Analysis of using the ArcCHECK Diode Array for Verifying Tomotherapy HDA™ Patient-specific Delivery Quality Assurance

การวิเคราะห์หัววัดรังสีรุ่นอาร์คเช็คเพื่อการทวนสอบแผนการรักษาสำหรับเครื่องฉายรังสีโทโมเทอราปี รุ่น HDA™

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Abstract

Background: The ArcCHECK cylindrical diode array, which is real time analysis and reusable tool, has been introduced as a patient QA device for Tomotherapy plan.

Objective: The aim of this study was to investigate the dosimetric characteristics of ArcCHECK for Tomotherapy including the clinical usage as a dose verification tool.

Materials and Methods: The dosimetric characteristics of the ArcCHECK in terms of short-term reproducibility, dose linearity, field size dependence, including sensitivity of cylindrical diode array to variation of the Tomotherapy planning parameters i.e., field width (FW) and pitch were investigated. The clinical tests were used on twenty prostate cancers. The measured dose distributions using ArcCHECK and dose measurement from EBT3 films were compared with dose calculation from Tomotherapy treatment planning. The results were evaluated following the gamma criteria of 3%/3mm. The clinical action level was established by given a higher percentage of gamma passing than (100-CL) while CL was [(100-mean) + 1.96σ].

Results: The sensitivity of diode showed linearity with dose delivery in the range from 5s to 300s (R2=1) and the variations of repeatedly measured in the short-term period was within ±1.52%. The field size dependence exhibited the same response as the ionization chamber (CC13) except for 1 cm field width; the diodes exhibited 14.81% over-response when compared with the CC13, which may result from volume averaging of the CC13. The influence of planning parameters on sensitivity of ArcCHECK showed no difference of gamma passing rate with higher passing rate than 97% for all various FW and pitch plans. For clinical plans, ArcCHECK measurements demonstrated in the similar trend of EBT3 films analysis with a moderate positive correlation (r=0.59). The clinical action level of our institution was found 97% when using ArcCHECK as a verification tool.

Conclusion: The detector achieves the efficient dosimetric characteristics and ArcCHECK response is independent of Tomotherapy planning parameters. The percent gamma passing for patient-specific QA evaluation shows moderate positive correlation with the film. The ArcCHECK system can be considered as a reliable and an effective QA tool for patient verification of the Tomotherapy.

Keywords: ArcCHECK, Patient-specific QA, Tomotherapy

บทคัดย่อ

หลักการและเหตุผล: หัววัดรังสีรุ่นอาร์คเช็คสามารถอ่านค่าได้ทันทีได้ ถูกนำเสนอเพื่อใช้สำหรับการทวนสอบแผนการรักษาในเครื่องโทโมเทอราปี

วัตถุประสงค์: เพื่อศึกษาผลของหัววัดรังสีรุ่นอาร์คเช็คต่อรังสีจากเครื่องโทโมเทอราปี รวมถึงการทวนสอบแผนการรักษาผู้ป่วย

วัสดุและวิธีการ: การทดสอบความสามารถนับวัดรังสีของอาร์คเช็ค ประกอบด้วยการทดสอบความแม่นยำในการวัดซ้ำ ความสัมพันธ์เชิงเส้นของการนับวัดรังสี ความสัมพันธ์ของพื้นที่รังสีต่อการนับวัด และการตอบสนองต่อพารามิเตอร์ที่ใช้ในการวางแผนการรักษาด้วยเครื่องโทโมเทอราปี ได้แก่ field width (FW) และ pitch จากนั้นทดสอบการใช้อาร์คเช็คทวนสอบแผนการรักษาผู้ป่วยมะเร็งต่อมลูกหมาก 20 ราย โดยเปรียบเทียบค่านับวัดจากอาร์คเช็คและฟิล์มรุ่น EBT3 กับค่าจากเครื่องวางแผนการรักษา และวิเคราะห์ผลด้วยอัตราค่าผ่านแกมมาที่เกณฑ์มากกว่า 100-CL เมื่อ CL เท่ากับ [(100-ค่าเฉลี่ย) + 1.96σ]

ผลการศึกษา: อาร์คเช็คสามารถทำการวัดซ้ำในระยะสั้นได้ มีค่าเบี่ยงเบนมาตรฐาน ±1.52% นับวัดปริมาณรังสีเป็นสัดส่วนโดยตรงกับเวลาในช่วง 5 ถึง 300 วินาที (R2=1) การทดสอบขนาดพื้นที่รังสีต่อการนับวัดพบว่าอาร์คเช็คมีผลการนับวัดเช่นเดียวกับหัววัดรังสี CC13 ยกเว้นสำหรับ field width 1 ซม. ที่แสดงค่านับวัดมากกว่าหัววัด CC13 ถึง 14.81% ทั้งนี้อาจเกิดจากการเฉลี่ยค่านับวัดในหัววัดรังสี CC13 สำหรับการทดสอบการตอบสนองต่อการปรับเปลี่ยนพารามิเตอร์ในการวางแผนการรักษา พบว่ามีอัตราค่าผ่านแกมมาไม่แตกต่างกันคือมากกว่า 97% ในทุก FW และ pitch และการทดสอบทางคลินิกพบว่า อัตราผ่านค่าแกมมาจากอาร์คเช็คสอดคล้องกับฟิล์ม มีความสัมพันธ์เชิงบวกปานกลาง (r=0.59) มีค่าอัตราผ่านแกมมาต่ำสุดที่ยอมรับได้ที่ 97%

ข้อสรุป: อาร์คเช็คมีความสามารถในการนับวัดรังสีที่ดี ไม่ขึ้นกับพารามิเตอร์ที่ใช้ในการวางแผนการรักษาสำหรับเครื่องโทโมเทอราปี มีอัตราค่าผ่านแกมมาที่มีความสัมพันธ์เชิงบวกปานกลางกับฟิล์ม สามารถสรุปได้ว่าอาร์คเช็คมีความเหมาะสมและสามารถนำไปใช้ในการทวนสอบแผนการรักษาสำหรับเครื่องโทโมเทอราปี

คำสำคัญ: หัววัดรังสีรุ่นอาร์คเช็ค, การทวนสอบแผนการรักษา, เครื่องโทโมเทอราปี

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Introduction

Helical Tomotherapy is a modality that was developed to deliver intensity-modulated radiation therapy (IMRT) in radiation oncology[1]. A linear accelerator is attached to a ring-shaped gantry that allows the delivery of the intensity of radiation beam and modulated the beam by a binary multi-leaf collimator to a patient while the couch is moving through the gantry rotation[1]. The sophisticated and complexities delivery technique make this possible delivery errors[2], i.e., mismatches between delivered and planned doses. To minimize an inaccuracy of dose delivery, the pre-treatment patient verification is strongly recommended for each helical-IMRT patient plan.

Currently, most Tomotherapy users perform delivery quality assurance (DQA) using the radiochromic film (EBT3)[3, 4]. The EBT3 film is a gold standard for performing as a plan verification

tool with its high spatial resolution, less energy dependence, almost dose rate independence, and near tissue-equivalent features[5-7]. However, the EBT3 film shows that its measurement protocol is still time-consuming. The scanning of post-irradiation EBT3 film has to be waiting for the film darkening to stabilized, generally scanned at least 24 hours after exposure[8-10]. This has led to a necessity to implement an effective pre-treatment verification protocol. The real-time dose-distribution detector such as diode or ionization chamber array has been introduced to use for more effectively[11, 12].

The performances of the ArcCHECK cylindrical diode array (Sun Nuclear, Melbourne, FL) are related to an ideal detector array for the verification of radiotherapy as followings; it shows dose linearity response and dose rate independence, it is a robust system, which has good short-term reproducibility. Moreover, it is easy to calibrate and it can perform real-time measurements and provides instant results[7]. Therefore, the ArcCHECK has been widely used for verifying the VMAT plan that delivered by LINAC-based for a decade[13-18].

Previously, few studies intended to evaluate ArcCHECK cylindrical diode array to use for Tomotherapy patient-specific DQA[2, 19]. Yue Q. et al. (2014) evaluated the necessary functional characteristics test of the ArcCHECK, including short-term reproducibility, linearly diode response, and dose per pulse dependence. The ArcCHECK provided stable and consistent measurement outcomes with helical Tomotherapy. Hence it is considered as an accurate device, which was implemented clinically for Tomotherapy DQA[2]. More recently, in 2016, Bresciani S. et al. supported Yue Q. et al. that the ArcCHECK could be used as a pre-treatment verification tool for Tomotherapy with the following recommendation: new agreement criteria of the percent gamma passing rate needed to be established[19].

This study aimed to validate the dosimetric characteristics of the ArcCHECK diode array and implement the device for Tomotherapy HDA™ plan verification. The proper evaluation of a QA dosimeter could inform the variations and response in dose measurement, minimizing the errors and building the user's confidence before using the device for QA properties. In order to achieve accurate measurement protocol and ensure that ArcCHECK is suitable as a pretreatment verification tool for Tomotherapy HDA™, the plan parameters effect and retrospective of 20 prostate cancer patients who treated by Tomotherapy HDA™ at Ramathi-bodi hospital were investigated. The gamma passing rate of retrospective patients was also evaluated, including finding a suitable gamma criteria and action level for Ramathibodi hospital Delivery Quality Assurance (DQA)

Materials and Methods

A three-dimensional array of 1,386 N-type diode detectors (0.019 mm3) has been developed by Sun Nuclear Corporation (Sun Nuclear, Melbourne, FL). All diode detectors are arranged in a spiral pattern around PMMA

phantom surface (2.9 cm thickness or 3.3 cm water equivalent depth) with 10 mm spacing and 10 mm distance from each detector. The ArcCHECK phantom geometry is cylindrical with 21 cm diameter and array length.

Before performing any test, the absolute dose calibration of ArcCHECK detector was carried out against the CC13 ionization chamber (IBA Dosimetry GmbH, Schwarzenbruck, Germany) inserted in solid water phantom (Gammex, Inc., Middleton, WI). The setup condition was followed the Sun Nuclear Corporation's recommendation, as shown in **Figure 1**. Finally, the absolute dose calibration data file was added in Sun Nuclear patient software and set as the default dose calibration.

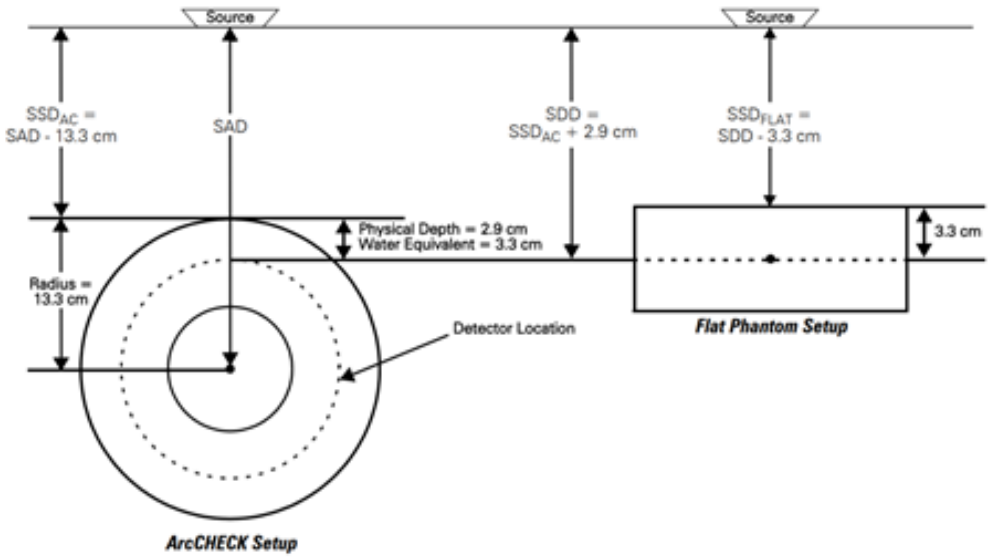

Figure 1 The configuration of ArcCHECK and the solid water phantom setup for dose calibration.

The dosimetric characteristics test

The dosimetric characteristics of the ArcCHECK were examined in terms of short-term reproducibility, dose linearity, and field size dependence. All tests were performed with the Tomotherapy HDA™ system (Accuray, Sunnyvale, CA), which provided a flattening filter-free 6 MV photon energy, 870 MU/min dose rate and equipped with a binary 64 multileaf collimator. The central of the ArcCHECK was aligned to the isocenter of the machine, 85 cm SAD geometry. Besides, the CC13, 0.13 cm3 was inserted in the central cavity within the cavity plug of the ArcCHECK in order to monitor the stability of photon beams output **(Figure 2).**

The short-term reproducibility test was purposed to ensure that ArcCHECK could be performed consecutive dose measurements. The

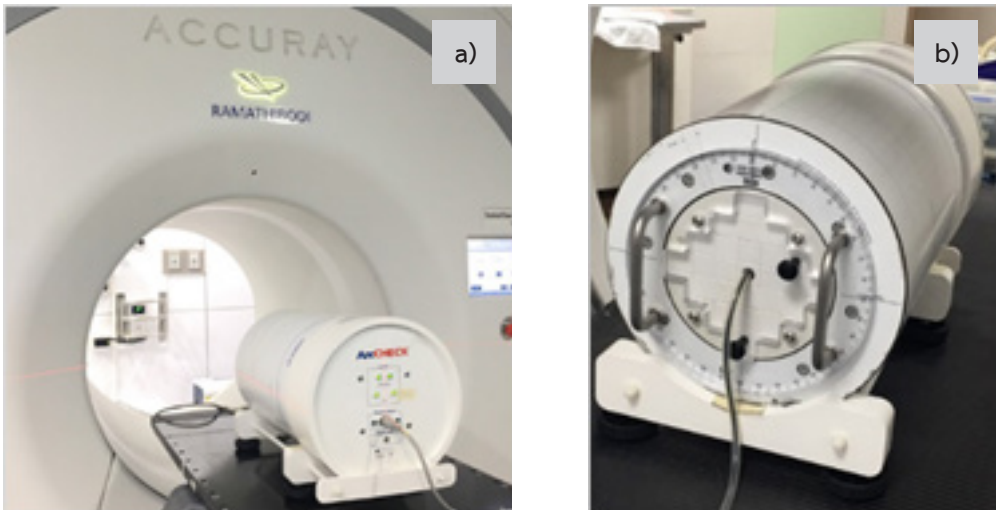

Figure 2 a) The experimental setup of the ArcCHECK combination for the Tomotherapy HDA™ system. b) The insertion part of the ArcCHECK (with the CC13 inserted).

measurements were conducted with a 5x10 cm^2 field size (reference field size for Tomotherapy[20]) for ten times consecutive measurements with less than a minute interval. The beam on time was set at 10 seconds. The readings form the six central diodes were averaged, and then the short-term reproducibility of ArcCHECK was evaluated by calculating the standard deviation (SD).

The dose linearity test was performed by varying delivery time from 5, 10, 15, 20, 30, 40, 60, 120, 180, 240, and 300 seconds based on clinical application in order to prove that ArcCHECK readings were directly proportional to the actual dose with a linear function. The measurements were conducted with a 5x10 cm^2 field size. The six central diodes readings were averaged.

Field size dependence test was purposed to quantify the response of ArcCHECK diodes which are known to provide the over-response to low-energy scattered photons, so that the diode readings may deviate from the reading of the ionization chamber[21]. This test was done by measuring beam deliveries of varied field width (Y) of 1, 2.5, 5 cm with different X of 5, 10, 15, 20, 30, 40 cm. The measurements were conducted with 10 seconds of beam-on time. Due to the small field width of 1 and 2.5 cm covered only the two central diodes on Y-axis, the two central diodes readings were averaged for all field sizes in order to simplify the comparison of diode ability between each field size. Finally, the measured ArcCHECK dose were compared with the measured dose by the CC13, which inserted in slab solid water

phantom a 3.3 cm-thick (relate to diode detectors depth) and irradiated under the same conditions including field size and beam-on time setting.

The planning parameters dependence test

The planning parameters affecting the sensitivity evaluation test was done by creating 15 treatment plans of 5 cm diameter sphere PTV, which simplified to the prostate size. The plans optimized using different parameters by varying the FW of 1, 2.5, 5 cm for fixed jaw, and FW of 2.5 and 5 cm for dynamic jaw for each pitch selected, i.e., 0.215, 0.287, and 0.43. For all created plans, the PTV was prescribed with a dose of 2 Gy per fraction and then optimized 100% dose for 95% PTV. Finally, the pitch and FW dependence were evaluated by determining the gamma passing rate of gamma analysis, which provided on Sun Nuclear patient software (Sun Nuclear, Melbourne, FL) and calculated a one-way ANOVA to statistically analyze the data. According to AAPM TG No.119 and No.148 report, the gamma passing rate of at least 90% with 3% DD/ 3mm DTA with 10% threshold was set as a criterion.

The clinical-used test

Routinely, the DQA of Tomotherapy HDA^{TM} in Ramathibodi hospital was performed by using EBT3 film. The film was positioned between two semi-cylinders of cheese phantom while performed measurement. The Extradin A1SL ionization chamber (0.053 cm^3) was also inserted below the film for point dose measurement. After DOA process, the film needs long time for processing, especially post irradiation waiting time (usually at least 24 hours) for being stabilized. After that, the film was scanned. All data was collected in the film analysis software, including film calibration file, film-measured file and calculated-plan file. Finally, the film was analyzed by the gamma analysis for a comparison between measured dose and calculated plan.

In the clinical-term, 20 retrospectives of prostate cancer patients who treated using Tomotherapy HDA^{TM} at Ramathibodi hospital were randomly selected including both only prostate gland cases and prostate with node cases. The averaged PTV size of all plans was 6.06±3.39 cm (3.10-18.00 cm).

The gamma passing rate of at least 90% using 3% DD/ 3mm DTA with 10% threshold was set as a criterion following AAPM TG No.119[22] and No.148[25] report. The gamma passing rate of each DQA plan was analyzed by the correlation analysis to find the strength of a correlation between ArcCHECK-measured analysis and the retrospective data of EBT3 films measurement analysis. Finally, the clinical action level was established by following: the treatment plan DQA must be given a higher percentage of gamma passing than (100-CL) as the confidence limit was obtained using the equation of CL = [(100-mean)+ 1.96σ][22].

It should be noted that the relative dose measurement mode was used for ArcCHECK measurement in this study. In addition, the global normalization was used for the dose

difference normalization of the ArcCHECK measurement since the global normalization is suitable for more clinically relevant than local normalization[23].

Results

The dosimetric characteristics test

The short-term reproducibility of Arc CHECK on the Tomotherapy HDA™ system was 178.39±1.52% as shown in **Figure 3**.

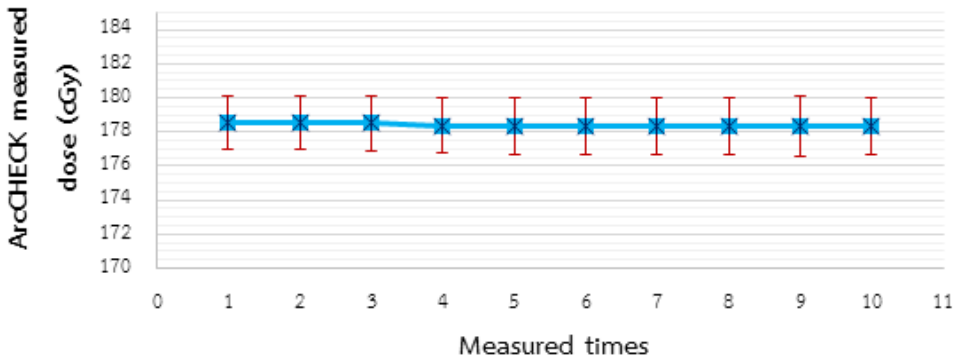

Figure 3 The short-term reproducibility of average six central diodes of the ArcCHECK with error bars of ±1SD.

The dose linearity was presented as a straight function graph of a relationship between ArcCHECK dose measurements (cGy) and varying beam on time (s). For beam-on time increments from 5s to 300s, the dose linearity response with a straight function (R2=1), as shown in **Figure 4**, which indicated that the diodes readings were proportional to the actual dose.

The field size dependence of the ArcCHECK is shown in **Figure 5a**). The diodes exhibited the same response with the CC13 by increasing response with increasing field size and the sensitivity variations deviated from the CC13 within ±0.71% and ±0.24% for all different X and field width of 2.5, and 5 cm, respectively. For field width 1 cm, the diodes exhibited higher response than the CC13, which deviated within ±14.81%. The percent differences between ArcCHECK readings and CC13 readings are shown in **Figure 5b**)

The planning parameters dependence test

The field width and pitch dependence are shown in **Table 1**. The fifteen plans optimized with various pitches, which performed measurements by ArcCHECK, obtained similar results. The percent gamma passing rate (%GP) of the plans were more than 97% (98.80-100.00%). The average percent passing rate of 3%/3mm criterion for each pitch and all FWs used were 99.73±0.60%, 99.71±0.84%, and 99.86±0.24% for 0.43, 0.287, and 0.215, respectively.

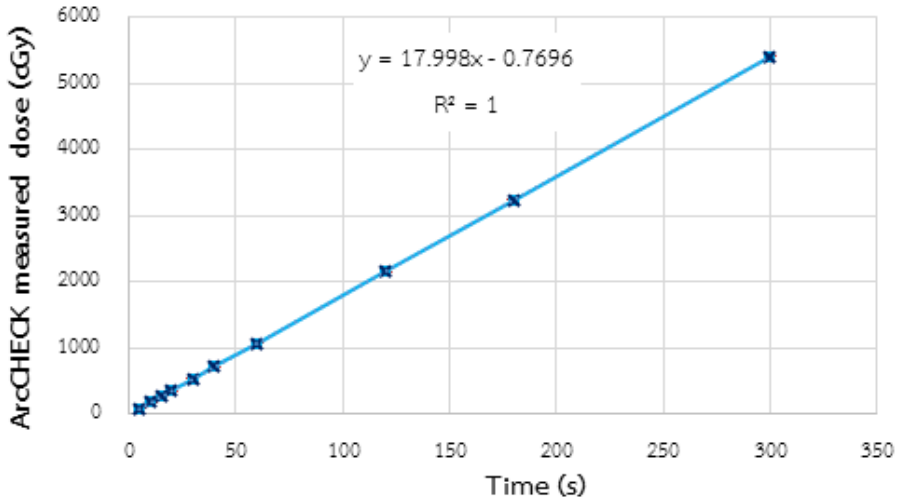

Figure 4 The Dose linearity response of ArcCHECK. The SDs of all diodes readings are too narrow to show on this chart.

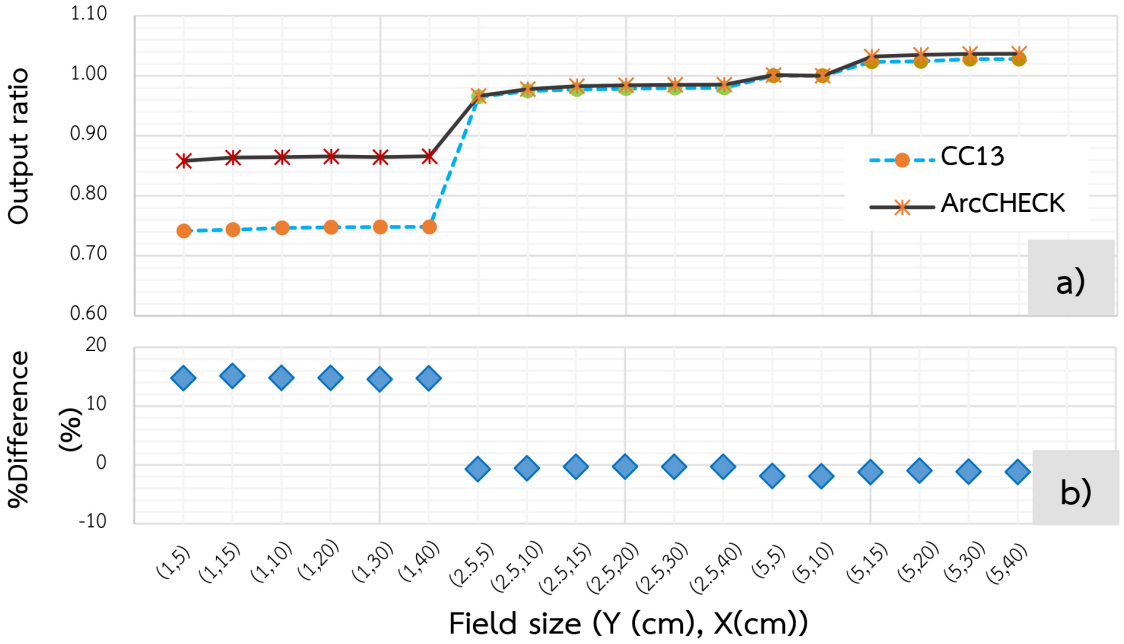

Figure 5 a) The output factors measured by ArcCHECK normalized to a 5x10 cm2 in comparison with the measured by the ionization chamber (CC13) for Tomotherapy. b) The percent differences between the ArcCHECK readings and the CC13 readings for the field size dependence test.

Table 1 The percent gamma passing rate for each field width and pitch dependence plan with criterion of 3%/3mm.

Field width (cm)	Pitch		
	0.430	0.287	0.215
1.048	99.93	99.73	99.43
2.512 Dynamic	99.93	100.00	99.90
2.512 Fixed	99.97	100.00	99.97
5.048 Dynamic	99.97	100.00	100.00
5.048 Fixed	98.83	98.80	100.00
Average	99.73±0.60	99.71±0.84	99.86±0.24

The clinical-used test

For the clinical-term, according to the experience of the AAPM TG-148 report established QA for helical tomotherapy supports the AAPM TG No.119 with the recommended gamma passing rate of at least 90% with 3%/3mm criterion[24], the percent gamma passing of all plans in this study was higher than 95% (96.10-100.00%) gamma passing of 3%/3mm criterion. The average percent gamma passing in this study was 99.46% ± 1.09. Our study also reported the correlation between the percent gamma passing rate of ArcCHECK measurement and retrospective data of the measurements of the EBT3 film, which was a positive correlation, as shown in **Figure 6.**

The absolute value of correlation coefficient (r) was 0.59, which between 0.40-0.59; this r indicated that this correlation was moderate. The strength of the correlation was described by using the guide that Evans suggested[25].

Discussion

The critical dosimetric characteristics of the ArcCHECK in the Tomotherapy HDA™ system was evaluated and provided satisfactory results. For field size dependence test, the diodes exhibited 14.81% higher response than the CC13 for field width 1 cm due to volume averaging of the CC13. Although the CC13 did not appropriate to use for small field measurement[26], it was selected with a limitation of chamber holder for the ArcCHECK cavity plug. However, the CC13 was proper to use for clinical-used test of the averaged PTV size (6.06±3.39 cm).

The results of each pitch and all FWs used for planning parameters dependence test were non-significant difference since P-value is greater than 0.05 (P-value = 0.84). Hence, it is indicated that there is no significant difference between each pitch with all FWs. Therefore, the results of this study could also be supported that the

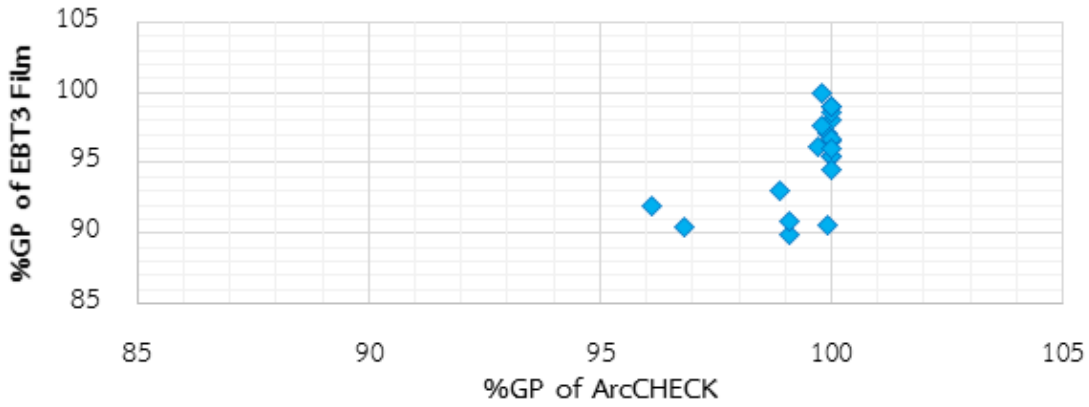

Figure 6 The correlational relationship between the percent gamma passing rate of ArcCHECK-measured analysis and the retrospective data of EBT3 films measurement analysis

ArcCHECK is accurate for any pitch and FW of the Tomotherapy treatment plan while using 3%/3mm criterion which use as a criteria for clinical patient verification.

In term of clinical-used, the analysis results of percent gamma passing cannot be directly compared between two devices (ArcCHECK vs. EBT3 film) owing to differences configuration, resolution, and number of detectors per area[21]. However, we determined the moderate correlational relationship between the ArcCHECK and EBT3 films, which is the gold standard and also used as a routine measurement device in Ramathibodi hospital.

Previously, Yue Q. et al. recommended every institutes to investigate their own action level, which related to the universal agreement criteria[2]. Based on the statistical analysis for the twenty cases analyzed with 3%/3mm criterion, the suggested clinical action level of our institution is 97%. Nevertheless, more data collection was also recommended.

Consequently, all ArcCHECK performances evaluated in this study demonstrated that this detector device is suitable to perform as a patient-specific QA verification tool for the Tomotherapy HDA™ system.

Conclusion

The detector achieves the efficient dosimetric characteristics and the ArcCHECK responses are independent of Tomotherapy planning parameters.

As a results of percent gamma passing for evaluate patient-specific QA in this study that show moderate positive correlation with the EBT3 film, the ArcCHECK system can be considered as a reliable and an effective QA tool for patient verification of the Tomotherapy HDA™.

Further study will be considered on the suitable action level of gamma passing rate for each clinical region use in Ramathibodi hospital.

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