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Patient-Specific Quality Assurance of Volumetric Modulated Arc Therapy (VMAT): Amorphous Silicon Type Compared with Diode 3D Array Phantom

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Abstract Purpose: To compare the results of amorphous silicon pre-treatment QA type and diode 3D array phantom for delivery pre-treatment quality assurance of head and neck and prostate Volumetric Modulated Arc Therapy (VMAT) with various gamma criteria evaluation. Materials and Methods: The Varian amorphous silicon (aSi) Portal Imaging Devices and its software was used for portal dosimetry system (PDs). A diode 3D array cylindrical phantom (ArcCheck) was used for the studies. Eclipse-TPS with VMAT treatment planning and portal dose prediction software was used for planar dose calculations. The 30 VMAT patient plans of head and neck site and prostate site from the radiotherapy department, Lopburi Cancer Hospital, were created for verification plan on two different QA system PDs and ArcCheck. Thirty patients' treatment plans, each with 2 or 3 arcs, were delivered on the EPIDs of the Varian Linac iX (PDs) and ArcCheck, respectively. The measured planar dose matrices were compared with the planned dose and analysed using global gamma evaluation with 3%/3mm, 3%/2mm, and 2%/2mm. Results: All head and neck plans measured by PDs and ArcCheck had the average passing rate using 3%/3mm of 97.91%±0.93 and 97.81%±0.81, respecttively. When using 3%/2mm and 2%/2mm, the average passing rate measured by PD was 95.65%±0.83 and 76.48±2.55, while the results measured by ArcCheck were 96.63% ± 0.77 and 79.77±2, respectively. All prostate plans measured by PDs and ArcCheck using 3%/3 mm criteria have the average gamma passing rate of 99.10±0.86 and 99.56±0.47, respectively. The average gamma passing rate when using 3%/2mm was 98.11%±1.02 for PD and 98.67% ± 0.90 for ArcCheck, while the passing rate decreased to 97.05%±0.82 for PD and 97.46%±0.68 for ArcCheck when using 2%/2mm.The prostate cases illustrated no significant difference for all gamma criteria with a *P-value* greater than 0.05. Conclusion: The PDs system and ArcCheck can be considered QA tools for the verification plan of VMAT. The results of planning verification were comparable for the criteria of 3%/3mm and 3%/2mm. *(Thai Cancer J 2022;42:30-41)*

Keywords: Volumetric Modulated Arc Therapy (VMAT), Pre-Treatment QA Tool, Diode 3D Array Phantom, Amorphous Silicon Type

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การเปรียบเทียบการตรวจสอบการฉายรังสีแบบหมุนรอบตัวผู้ป่วยด้วยเครื่องมือวัดปริมาณรังสีชนิด Amorphous Silicon และไดโอดแบบสามมิติ

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กลุ่มงานรังสีรักษา สถาบันมะเร็งแห่งชาติ , [2] กลุ่มงานรังสีรักษา โรงพยาบาลมะเร็งลพบุรี

บทคัดย่อ การวิจัยนี้มีวัตถุประสงค์เพื่อศึกษาการเปรียบเทียบการตรวจสอบการฉายรังสีแบบหมุนรอบตัวผู้ป่วย (VMAT) ด้วยเครื่องมือวัดการกระจายปริมาณรังสีชนิด Amorphous Silicon และไดโอดแบบสามมิติในผู้ป่วยมะเร็งศีรษะและคอและมะเร็งต่อมลูกหมากโดยประเมินด้วยเกณฑ์ค่าการกระจายปริมาณรังสีเชิงคณิต (Gamma Criteria evaluation) โดยการใช้แผ่นรับภาพชนิด Amorphous Silicon ยี่ห้อ Varian Postal Image Device รุ่น LinaciX พร้อมโปรแกรมคำนวณปริมาณรังสี (Portal Dose System;PDs) และหุ่นจำลองชนิดไดโอดแบบสามมิติ ยี่ห้อ ArcCheck ที่โรงพยาบาลมะเร็งลพบุรีมีอยู่ตลอดจนโปรแกรมการคำนวณและวางแผนการรักษา ยี่ห้อ Eclipse ใช้ในการวางแผนการรักษาและคำนวณปริมาณรังสีด้วยเทคนิคการฉายรังสีแบบหมุนรอบตัวผู้ป่วยที่มีลักษณะแบบ 2-3 แนวหมุน จำนวน 30 ราย โดยสร้างปริมาณรังสีแนวระนาบเพื่อใช้ในเปรียบเทียบการกระจายปริมาณรังสีด้วยเครื่องมือตรวจสอบและวัดการกระจายปริมาณรังสีทั้งสองแบบ โดยกำหนดเกณฑ์ค่าความแตกต่างของปริมาณรังสีเชิงคณิตที่วัดได้จากเครื่องมือวัดรังสีทั้งสองระบบเปรียบเทียบกับการกระจายของปริมาณรังสีจากแผนการรักษาในตำแหน่งต่าง ๆ กำหนดเกณฑ์ค่าการกระจายปริมาณรังสีเชิงคณิต (Gamma Criteria)ที่ 3%/3 mm, 3%/2 mm และ 2%/2 mm ตามลำดับ ผลการศึกษาพบว่า ค่าเฉลี่ยอัตราการผ่าน (passing rate) ตามเกณฑ์ของการกระจายปริมาณรังสีเชิงคณิตจากการประเมินด้วยเครื่องมือวัดปริมาณรังสีชนิด(PDs)และหุ่นจำลองชนิดไดโอดแบบสามมิติ (ArcCheck) โดยกำหนดเกณฑ์ค่า Gamma Criteria ที่ 3%/3 mm, 3%/2 mm และ 2%/2 mm ของแผนการรักษาของผู้ป่วยโรคมะเร็งศีรษะและลำคอ พบว่ามีค่าเฉลี่ยเท่ากับ 97.91% ±0.93, 95.65%±0.83, 76.48%±2.55 และ 97.81%±0.81, 96.63%±0.77, 79.77%±2.00 ตามลำดับ และแผนการรักษาของผู้ป่วยโรคมะเร็งต่อมลูกหมาก พบว่ามีค่าเฉลี่ยเท่ากับ 99.10% ±0.86, 98.11%±1.02, 97.05%±0.82 และ 99.56%±0.47, 98.67%±0.90, 97.46%±0.68 ตามลำดับ ซึ่งพบว่าไม่มีความแตกต่างอย่างมีนัยสำคัญทางสถิติ ($P > 0.05$) สำหรับทุกแผนการรักษาของผู้ป่วยมะเร็งต่อมลูกหมาก สรุปได้ว่าเครื่องมือวัดปริมาณรังสี Amorphous Silicon (PDs) และไดโอดแบบสามมิติ (ArcCheck) สามารถใช้ในการตรวจสอบแผนการรักษาผู้ป่วยในการฉายรังสีแบบหมุนรอบตัวผู้ป่วย ที่กำหนดค่า Gamma Criteria เท่ากับ 3%/3 mm, 3%/2 mm

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Keywords: Volumetric Modulated Arc Therapy (VMAT), Pre-Treatment QA Tool, Diode 3D Array Phantom, Amorphous Silicon Type

Introduction

Volumetric Modulated Arc Therapy (VMAT) is radiotherapy treatment technique widely used for head and neck (H&N) and prostate cancer. Because it provide highly radiation dose distribution to the target while sparing the radiation dose to the close organ at risk (OAR)[1]. This treatment technique uses beams sequence generated by the multi-leaf collimator (MLC) with continuously moving gantry rotation, dose rate modulation and collimator angulation[2].

Due to the complexity of the VMAT dose distribution, implementation of pre-treatment quality assurance(QA) or verification is an essential procedure in clinical practice to ensure that the accuracy radiation dose is delivered to the patient as planned[3]. The systematic pre-treatment QA can detect the errors which leading to inaccurate doses of radiation causing side effects to patients[4]. The pre-treatment QA process for VMAT can be done with different measurement systems.

The pre-treatment QA devices intended and design for VMAT QA is diode 3D array phantom such as ArcCheck. Its detector characteristic (type and design) and its ability of VMAT QA has been many reported by authors[5-8]. The portal dosimetry system (PDs) has become another QA system for VMAT plan verification. PD system consist of electronic portal imaging devices (EPID) for obtain the dose image and the specialize analysis software for matching the dose image and predicted dose by the treatment planning system (TPS)[9]. This system was used because of its resolution, large detector density, large detector surface and friendly for user. There are many studies reported the use of PD system for VMAT pre-treatment QA[10-12].

Gamma evaluation is a common quantitative technique for assessment the agreement between measured dose and the planned dose by using gamma index (γ). The concept of gamma evaluation was descripted by Low et al[13]. At the reference point and all points of the matrix, an assumption is made that once the passing criteria are selected, either the dose-difference(DD) or distance-to agreement(DTA). AAPM Task Group 119 suggested the acceptance criteria of 3% DD and 3mm DTA[18,19]. The gamma passing rate of 90% - 95% with 10% threshold to get rid of background noise was also recommended[14]. However, number of studies have discussed the acceptance of gamma criteria by reducing the criteria to 2% DD and 2mm DTA or 1% DD /1mm DTA. They found the higher sensitivity of error detection[15-16].

This study aims to investigate the difference of two pre-treatment QA system (amorphous silicon pre-treatment QA type and diode 3D array phantom) when perform the plan QA for head and neck and prostate VMAT plans. The gamma passing rate with various gamma criteria will be applied to study of those two pre-treatment QA tools.

Materials and Methods

Amorphous Silicon Pre-Treatment QA Type (Portal dosimetry system (PDs))

PDs (Varian Medical system Palo Alto CA) corresponding to an image receptor Electronic Portal Imaging Device (EPID) model aS1000 that has a 30 x 40 cm^2 at source to detector distance (SDD) 100 cm with Amorphous Silicon (A-Si) semiconductor which has a 1024 x 768 pixel of active area and a pixel resolution of 0.39 mm. EPID is attached to the Varian Clinac iX by Exact arm. The portal dosimetry software version 13 which uses an algorithm to transfer the integrated images to a dose map for comparison with a dose map from the TPS. The details of PDs algorithm was descried by Van Esch et al[17]. Dark field and flood field were performed for EPID calibration with field size of 10 x 10 cm^2 and source to axis distance (SAD) 100 cm before measurement. The dark field calibration was done for background and noise correction while the flood field calibration was done for pixel sensitivity correction[11]. The detector was scaled to Calibration Unit (CU). The CU is calibrated in centi-gray (1 CU = 1 cGy)[11].

Diode 3D array phantom (ArcCheck)

ArcCheck (Sun Nuclear Inc, Melbourne, FL) is a 3D silicon diode detector . Its geometry cylindrical with 21 cm diameter and consists of 1386 detectors (0.019 mm^3) with a 1 cm detector spacing. The inherent detector is 2.85 cm. The device has accommodate with a MultiPlug insert inside in the center of the phantom. AC calibration was performed follow the manufacturer guidelines before measurement for 6 MV photon beam. The correction of detector sensitivity was the first step for detector array calibration dose 200 MUs delivered with a 10x10 cm^2 filed. In this process, the raw measurement of each detector was eliminated the relative response different for individual detector. The actual dose delivered to the diode detectors was entered in the vendor software (SNC Patient) and a calibration factor was obtained. The known delivered dose to the detectors was calculated using the TPS and the virtual phantom provided by the vendor with a density override of 1.15 g/cm^3. In the TPS, identified the depth of diode detector at 2.9 cm and the dose for 200 MUs delivered with a 10 × 10 cm^2 field was calculated and recorded.

Patients and Treatment Planning System (TPS)

30 patients with H&N cancer (n=15) and prostate cancer (n=15) who were treated in Lopburi Cancer Hospital between 2019 and 2020 were randomly selected for study and approved by hospital research ethics committee. Treatment planning technique by VMAT using 6 MV photon beams were selected retrospectively. Two arcs or three arcs were created with

a dose rate of 400 MU/min for each patient by Eclipse TPS version 13.6 (Varian Medical System, Palo Alto, CA, USA). For H&N plans, the prescribe dose ranged from 66-70 Gy. The treatment plan includes 2-3 dose level of 66-70 Gy (High risk CTV), 59.4 Gy (Intermediate risk CTV) and 54 Gy (Low risk CTV) with a fraction of 2-2.12 Gy. For prostate plans, the prescribe dose of 70-76 Gy with a fraction of 2 Gy were used.

Pre-treatment verification

To create treatment verification plan, the plan containing an actual fluence and calculated MLC leaf motion was exported to the QA tools: PDs and ArcCheck. PDs system will generate the calculated portal image and ArcCheck will recalculate all parameters as a planned dose map. All verification plans were delivered on a Clinac iX Linac (Varian Medical Systems) equipped with a Millennium 120 MLC.

For PDs, the source to EPID distance was set to 105 cm for portal image acquisition. A composite portal dose image was used to compare with the calculated dose by the TPS.

For ArcCheck, the detector is set isocentically with the SAD of 86.3 cm. The calculated dose by the TPS and the measured dose will be compared. The example of the comparison between measured and calculated dose with EPID and ArcCheck is shown in Figure 1 and Figure 2, respectively.

Evaluation protocol

Table 1 show the analysis protocol for planned and measured dose matrices. DD is the accepted dose difference. DTA is the distance difference accepted. Mode corresponds to the dose normalization mode. TH corresponds to the thresholding pixel criterion. 10% Dmax and 20% Dmax correspond to a thresholding of all the pixels, with a dose greater than or equal to 10% and 20% of the maximum dose of the plan. MLC CIAO + 1 cm correspond to a threshold of all the pixels included in Complete Irradiated Area Outline (CIAO) of the MLC incremented by 1 cm. PR is the minimum success criterion on the pixel percentage with a Gamma index less than one for the plan to be considered compliant. A 95% pass rate was used for gamma criterial of 3%/3mm and 3%/2mm and 90% pass rate was used for 2%/2mm.

Table 1 The analysis protocol for planned and measured dose matrices.

Gamma Critera Mode	Operation	Threshold	% Pass rate
3%/3mm	AC	10% Dmax	90%
	PDs	Field + 1 cm	
3%/2mm	AC	10% Dmax	90%
	PDs	Field + 1 cm	
2%/2mm	AC	10% Dmax	
	PDs	Field + 1 cm	80%

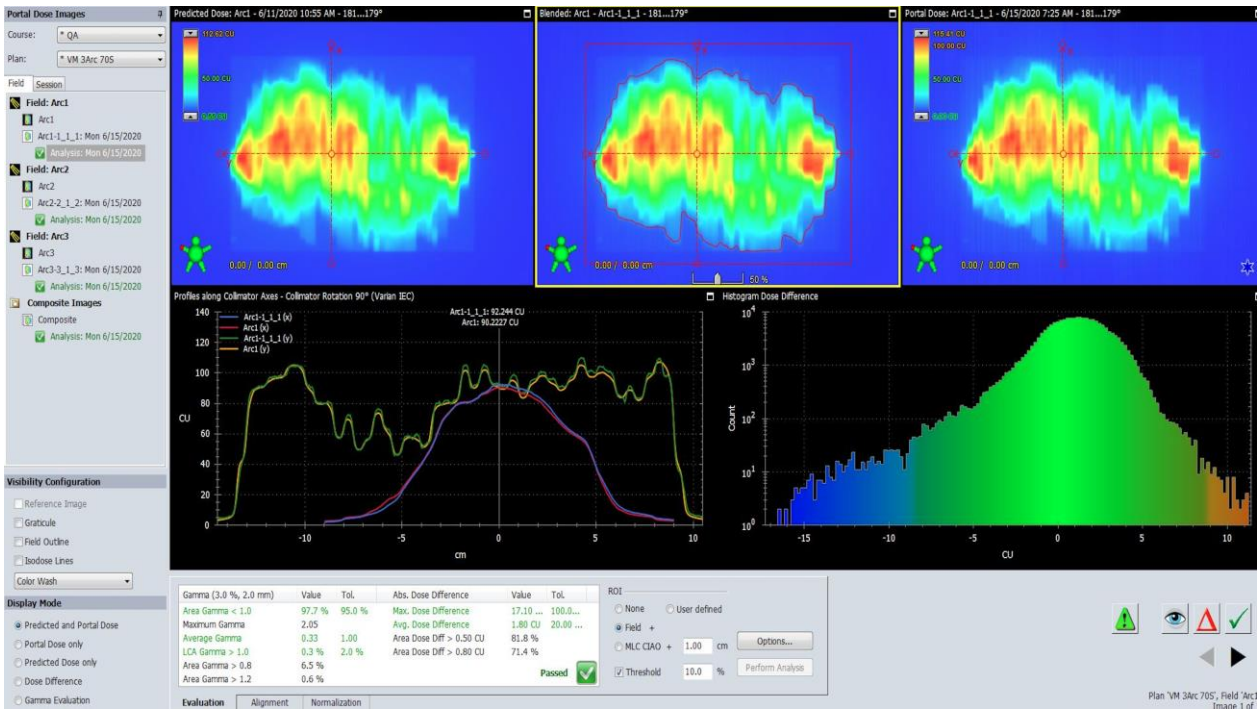

Figure 1 Comparison of PDs calculated (top left) and EPID measured planar dose distribution (top right) showing gamma analysis results (bottom) and line profile agreement (top middle).

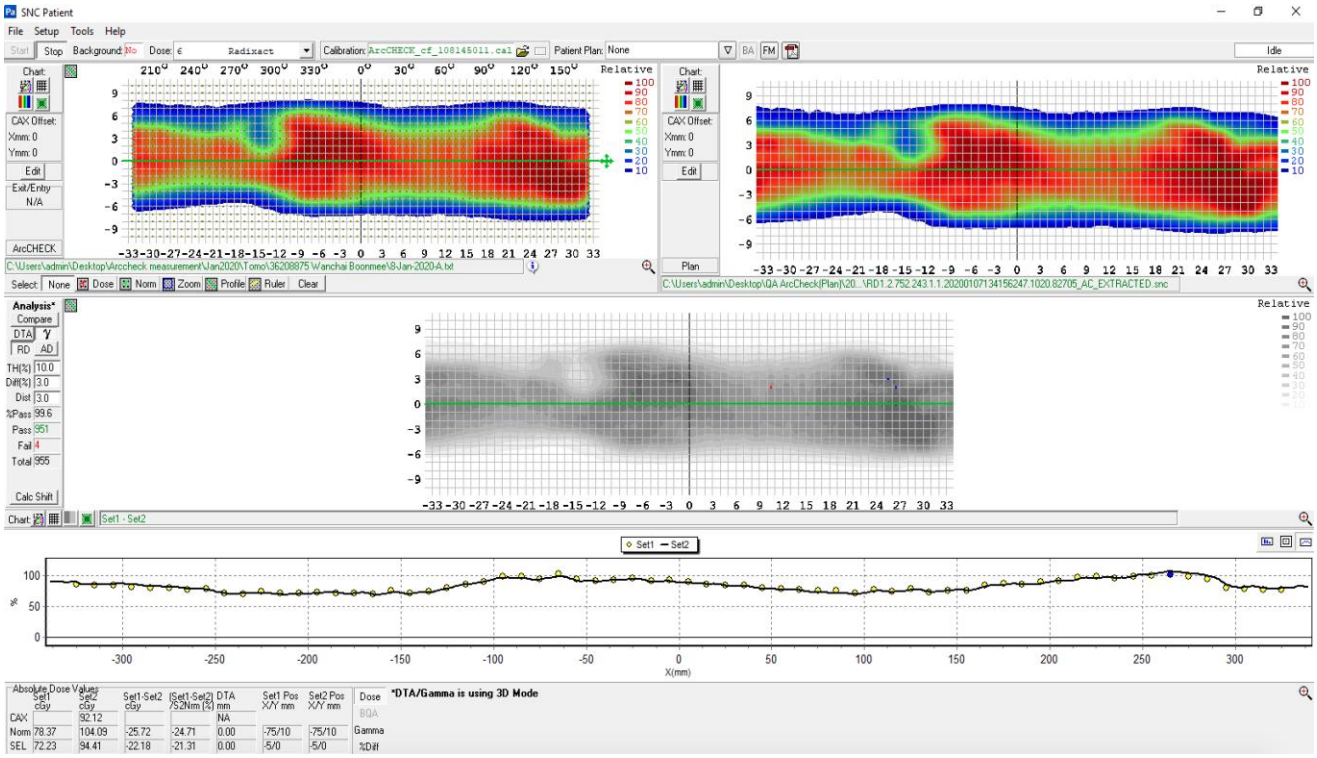

Figure 2 Comparison of TPS calculated (top right) and diode 3D array phantom(ArcCheck) measured planar dose distribution (top left) showing gamma analysis results and line profile agreement (bottom).

Results

The mean value and standard deviation (SD) of percent gamma passing rate for all gamma criteria of 30 plans using Amorphous Silicon Pre-Treatment QA Type (PDs) and Diode 3D array phantom (ArcCheck) are presented in Table 2 (head and neck) and Table 3 (prostate), respectively. Table 4 shows the comparison of mean value and standard deviation (SD) of gamma pass rate using various criteria. All head and neck plans measured by PDs and ArcCheck had the average gamma passing rate using 3%/3mm of 97.91%±0.93 and 97.81%±0.80, respectively. When using 3%/2mm and 2%/2mm, the average passing rate measured by PDs was greater than 95.65%±0.83 and 76.48 ± 2.55 while the results measured by ArcCheck was 96.63%±0.77 and 79.77±2.11, respectively. The result showed difference between measured dose for both Pre-Treatment QA system when decrease the criteria to 3%/2mm and 2%/2mm.

All prostate plans measured by PDs and ArcCheck when 3%/3mm criteria was applied has the average gamma passing rate of 99.10%±0.86 and 99.56%±0.47, respectively.The average gamma rate when using 3%/2mm was 98.11%±1.02 for PD and 98.67%±0.90 and for ArcCheck while the passing rate decreased to 97.05%±0.82 for PD and 97.46%±0.68 for ArcCheck.

Discussion

Both amorphous silicon pre-treatment QA type (PDs) and diode 3D array phantom (ArcCheck) dosimetry system currently operate at our hospital were tested and characterized before being used for clinical patient specific VMAT QA. This study investigated the PDs results comparing to the ArcCheck relative dose measurements by utilizing various types of gamma criteria evaluation.

The difference between the gamma passing rates of PDs and the ArcCheck measurements for both head and neck and prostate plans were comparable for all gamma criteria ($P > 0.05$) except for the criteria of 2%/2mm for head and neck cases (p value < 0.05).

By applying more stringent gamma criteria the passing rates of PDs and ArcCheck were less than 80% for head and neck because the gamma failing points were detected and increased. Especially at high dose gradient region or beam edge. The results showing statistically difference between PD and ArcCheck with p-value of 0.0006 (table 3). While the passing rate higher than 95% of prostate verification plans was presented when the stringent criteria were used.

Table 2 The mean value and standard deviation (SD) of % gamma passing rate for all gamma criteria of head and neck plans using amorphous silicon pre-treatment QA type (PDs) and diode 3D array phantom (ArcCheck)

Patient No.	Diagnosis	3%/3 mm		3%/2mm		2%/2mm	
		PDs	ArcCheck	PDs	ArcCheck	PDs	ArcCheck
1	Nasopharynx	98.20	97.10	97.00	97.50	78.00	81.20
2	Neck node	97.80	98.50	96.20	96.90	75.00	80.00
3	BOT	98.20	96.90	96.70	97.00	79.40	79.00
4	Buccal	98.50	97.80	95.60	97.60	77.60	82.50
5	Lower gum	98.50	99.00	95.90	97.50	74.70	79.30
6	Soft palate	99.90	97.60	95.90	96.80	78.20	80.10
7	Tongue	96.00	96.00	94.90	96.00	69.90	73.70
8	Paranasal sinus	98.70	97.80	94.90	96.10	73.60	77.00
9	FOM	96.60	98.00	94.00	96.40	79.90	80.30
10	Esophagus	98.00	98.30	95.00	95.20	76.90	82.00
11	Esophagus	98.00	97.80	95.00	95.20	74.80	80.50
12	Tonsil	97.90	98.00	96.30	97.20	78.30	80.30
13	Pharynx	97.40	98.30	95.00	96.90	77.00	80.80
14	Supraglottic	96.90	97.00	95.90	96.10	76.50	80.20
15	FOM	98.00	99.00	96.50	97.00	77.40	79.70
Average		97.91	97.81	95.65	96.63	76.48	79.77
SD		0.93	0.81	0.83	0.77	2.55	2.11

Table 3 The mean value and standard deviation (SD) of % gamma passing rate for all gamma criteria of prostate plans using amorphous silicon pre-treatment QA type (PDs) and diode 3D array phantom (ArcCheck)

Patient No.	Diagnosis	3%/3mm		3%/2mm		2%/2mm	
		PDs	ArcCheck	PDs	ArcCheck	PDs	ArcCheck
1	Prostate	99.00	99.70	97.00	98.90	95.70	96.00
2	Prostate	99.40	99.90	98.00	99.40	96.70	97.70
3	Prostate	100.00	99.50	99.00	97.40	96.00	98.00
4	Prostate	100.00	99.10	97.00	97.80	96.00	96.70
5	Prostate	98.00	100.00	98.00	98.40	97.80	97.00
6	Prostate	100.00	99.30	97.00	99.40	97.40	98.00
7	Prostate	99.90	98.90	99.00	97.90	98.00	98.00
8	Prostate	98.00	99.20	97.00	98.10	96.80	97.00
9	Prostate	99.70	100.00	98.00	99.00	96.80	97.00
10	Prostate	99.50	100.00	97.00	99.00	97.00	97.50
11	Prostate	99.90	100.00	99.90	99.60	98.40	98.00
12	Prostate	98.00	100.00	99.90	100.00	98.20	98.70
13	Prostate	99.10	100.00	98.10	99.90	97.30	97.90
14	Prostate	98.00	99.00	98.80	98.00	96.50	97.00
15	Prostate	98.00	98.80	98.00	97.20	97.20	97.40
Average		99.10	99.56	98.11	98.67	97.05	97.46
SD		0.86	0.47	1.02	0.90	0.82	0.68

Table 4 The comparison between the gamma passing rates of amorphous silicon pre-treatment QA type (PDs) and diode 3D array phantom (ArcCheck) measurements.

Tumor Site	Gamma Criteria	Portal Dosimetry	ArcCheck	P
Head and Neck	3%/3mm	97.90 ± 0.93	97.80 ± 0.80	0.7600
		(96.60 ~ 99.90)	(96.90 ~ 99.00)	
	3%/2mm	95.65 ± 0.83	96.62 ± 0.77	0.0025
		(94.00 ~ 97.00)	(95.2 ~ 97.50)	
	2%/2mm	76.46 ± 2.55	79.77 ± 2.11	0.0006
		(69.90 ~ 79.40)	(73.70 ~ 82.50)	
Prostate	3%/3mm	99.10 ± 0.86	99.56 ± 0.47	0.0800
		(98.00 ~100.00)	(98.80 ~ 100.00)	
	3%/2mm	98.11 ± 1.02	98.67 ± 0.90	0.1300
		(97.00 ~ 99.90)	(97.20 ~ 100.00)	
	2%/2mm	97.05 ± 0.81	97.46 ± 0.68	0.1508
		(95.70 ~ 98.40)	(96.00 ~ 98.70)	

From simple plan verification (prostate), there is very good agreement with all acceptance criteria for both PDs and ArcCheck dosimetry system with the passing rate higher than 95%. ArcCheck always shows slightly higher passing rate than those of measurement by PDs for prostate cancer. This is mainly due to the plan consist of the field size that is large enough to contain all diodes in the transverse section. The diodes located on either side of the beamlet in transverse section will have a higher measured than planned dose. Thus, a higher dose can be observed.

Further study on the correlation between the measurement of PDs and ArcCheck will be performed in the future by utilizing more high modulation treatment plan.

Conclusion

The gamma passing rates of amorphous silicon pre-treatment QA type (PDs) were comparable to those of the diode 3D array phantom (ArcCheck) measurements for all gamma criteria. There distinctive differences were observed when the stringent gamma criteria were applied. Therefore, both dosimeter system can be used as an alternative to each other for patient- specific QA of both VMAT with suitable gamma criteria to ensure clinically acceptable dose errors.

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