Physica Medica (2013) **29**, 295–303

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ORIGINAL PAPER

Evaluation of the ArcCHECK QA system for IMRT and VMAT verification

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Received 7 October 2011; received in revised form 9 April 2012; accepted 14 April 2012
Available online 12 May 2012

KEYWORDS
IMRT;
VMAT;
Diode array;
Quality assurance

Abstract The purposes of this study were to perform tests for the ArcCHECK QA system, and to evaluate the suitability of this system for IMRT and VMAT verification. The device was tested for short term reproducibility, dose linearity, dose rate dependence, dose per pulse dependence, field size dependence, out of field dependence and directional dependence. Eight simple plans that each used four beams of different field sizes as well as IMRT and VMAT plans for various organs of 10 patients were measured by ArcCHECK. The phantom data was then compared with ion chamber measurements and planned results. The ArcCHECK diodes performed well for all tests except directional dependence, which varies from a minimum of −4.9% (seen only when the beam is incident on the diode at 180°) to a maximum of 9.1% (approximately at 105°). For simple plan verification, the absolute dose pass rates of γ index (3%/3 mm) were almost identical. They had an average pass rate of 94.6% ± 1.3% when the field size was ≤20 cm in the *X* direction (right to left direction), but the pass rate fell rapidly when the field size was >20 cm in the *X* direction. For all patient-specific IMRT and VMAT QA, the pass rates exceeded 95% and 93%, respectively, and high reproducibility of these results has been observed from week to week. The comparative measurements show that the ArcCHECK QA system is completely suitable for clinical IMRT and VMAT verification.

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1120-1797/$ - see front matter
http://dx.doi.org/10.1016/j.ejmp.2012.04.005

Introduction

Intensity-modulated radiation therapy (IMRT) is a complicated treatment technique. IMRT has been shown to be superior to three-dimensional conformal radiotherapy (3DCRT), especially for patients with complex-shaped target volumes [1]. IMRT plans are much more complex because they contain multiple segments. Thus dosimetry verification and quality assurance (QA) for IMRT are important [2].

Volumetric modulated arc therapy (VMAT) is a novel treatment delivery technique. VMAT treatments can be delivered efficiently and accurately in single or multiple arcs [3,4]. VMAT delivery requires more strict mechanical performance for the linear accelerator than IMRT delivery because of the simultaneous gantry speed, dose rate and multileaf collimator (MLC) aperture shape variations. Therefore, dosimetry verification and QA for VMAT are required before clinical delivery [5].

2D detector arrays, such as MapCHECK (Sun Nuclear, Melboume, FL) and MatriXX (IBA Dosimetry, GmbH, Schwarzenbrook, Germany), are often used to validate planar dose distributions [6–13]. A three-dimensional (3D) diode array (Delta4, ScandiDos AB, Uppsala, Sweden) that consists of 1069 p-type Silicon diodes in a crossed array inside a cylindrical polymethylmethacrylate (PMMA) phantom has recently been described [14–16].

A new 3D diode array (ArcCHECK, Sun Nuclear, Melbourne, FL) has been developed for routine QA of IMRT and VMAT [17,18]. ArcCHECK is a cylindrical water-equivalent phantom with a three-dimensional array of 1386 diode detectors with 10 mm detector spacing. The device geometry is cylindrical. The detectors spiral down the cylinder of 21 cm diameter and length in order to increase the spatial sampling rate and reduce detector overlap from the beam's eye view (BEV). The active detector size is 0.8 mm × 0.8 mm. There is a 15 cm diameter cavity in the phantom which can hold an insert with an ionization chamber for absolute dose measurement. The ArcCHECK measures in 50 ms intervals, saves all measurement data as a function of time, and makes both relative and absolute dose measurements.

As QA equipment, ArcCHECK should be accurate enough for absolute dose measurement. Therefore, it is necessary to understand the characteristics of ArcCHECK. Kozelka et al. reported the repetition rate, field size dependence and angular position dependence of ArcCHECK [19]. Some differences were noted at the lower repetition rates with the plug in place, and field size dependence and angular position dependence were obvious. Feygelman et al. reported response equalization of the individual detectors, minor field size dependence and angular response dependence for ArcCHECK [20].

It should be noted that the dose calculation algorithm in treatment planning system (TPS) could affect the verification results in comparing the measured and calculated doses. Petoukhova et al. reported the comparison of the absolute dose distributions measured and calculated in iPlan RT Dose with Monte Carlo (MC) and Pencil Beam (PB) dose algorithms at the cylinder of the ArcCHECK diode array for HybridArc plans [21]. The PB calculations significantly differ from the ArcCHECK measurements so that the MC algorithm is found to be superior to the PB algorithm in the calculation of the HybridArc plans. Kozelka et al. studied a number of sophisticated treatment planning algorithms for their ability to handle a large air cavity in the phantom of ArcCHECK [19]. They found that some algorithms in the convolution/superposition family were not sufficiently accurate in predicting the exit dose in the presence of a 15 cm diameter air cavity.

In this paper, we show more details of the specific performance characteristics of the ArcCHECK QA system, which contain short term reproducibility, dose linearity, dose rate dependence, dose per pulse dependence, field size dependence, out of field dependence and directional dependence. A total of 10 plans were used to evaluate this device for IMRT and VMAT delivery verification, and the plans measured stability was also validated.

Materials and methods

Performance tests

Several basic tests were carried out to examine specific performance characteristics of the ArcCHECK QA system. All tests were carried out on an Elekta Synergy accelerator using a nominal energy of 6 MV X-rays with 1 cm leaf width MLCs (Elekta, Crawley, UK). A PTW 0.125 cc ion chamber was used for absolute dose measurement at the isocenter (Fig. 1a). The 5.00.00 version of the ArcCHECK software was used for all tests. The accelerator was previously commissioned for IMRT and VMAT [22,23]. The dose distributions were calculated using the Pinnacle v.9.0 (Philips Radiation Oncology Systems, Fitchburg, WI) TPS. Pinnacle used the superposition-convolution algorithm, which is a model-based method [24]. The planned doses were calculated with a voxel size of 3 mm × 3 mm × 3 mm.

Short term reproducibility

The ArcCHECK diode array short term reproducibility over a measurement session was evaluated by calculating the standard deviation (SD) and the maximum deviation (MD) of 10 consecutive readings made by the 6 central diodes in the radiation field. These measurements were acquired with a SAD of 100 cm (SSD of 86.7 cm). The field size was 10 cm × 10 cm and the dose delivery was 100 MU. An ion chamber was used for absolute dose at the isocenter so as to correct for any variation in accelerator output. The measured doses made by the ArcCHECK diodes were normalized to the dose measured by the ion chamber, and the ten results taken by each diode were normalized to the average.

Dose linearity

Measurements were made with 10 cm × 10 cm field size and 100 cm SAD geometry. The dose linearity response of the ArcCHECK diode A (−5, 0) (The coordinates are defined as following: if the phantom is cut from its bottom and all diodes are spread on the same plane, and it defines the central point of the spreading phantom as coordinate origin, *X* and *Y* axis as left-to-right and gantry-to-target directions, respectively, thus the coordinates of diode A are (−5 mm, 0 mm) as shown in Fig. 2b) was evaluated by measuring its output for beam deliveries of 2–500 MUs. The

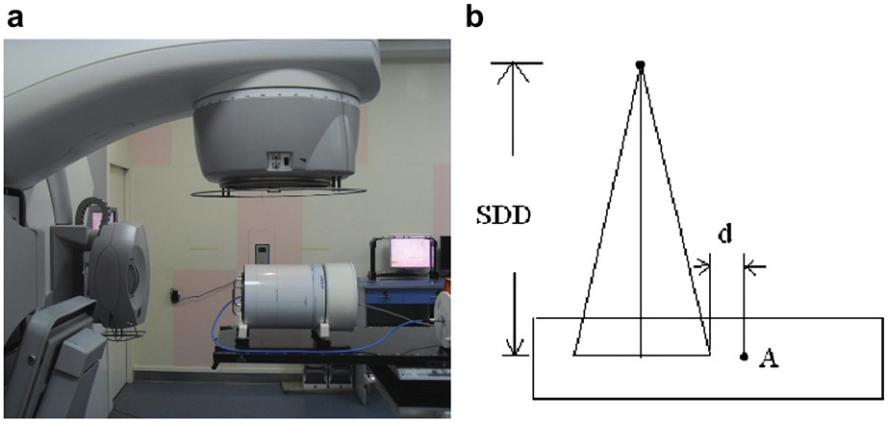

Figure 1 (a) For clinical IMRT/VMAT QA, a PTW 0.125 cc ion chamber was used for absolute dose at the isocenter and was inserted in the ArcCHECK phantom. The crosshairs inscribed on three sides of the phantom were aligned with the room lasers. (b) For the out of field dependence tests, the ion chamber in the slab solid water phantom and the diode detector of ArcCHECK are both positioned at point A, *d* is the out of field distance and the source-to-detector distance (SDD) is 89.6 cm.

absolute dose was measured by the ion chamber at the isocenter so as to correct for any variation in accelerator output. Four measurements were taken for each beam to eliminate the uncertainty in the measurement. Each measurement of ArcCHECK was normalized to the associated measurement of the ion chamber.

Dose rate (pulse rate) dependence

Measurements were made with 10 cm × 10 cm field size, 100 cm SAD geometry and 100 MU delivery. The dose rate dependence of diode A was evaluated by measuring its output for beam dose rates of 29, 59, 118, 236 and 473 MU/min. The ion chamber was used for absolute dose at the isocenter so as to correct for any variation in accelerator output. Four measurements were taken for each beam to eliminate the uncertainty in the measurement. Each measurement of ArcCHECK was normalized to the associated measurement of ion chamber.

Dose per pulse dependence

Measurements were made at 10 cm × 10 cm field size and 100 MU delivery. The dose per pulse dependence of diode A was evaluated by measuring its output for 85 cm, 100 cm, 115 cm and 125 cm SAD geometry (SAD distances are to the center of the ArcCHECK device). The ArcCHECK results were referenced to the measurements made with the ion chamber inserted in a slab solid water phantom under the same irradiation conditions (source-to-detector distances (SDD) were 74.6 cm, 89.6 cm, 104.6 cm and 114.6 cm, respectively, and SDD of ion chamber and diode A were consistent). Four measurements were taken for each beam to eliminate the uncertainty in the measurement. The phantom was scanned by fan-beam computed tomography (FBCT) and imported into Pinnacle, and each measurement was simulated in the TPS. The ArcCHECK results were compared with TPS calculated dose and ion chamber measured results, respectively.

Field size dependence

Measurements were made at 100 cm SAD geometry and 100 MU. The field size dependence of diode A was evaluated by measuring its output for 5 cm × 5 cm, 10 cm × 10 cm, 15 cm × 15 cm and 20 cm × 20 cm field sizes. ArcCHECK results were referenced to the measurements made by the

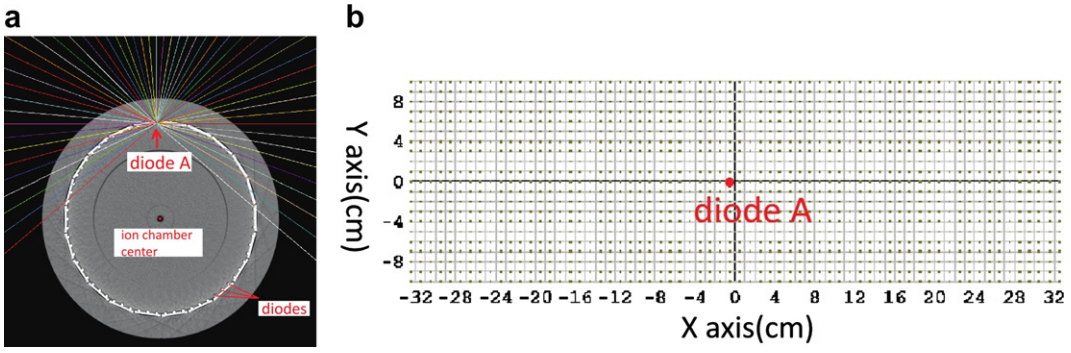

Figure 2 (a) When the crosshairs of phantom inscribed on three sides of the phantom are aligned correctly with the room lasers, the SAD is 100 cm and the ion chamber is at the isocenter. For the directional dependence test, the diode A is at the isocenter, and the gantry angles from 230° to 130° at intervals of 5° are shown in the figure. (b) If the phantom was cut from its bottom, all diodes will be spread on the same plane, and it defines the central point of the spreading phantom as coordinate origin, *X* and *Y* axis as left-to-right and gantry-to-target directions respectively, thus the coordinates of diode A are (−5 mm, 0 mm).

ion chamber inserted in a slab solid water phantom under the same irradiation conditions. Four measurements were taken for each beam to reduce the uncertainty in the measurements. Each measurement was calculated in Pinnacle TPS. The ArcCHECK results were compared with TPS calculated dose and ion chamber measured results.

Out of field dependence

The out of field dependence (response to scatter radiation) of the ArcCHECK diode detector was evaluated by measuring its output for 5 cm × 5 cm, 10 cm × 10 cm and 15 cm × 15 cm field sizes. The measurements were made at 100 cm SAD geometry (crosshairs inscribed on three sides of phantom are aligned with the room lasers) and 100 MU delivery. The ion chamber inserted in a slab solid water phantom was used with an out of field distance of 1.76−5.76 cm under the same irradiation conditions (Fig. 1b). Four measurements were taken for each beam to reduce the uncertainty in the measurements. The results were compared with ion chamber measurement results.

Directional dependence

The diodes in the phantom have an inherent angular response to radiation. Measurements were made with 10 cm × 10 cm field size and 100 MU dose delivery. Firstly, diode A was positioned at the isocenter with source-to-detector distance (SDD) of 100 cm. The responses of the diode with clockwise gantry rotation from 230° to 130° were measured with an interval of 5° as shown in Fig. 2a. Secondly, to avoid the effect of couch attenuation, the phantom was rotated 180° around its axis, and diode A was repositioned at the isocenter. The responses of the diode to clockwise gantry angles from 270° to 90° were measured with an interval of 5°. Four measurements were taken at each gantry angle to reduce the uncertainty in the measurements. TPS was used to calculate the doses of three selected diodes at each measurement situation for comparison. The diode coordinates are (−5, 0), (−5, 10) and (−5, −10) respectively. The results of each diode were normalized to 0° incident angle.

Comparison studies

Having tested the basic characteristics of ArcCHECK, we further evaluated the ArcCHECK QA system for verification of simple, IMRT, and VMAT plans. The optimization algorithm was direct machine parameter optimization (DMPO) for step-and-shoot IMRT (sIMRT) plans and SmartArc for VMAT plans. We used the pass rate of γ index to compare the measured dose distributions from ArcCHECK with the calculated dose distribution from TPS, and the percent dose difference and dose to agreement criteria of 3%/3 mm and 2%/2 mm were adopted for comparison. The dose difference was calculated with the global normalization.

Simple plan verification

Eight simple plans with four symmetric rectangular fields were verified by the ArcCHECK QA system. The field sizes of the four beams were the same in each plan and their gantry angles were 0°, 90°, 180° and 270°. The field sizes of these plans were 10 cm × 30 cm, 12 cm × 30 cm, 14 cm × 30 cm, 16 cm × 30 cm, 18 cm × 30 cm, 20 cm × 30 cm, 22 cm × 30 cm and 24 cm × 30 cm. To compare the measured dose distributions by ArcCHECK with the calculated dose distributions by TPS, we evaluated the absolute dose pass rate of γ index (with dose non-normalized).

sIMRT and VMAT planning patient-specific verification

Ten sIMRT clinical plans were selected randomly and included several typical treatment sites: six nasopharyngeal cancers, one prostate cancer, one cervix uteri cancer, one esophageal cancer and one rectal cancer. We designed a VMAT plan with the same dose prescription for each patient. The ArcCHECK QA system and ion chamber were used for sIMRT and VMAT patient-specific verification. The details of the treatment plans for these patients are summarized in Table 1. All VMAT plans of nasopharyngeal cancers consisted of two 360° arcs due to its complicated target shapes. Other VMAT plans consisted of one 360° arc. The minimum segment size and minimum MU used in optimization for all sIMRT plans are 4 cm^2 and 4 MU, respectively. All plans satisfied the clinical dose limitations according to our institutional IMRT protocols.

The VMAT plans were then computed on CT images of ArcCHECK phantom. In order to compare the measured dose distributions by ArcCHECK with the calculated dose distributions by TPS, we evaluated the pass rate of γ index. To compare the absolute dose at the isocenter measured by the ion chamber with the dose calculated by TPS, we validated the calculation precision at the isocenter. A paired *t*-test was used to calculate the statistical difference of all results between IMRT and VMAT verification, and *p*-values less than 0.05 were considered statistically significant.

Due to the complexity of nasopharyngeal plans, the sIMRT and VMAT plans of six nasopharyngeal patients were measured three times week by week. The purpose of this work was to validate the stability of the planning verification.

Table 1 The description of the plans designed for 10 selected patients. The dose prescription of the VMAT plan was the same as that of sIMRT for each patient, and all plans satisfied the clinical dose limits stated in our institutional IMRT protocols.

	Number of patients	SIMRT		VMAT	
		Beams	Segments	Degree	Control points
Nasopharyngeal cancer	6	7	120	720	182
Prostate cancer	1	5	59	360	91
Cervix uteri cancer	1	5	48	360	91
Rectal cancer	1	5	40	360	91
Esophageal cancer	1	7	44	360	91

Results

Performance tests

Short term reproducibility

Figure 3 shows the short term reproducibility of ArcCHECK. For the six diodes evaluated over 10 irradiations, the standard deviation is 0.05%, and the maximum deviation is 0.12%.

Dose linearity

Figure 4 shows the dose linearity of ArcCHECK compared to accelerator output. The R^2 value is better than 0.99999. Figure 5 shows the dose linearity of ArcCHECK compared with ion chamber results which can eliminate the instability of accelerator delivery. When its output was 2 MU, the dose response error was maximal at −0.88% (the dose response is normalized to the result of the 100 MU delivery). When its output was greater than 10 MU, the dose response variations were within ±0.2%.

Dose rate (pulse rate) dependence

The dose rate dependence of diode A for repetition dose rate ranging from 29 to 473 MU/min is shown in Fig. 6. Curves are normalized to the measurements at maximum dose rate. Eliminating the effect of accelerator delivery, the diodes exhibited a monotonically increasing sensitivity variation of 1.1% with increasing the dose rate. Furthermore, the ion chamber exhibited 0.6% variation, which can be attributed to the variation of dose delivery of the linear accelerator as a function of dose rates. The dose rate dependence of the diode may be a concern for dynamic IMRT and VMAT delivery.

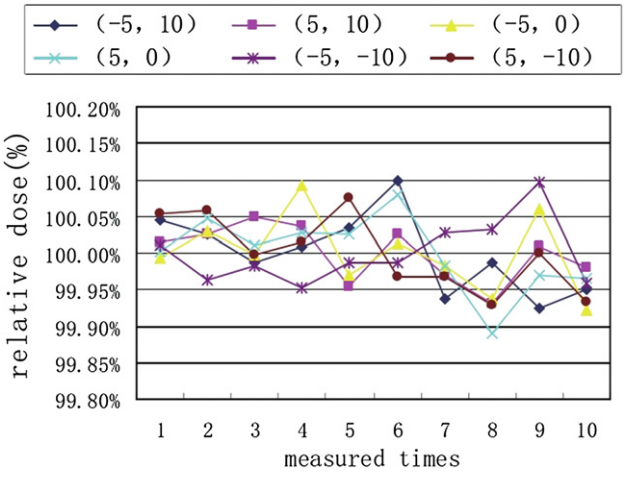

Figure 3 The short term reproducibility of six ArcCHECK diodes. If the phantom was cut from its bottom, all diodes will be spread on the same plane, and it defines the central point of the spreading phantom as coordinate origin, *X* and *Y* axis as left-to-right and gantry-to-target directions respectively, thus the coordinates of six diodes are showed in the figure and the unit of length is millimeter. These detectors are in the middle part of the irradiation field. Ten results of each diode are normalized to the average.

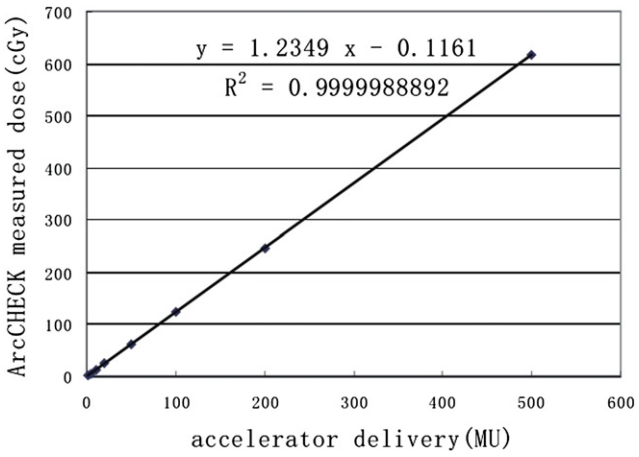

Figure 4 The dose linearity of the ArcCHECK detector compared with accelerator delivery, and the selected diode A coordinate is (−5, 0). The beam deliveries are from 2 to 500 MUs. R^2 is better than 0.99999.

Dose per pulse dependence

The dose per pulse dependence of diode A for SAD of 85−125 cm is presented in Fig. 7. By comparing with calculated and measured doses, the diode response exhibited a decreasing sensitivity variation of 1.4% and 0.6% with increasing SAD of 85−125 cm, respectively. Jursinic et al. [7] and Letourneau et al. [8] reported similar results with regard to MapCheck diodes.

Field size dependence

Figure 8 shows field size dependence of diode A for field sizes of 5 × 5 to 20 × 20 cm^2. To compare the results of ArcCHECK with calculated dose and measured dose by ion chamber, the diodes response exhibited a monotonically increasing sensitivity variation of 1.2% and 1.7% with increasing the field size, respectively.

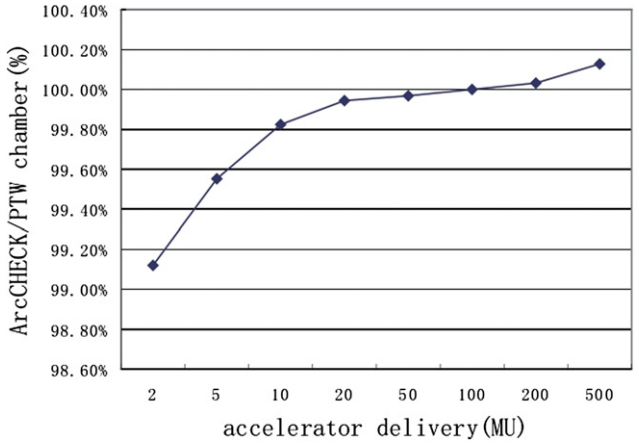

Figure 5 The dose linearity of ArcCHECK detector compared with ion chamber, and the diode A coordinate is (−5, 0). The beam deliveries are from 2 to 500 MUs. Each measurement of ArcCHECK was normalized to associated measurement of the ion chamber and all deliveries are normalized to the result of 100 MU delivery.

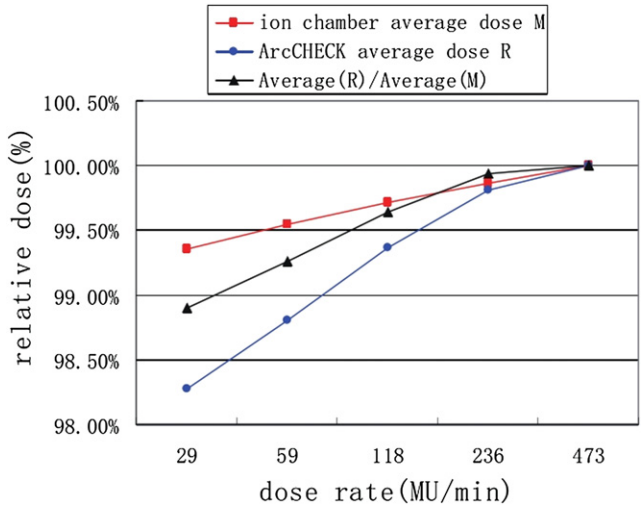

Figure 6 The dose rate dependence of the ArcCHECK diode for a repetition rate ranging from 29 to 473 MU/min, and the diode A coordinate is (−5, 0). All curves are normalized to the tests of maximum dose rate. The red and blue points indicate the measured average dose by ion chamber and ArcCHECK, respectively, and the black points indicate the ratio of diode to ion chamber. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

Out of field dependence

Out of field dependence of ArcCHECK for field sizes of 5 × 5 cm^2 to 15 × 15 cm^2 and out of field distances of 1.76 cm—5.76 cm are shown in Table 2. For all field sizes and out of field distances, the measured doses of ArcCHECK were higher than the doses of ion chamber and exhibited an increasing trend with increasing field size. The average errors of all tests for the field sizes of 5 × 5 cm^2, 10 × 10 cm^2 and 15 × 15 cm^2 are 0.09%, 0.40% and 0.88% on the high side, respectively.

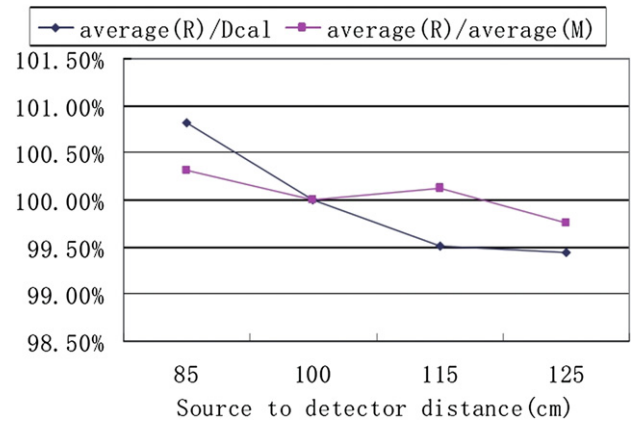

Figure 7 The dose per pulse dependence of ArcCHECK diode for SAD of 85—125 cm, and the diode A coordinate is (−5, 0). Average(*R*)/Dcal indicates the ratio of ArcCHECK measured dose to TPS calculated dose, and average(*R*)/average(*M*) indicates the ratio of ArcCHECK to ion chamber measured dose.

Directional dependence

Figure 9 shows the directional dependence of three selected diodes normalized to their respective responses at the 0° incident angle. The selected diodes made an angle of 8.18° with the beam when the gantry angle was 0°. All diodes exhibited similar directional response pattern. When the incident angle was smaller than 60°, the directional response variation is less than ±1%. The directional response sensitivity was highest (9.1%) when the incident angle was about 105° and lowest (−4.9%) when the incident angle was 180°. Furthermore, we observed that the directional response sensitivity tended to fluctuate when irradiated from either side of the diodes. A 14% maximum variation was observed from 105° to 180° incident angle, giving an average of 0.19% response change per degree. These results are similar to reports by Yan et al.'s [18].

Comparison studies

Simple plan verification

Figure 10 shows the absolute dose pass rate at the γ (3%/3 mm) level with eight simple plan verifications using the ArcCHECK QA system. When the field size was less than 20 cm in the direction *X* (RL), the absolute dose pass rates were almost identical, and the average pass rate was 94.6 ± 1.3%. When the field size was larger than 20 cm in the direction *X*, the pass rate fell rapidly to 64.9% associated to field size of 24 cm in the direction *X*.

sIMRT and VMAT planning patient-specific verification

In Table 3, the fraction of passed γ values for the delivered plans compared to the planned doses were shown for IMRT and VMAT plans of ten patients. For all IMRT and VMAT plans, the pass rates at the γ (3%/3 mm) level exceeded 95% and 93%, respectively, and the average pass rates were 97.5% and 95.9% respectively. While the average pass rates at the γ (2%/2 mm) level were 89.6% and 87.6%, respectively. For the complicated plans re-delivered over several

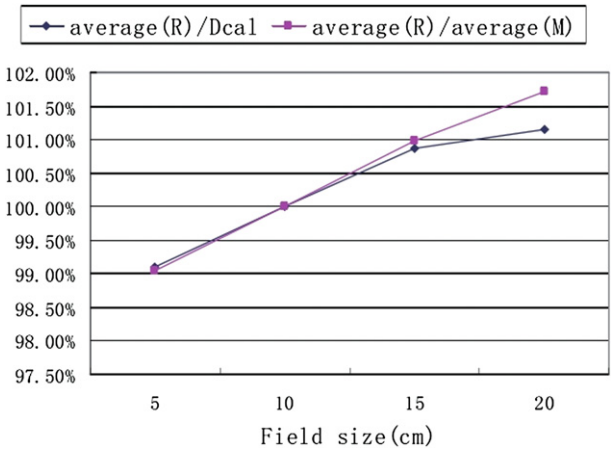

Figure 8 The field size dependence of ArcCHECK diode for field sizes of 5 × 5 cm^2 to 20 × 20 cm^2, and the diode A coordinate is (−5, 0). Average(*R*)/Dcal indicates the ratio of ArcCHECK measured dose to TPS calculated dose, and average(*R*)/average(*M*) indicates the ratio of ArcCHECK to ion chamber measured dose.

Table 2 Out of field dependence of ArcCHECK for field sizes of 5 × 5 to 15 × 15 cm^2 and out of field distances of 1.76—5.76 cm. For comparison the ion chamber inserted in a slab solid water phantom was used to measure doses under the same irradiation conditions.

Field size (cm^2)	Out of field distance (cm)	ArcCHECK dose *R* (cGy)	Ion chamber dose *M* (cGy)	[a](*R*-*M*)/Mcentral × 100%
5 × 5	1.76	1.92	1.80	0.11%
	2.76	1.16	1.01	0.13%
	3.76	0.82	0.70	0.11%
	4.76	0.58	0.55	0.03%
	5.76	0.54	0.45	0.07%
10 × 10	2.52	3.22	2.66	0.46%
	3.52	2.41	1.87	0.44%
	4.52	1.83	1.38	0.36%
	5.52	1.46	1.06	0.33%
15 × 15	2.28	5.25	4.10	0.90%
	3.28	3.97	2.88	0.86%

[a] Mcentral is the central dose of each field size.

weeks, the difference is not statistically significant ($p > 0.05$ with a paired *t*-test). There was also very good agreement from week to week as the mean standard deviation of passed gamma values is 0.47% and the maximum standard deviation is 1.06%. For all delivered IMRT and VMAT plans that compared ion chamber measurements to the planned isocenter doses, the maximum dose errors are 1.84% and 3.98% and the average dose errors are −0.62% ± 0.78% and 1.74% ± 2.01%, respectively.

Discussion

Performance tests

ArcCHECK N-type diodes are identical to those used in MapCheck, so the discrepancy between the characteristics of the two devices is mainly due to the changes of buildup and backscatter conditions induced by the different phantom geometries. This obviously affects the directional response. In our study, the short term reproducibility, dose linearity, dose rate dependence, dose per pulse dependence, field size dependence and the out of field dependence of ArcCHECK were acceptable in the clinical QA. The good field size dependence and out of field dependence implies that the ArcCHECK diodes are less sensitive to low energy scattered photons, which is an important aspect of IMRT/VMAT QA due to the complexity of the plans and the magnitude of segment numbers.

Kozelka et al. reported that the standard deviation for all the diodes in a hollow phantom configuration did not exceed 0.3% for repetition rates of 40 MU/min and up, and the difference between all tested accelerators did not exceed 0.2% in the range of average dose rate encountered in their work (250—600 MU/min). They also found that the largest difference between the hollow and plugged configurations was observed for the larger field sizes [19]. Feygelman et al. reported that the percentage measured

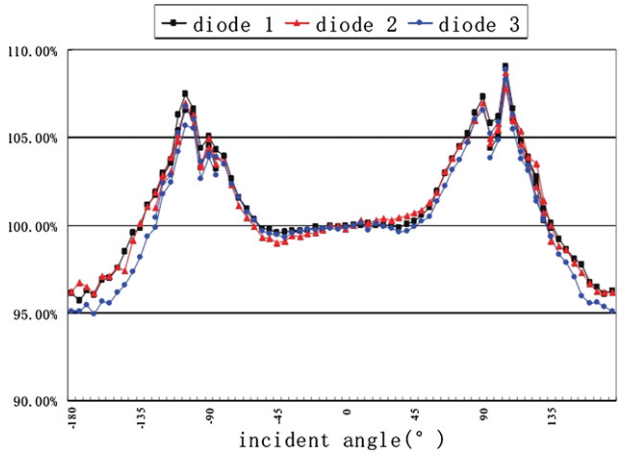

Figure 9 The directional dependence of ArcCHECK for three selected diodes normalized to their respective response at the 0° incident angle. The coordinates of diode 1, 2 and 3 are (−5, 0), (−5, 10) and (−5, −10) respectively. All results of each diode are normalized to 0° incident angle.

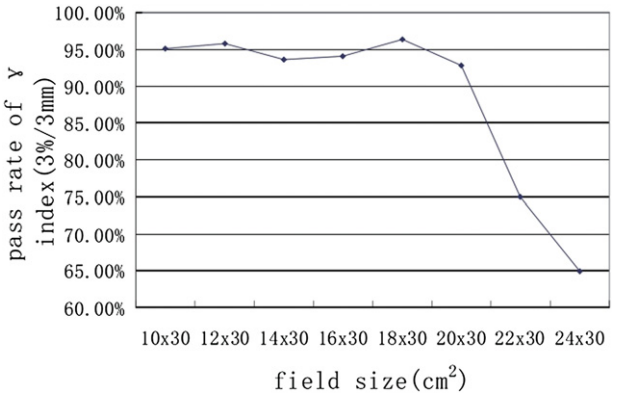

Figure 10 The absolute dose pass rate of γ index with eight simple plan verification using ArcCHECK QA system, the criteria is 3% for %Diff and 3 mm for DTA at a 10% threshold. Each plan consists of four symmetric rectangular beams with the same field size, and all field sizes in gantry-target orientation were 30 cm constantly.

Table 3 The fraction of passed γ values for the delivered plans compared to the planned doses for sIMRT and VMAT plans of ten patients. The QA plans of six nasopharyngeal patients were measured three times week by week for the stability of ArcCHECK.

% of points with $\gamma \leq 1$	Week 1				Week 2		Week 3	
	sIMRT		VMAT		sIMRT	VMAT	sIMRT	VMAT
	3%/3 mm	2%/2 mm	3%/3 mm	2%/2 mm	3%/3 mm	3%/3 mm	3%/3 mm	3%/3 mm
NPC1	97.3%	90.1%	96.0%	87.2%	96.7%	96.0%	98.2%	95.7%
NPC2	96.5%	88.4%	96.0%	85.5%	97.1%	94.9%	96.9%	94.3%
NPC3	97.3%	89.5%	94.8%	84.3%	97.8%	95.2%	96.7%	95.0%
NPC4	98.6%	92.3%	95.4%	85.8%	98.5%	95.1%	97.7%	95.2%
NPC5	97.3%	86.7%	93.0%	82.1%	97.3%	95%	96.5%	94.6%
NPC6	97.3%	89.7%	96.5%	88.2%	97.7%	96.6%	97.8%	97.1%
Prostate cancer	96.9%	88.6%	98.5%	90.9%				
Cervix uteri cancer	97.9%	90.4%	98.0%	90.3%				
Rectal cancer	98.3%	89.2%	99.5%	92.2%				
Esophageal cancer	98.5%	90.6%	98.2%	89.6%				

dose difference (ArcCHECK-ion chamber) changed from −0.7% to 1.7% for the hollow phantom, and from −1.1% to 1.3% for the PMMA plug inserted [20].

In this paper, comparisons of the ArcCHECK results with calculated doses and ion chamber measurements indicate that there is a slight difference in the tests of dose per pulse dependence and field size dependence. The scatter condition is not identical between the ion chamber inserted in the slab phantom and the ArcCHECK diode, especially for large field sizes (Fig. 8, 20 × 20 cm^2). Thus the comparisons with TPS calculated doses are more reliable.

Feygelman et al. reported that the largest difference between the measured and calculated dose was observed up to 7% for angular dependence in the axial plane [20]. In this paper, the directional dependence of ArcCHECK is significant (from −4.9% to 9.1%). This is partly due to the nonuniform high-Z packaging material surrounding the diode. The non-isotropic design of the diode depletion region, backscattering, and the nonuniform airspace containing each diode in the phantom also contribute to the non-isotropic diode response [18].

Comparison studies

The purpose of the ArcCHECK QA system is to verify clinical radiation therapy plans, especially VMAT plans. In this paper, we verified the simple plan of four beams of different field sizes and 10 IMRT and 10 VMAT plans of various cancer sites and of varying complexity.

From the simple plan verification, we found that there is very good agreement when the field size is smaller than the device in the transverse direction. However, when it is outside the diodes range, the absolute dose pass rate of γ index falls rapidly. This is mainly due to the directional dependence of ArcCHECK diodes. When the field size 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 in these regions compared with the calculated dose distribution.

The ten selected clinical cases are different in target volumes and complexities. Both ArcCHECK and ion chamber results showed good agreement in pre-treatment verifications of all these IMRT and VMAT plans. This suggests that the ArcCHECK QA system was successfully designed for verification of IMRT and VMAT treatments, and TPS calculated precision and linear accelerator delivery for IMRT and VMAT treatments can be contented for clinical situations. The impact of directional dependence of ArcCHECK diodes for clinical IMRT and VMAT verification is almost negligible, due to the following two reasons: Firstly, ArcCHECK detectors remain perpendicular to the treatment beams regardless of gantry angles for the couch angle of zero degree. The impact of small couch angle for the verification is negligible due to the small directional dependence (<60°) of the diodes, while the impact of large couch angle is obvious. Furthermore in clinical cases the target volume sizes are usually in the range of 20 cm, thus the irradiation hardly passes through the detectors from either side; Secondly, radiation first passes through the phantom materials close to 24 cm before the detectors from its back, therefore the contributions of irradiation from the back is low. In addition, for nasopharyngeal cancer, the pass rate of γ index and absolute dose error are both considered statistically significant with $p < 0.05$ which indicates that the precision of TPS calculated dose (in homogeneous phantom) and/or linear accelerator delivery for VMAT in complex nasopharyngeal cases is less than the precision for IMRT. But for the other four cases, the pass rate of γ index and absolute dose error are not considered statistically significant with $p > 0.05$ which indicates that there is no significant discrepancy in calculation and delivery for VMAT and IMRT treatments.

Conclusions

The short term reproducibility, the dose linearity, the dose rate dependence, the dose per pulse dependence, the field size dependence and the out of field dependence of ArcCHECK are very good, and they are satisfied in the clinical QA conditions. The directional response of the diodes varies from a minimum of −4.9% (seen only when the beam is

incident on the diode at 180°) to a maximum of 9.1% (approximately at 105°), but its impact on clinical IMRT and VMAT verification is nearly negligible. Based on the successful comparative measurements, the ArcCHECK QA system is suitable for clinical IMRT and VMAT verifications.

Conflict of interest

None.

Acknowledgments

This research work was funded by National Natural Science Foundation of China (Grant No. 81101697).

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