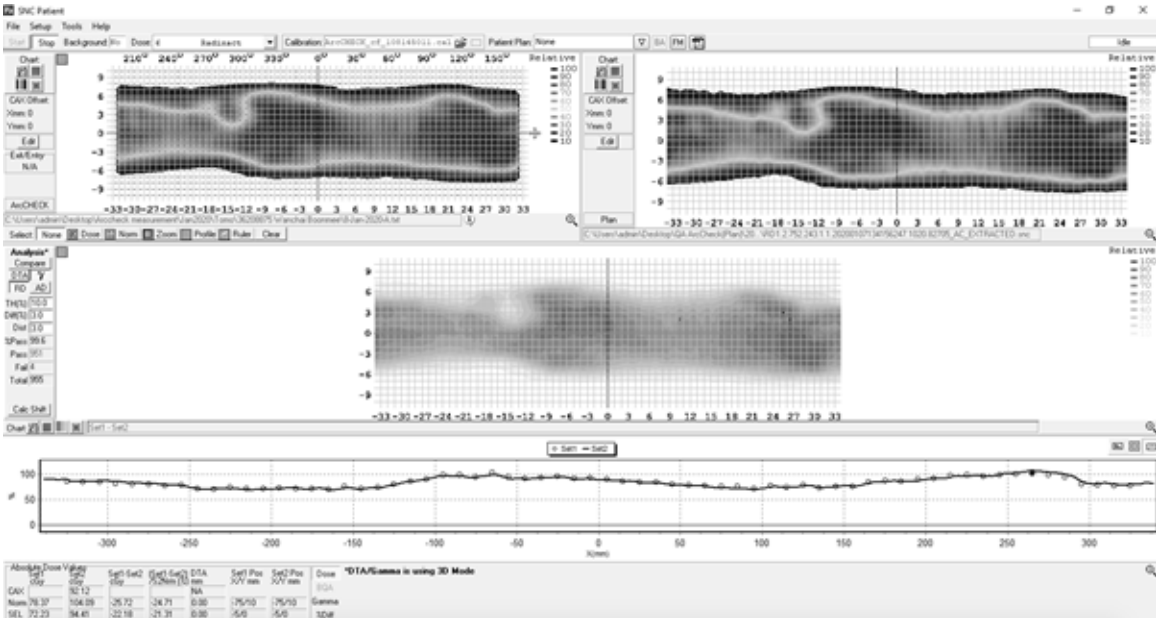

Figure 2 The comparison of TPS calculated (top right) and ArcCHECK measured planar dose distribution (top left) showing gamma analysis results and line profile agreement (bottom).

Table 1 The mean value and SD of % gamma passing rate for all gamma criteria of head and neck plans using PDs and ArcCHECK dosimetry.

Patient No.	3%/3 mm		3%/ 2 mm		2%/2 mm	
	Portal dose	ArcCHECK	Portal dose	ArcCHECK	Portal dose	ArcCHECK
1	98.2	97.1	97.0	97.5	78.0	81.2
2	97.8	98.5	96.2	96.9	75.0	80.0
3	98.2	96.9	96.7	97.0	79.4	79.0
4	98.5	97.8	95.6	97.6	77.6	82.5
5	98.5	99.0	95.9	97.5	74.7	79.3
6	99.9	97.6	95.9	96.8	78.2	80.1
7	96.0	96.0	94.9	96.0	69.9	73.7
8	98.7	97.8	94.9	96.1	73.6	77.0
9	96.6	98.0	94.0	96.4	79.9	80.3
10	98.0	98.3	95.0	95.2	76.9	82.0
11	98.0	97.8	95.0	95.2	74.8	80.5
12	97.9	98.0	96.3	97.2	78.3	80.3
13	97.4	98.3	95.0	96.9	77.0	80.8
14	96.9	97.0	95.9	96.1	76.5	80.2
15	98.0	99.0	96.5	97.0	77.4	79.7
Average	97.9	97.8	95.7	96.6	76.5	79.8
SD	0.9	0.8	0.8	0.8	2.6	2.1

For head and neck cases, the passing rate for both PDs and ArcCHECK were more than 95% when using 3%/3 mm and 3%/2 mm criteria. The results agreed well with previous studies presented in **Table 4**. However, when reduced the criteria to 2%/2 mm, our study presented the lowest passing rate which was less than 80%. This might be because most of the VMAT plans in this study consisted of at least 3 PTV which represented the complex plan. The complex plans showed more gamma failing points, especially at high dose gradient region or beam edge. Another reason was our study used absolute gamma analysis, while studies reported in Table 4 did not clarify weather global/local gamma method or absolute/ relative gamma analysis were applied. The passing rate in relative gamma analysis could be higher than in absolute

Table 2 The mean value and SD of % gamma passing rate for all gamma criteria of prostate plans using PDs and ArcCHECK dosimetry.

Patient No.	3%/3 mm		3%/ 2 mm		2%/2 mm	
	Portal dose	ArcCHECK	Portal dose	ArcCHECK	Portal dose	ArcCHECK
1	99.0	99.7	97.0	98.9	95.7	96.0
2	99.4	99.9	98.0	99.4	96.7	97.7
3	100.0	99.5	99.0	97.4	96.0	98.0
4	100.0	99.1	97.0	97.8	96.0	96.7
5	98.0	100.0	98.0	98.4	97.8	97.0
6	100.0	99.3	97.0	99.4	96.0	98.0
7	99.0	98.9	99.0	97.9	98.0	97.0
8	98.0	99.2	97.0	98.1	96.8	97.0
9	99.7	100.0	98.0	99.0	96.8	97.0
10	99.5	100.0	97.0	99.0	97.0	97.5
11	99.9	100.0	99.9	99.6	98.4	98.0
12	98.0	100.0	99.9	100.0	98.2	98.7
13	99.1	100.0	98.1	99.9	97.3	97.9
14	98.0	99.0	98.8	98.0	96.5	97.0
15	98.0	98.8	98.0	97.2	97.2	97.0
Average	99.1	99.6	98.1	98.7	97.0	97.4
SD	0.9	0.5	1.0	0.9	0.9	0.7

gamma analysis because the average depth dose (DD) between the calculated and measured dose distributions was minimized.

Similar trend of passing rate was found for the prostate cases which represented the simple plan. When reduced the gamma criteria, the passing rate was reduced. The results were more than 95% for all gamma criteria even for the stringent criteria of 2%/2 mm with no significant difference (p-value > 0.05) for both PDs and ArcCHECK. This was probable because the spherical shape of the prostate and simple surrounded organ at risk generated less complicated dose distribution than head and neck plans. Comparable results with others were observed as presented in **Table 4**.

Although EPID have higher detector resolution, ArcCHECK always showed slightly

Table 3 The summarize of gamma passing rate (%) comparison between measured and calculated planar dose of PDs and ArcCHECK dosimetry.

Tumor site	Gamma criteria	Portal dosimetry	ArcCHECK	P-value
Head and Neck	3%/3 mm	97.9 ± 0.9	97.8 ± 0.8	0.760
	3%/2 mm	95.7 ± 0.8	96.6 ± 0.8	0.003
	2%/2 mm	76.5 ± 2.6	79.8 ± 2.1	0.001
Prostate	3%/3 mm	99.1 ± 0.9	99.6 ± 0.5	0.080
	3%/2 mm	98.1 ± 1.0	98.7 ± 0.9	0.130
	2%/2 mm	97.0 ± 0.9	97.4 ± 0.7	0.161

Table 4 The comparison of gamma passing rate in this study and previous works.

Dosimeter	First Author	3%/3mm		3%/2mm		2%/2mm	
		H&N	Pelvis	H&N	Pelvis	H&N	Pelvis
PDs	This study	97.9	99.1	95.6	98.1	76.4	97.0
	Huang[21]	96.3	96.2	_	_	97.1	97.0
	Mohamed[22]	97.7	_	_	_	94.7	_
	Bailey[10]	95.3	98.2	_	_	_	_
	Woon[23]	97.8	_	96.5	_	96.3	_
ArcCHECK	This study	97.8	99.5	96.6	98.6	79.7	97.4
	Li[24]	98.2	98.5	_	_	89.6	90.9
	Thiyagarajan[25]	98.1	100.0	_	_	_	_
	Ahmed[26]	_	_	98.4	99.9	94.2	97.5
	Woon[23]	97.8	_	96.5	_	96.3	_

higher passing rate than those of measurements by PDs for all gamma criteria. This was due to the plans consisting of the large enough field size to contain all diodes in the transverse section. The diodes located on either side of the beamlet in transverse section would have a higher measured than planned dose. Therefore, a higher dose could be observed. The lower passing rate of PDs may be because the closely embedded chambers in EPID provided slightly higher sensitivity to detect the DD in high dose gradient region. Thus, a lower passing rate was presented.

The performance showed that PDs and ArcCHECK agreed well with each other for all gamma criteria. However, the passing rates reduced as tightening passing criteria was applied. This illustrated that detector configuration and resolution had impact on the calculation of the gamma index. For the tightening criteria (2%/2mm), the ratio between the detector grid spacing and the DTA would be less than the conventional gamma index of 3%/3mm. Our results presented that, if the stringent DTA was applied, a larger %DD was required to obtain the higher pass rate.

This work indicated that either 3%/3 mm or 3%/2 mm could achieve the action level of 95% with the comparable results for two types of dosimeters. However, 2%/2 mm might be too strict for our clinic. More measurement data and more samples are needed for further evaluation. Introduction of the errors by utilizing more high modulation treatment plans to study the detectors sensitivity of error detection will be performed in the future with additional other analysis such as percentage dose error (%DE) from dose volume histogram (DVH) and dose ratio comparison.

Conclusion

In this study, the gamma passing rates of the portal dosimetry system were comparable to those of the ArcCHECK measurements for all gamma criteria. The distinct differences were observed when the stringent gamma criteria were applied. The results revealed both systems to be suitable for patient-specific QA measurements for VMAT with 3%/3 mm or 3%/2 mm gamma criteria, depending on the status of clinic, both systems could be used interchangeably for routine pretreatment QA.

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