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# Comparison of Arccheck and Portal Dosimetry in dose Verification for Intensity Modulated Radiotherapy (IMRT) and Rapidarc Plans

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**ABSTRACT**

This study compares Portal Dosimetry with the ArcCheck phantom for patient-specific QA of RapidArc and IMRT plans. The Electronic Portal Imaging Device (EPID) from Varian and the Eclipse Treatment Planning System (TPS) were used for portal dosimetry, while the ArcCheck cylindrical phantom from Sun Nuclear was used for phantom studies. Eclipse-TPS facilitated RapidArc and dynamic IMRT treatment planning and portal dosimetry (PD) for planar dose calculations. Two verification plans were created for each of the 12 patient plans, totaling 24 arcs delivered on two QA systems. The 12 plans, each with two arcs, were delivered on the EPID of the Varian TrueBeam Linac and the ArcCheck phantom. Planar dose matrices were analyzed using the global Gamma Index criteria of 2mm DTA and 2% dose difference. Measurements were performed using the Varian TrueBeam Linac mounted EPID (aS-1200) with Portal dosimetry and the ArcCheck phantom with its software. The QA results from both methods were evaluated and compared. The maximum deviations of dose points (γ>1) were 2.9% and 2.2 CU in the ArcCheck phantom and Portal dosimetry, respectively. Mean and standard deviation values were lower in portal dosimetry than in phantom studies, attributed to the closely embedded chambers in the EPID compared to the detector spacing in the phantom. Both dosimetric QA systems are suitable for patient-specific QA of RapidArc or VMAT and IMRT treatments. With a 2%/2mm criterion, the average γ passing rates were over 98% for PD and over 95% for ArcCheck, with PD showing slightly higher consistency.

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## Introduction

Radiation therapy has transformed the field of cancer treatment, with treatments such as IMRT and RapidArc or VMAT allowing for the delivery of very precise doses to the tumor while sparing the surrounding normal tissues. However, such intricacies in the techniques demand the absolute need for robust verification methods of dose delivery accuracy.

This paper aims to explore the comparative effectiveness of the two major dosimetry verification systems: ArcCHECK and portal dosimetry. ArcCHECK is a 3D diode array system that offers comprehensive spatial dose verification, while portal dosimetry uses electronic portal imaging devices to evaluate the dose delivery based on pretreatment imaging. The strengths and limitations of these two dosimetric systems are analyzed for IMRT and RapidArc plans in different anatomical sites, enabling us to better understand their role in ensuring safety and efficacy during treatments. Eventually, this knowledge will be used to optimize quality assurance procedures in radiation oncology and improve patient outcomes.

Recent advances in technology have greatly improved radiation therapy techniques, including 3D Conformal Radiation Therapy (3D-CRT), IMRT, and VMAT. These techniques offer superior dose distribution and better protection of OARs. RapidArc is a sophisticated form of IMRT that delivers treatment through single or multiple rotations of a linear accelerator gantry. During these rotations, the MLCs move dynamically, while the dose rate and gantry speed vary continuously.

Advanced radiotherapy techniques such as IMRT and RapidArc or VMAT have significantly improved the treatment of cancer by allowing highly precise and conformal dose delivery. However, the complexity of these techniques requires rigorous quality assurance processes to ensure accuracy and patient safety. Several commercial QA systems are in common use to verify dose distributions.

Traditional QA methods may fall short for advanced radiotherapy techniques. The ArcCHECK offers a significant verification range up to 36 cm through its Merge function, while systems such as EPID based PD, integrated into linear accelerators, offer a larger verification area of 43 cm × 43 cm with added convenience.

The performance of ArcCHECK and Portal Dosimetry in the verification of dose distributions at different anatomical sites, including head and neck, pelvis, prostate, breast, thorax, and brain metastases, is evaluated. Using gamma passing rates with a 2%/2mm criterion, this research aims to identify strengths and limitations of these QA systems. Results will be helpful in optimizing QA protocols and improving the accuracy of dose delivery in clinical practice.

Patient specific pretreatment QA of Rapid Arc and IMRT clinical setup is performed in a retrospective study. The dosimetric QA devices used were the following: (1) Linac-mounted EPIDs (aS-1000) with Portal Dosimetry and (2) the ArcCHECK cylindrical phantom from Sun Nuclear Corporation, FL, USA, together with its software.

**Methods and Materials**

A total of 12 VMAT and IMRT verification plans were developed for patients who underwent radiotherapy treatment. Each verification plan had single-isocenter setups. The dose distributions were verified using the ArcCHECK system and Portal Dosimetry (PD) using 2% 2mm analysis criteria. γ passing rates of the two QA systems were compared using a paired samples t-test to assess mean differences.

This retrospective study includes 12 patients treated with RapidArc and IMRT in various anatomical sites, utilizing 6MV, 6MV FFF, and 10MV photon beams. Each RapidArc plan consisted of two arcs, one clockwise and one counterclockwise, and was verified with two different dosimetric QA systems. The plans were delivered on the EPIDs of the Varian TrueBeam Linac and the ArcCHECK cylindrical phantom for comparison.

Verification plans were created in Eclipse version 16.1 (Varian Medical Systems Inc., Palo Alto, CA) for inverse planning, RapidArc optimization (PO) algorithm, and forward dose calculations with both AAA and Acuros XB algorithms. Portal dosimetry was performed as part of the planning. Transfers of plans were managed through the Elekta Mosaiq networking system, whereas recordings and verifications were performed on the 4DITC of the Varian TrueBeam Linac. Deliveries used the linear accelerator with amorphous silicon (aS1200) EPIDs.

More details on the dosimetric QA equipment and measurement procedures are given in the following sections.

**Portal Dosimetry (PD) System Based on EPID**

The PD system projects and verifies the dose distributions using an amorphous silicon EPID integrated into the TrueBeam linear accelerator (Varian, USA). The characteristics of the EPID used are an active area of 43 cm × 43 cm, an SID that can be adjusted in the range between 100 and 180 cm, with a pixel resolution of 1280 × 1280. Two-dimensional dose verification was performed using the dedicated Portal Dosimetry software.

The PD system uses the PDIP algorithm to process the data acquired by the EPID. The acquired data are reconstructed to a two-dimensional dose distribution and then compared with the TPS-calculated dose distribution to check the γ passing rates of the plans. Pre-verification, calibration of the EPID is performed to have uniform responsiveness for all the points of measurement. It also involves energy-specific calibration, Dark Field, and Flood Field image acquisitions that aim to remove background noise and defective pixels for uniform spatial response. Calibration steps include:

- **Absolute Dose Calibration:** The system accurately correlates dose measurements with absolute dose values.
- **Field Dependence Tests:** The test verifies the uniformity of the dose at different field sizes.
- **Dose Linearity Tests:** Verifies the linear relationship between dose and monitor units.
- **Dose Rate Dependence Tests:** Evaluates the consistency of dose measurements across different dose rates.

These steps optimize the quality and accuracy of the images captured by the EPID. After calibration, a verification plan is generated for dose evaluation. In verification, the SID is set to 100 cm and dose images are collected for the IMRT or RapidArc plans at beam delivery. For RapidArc plans that contain two arcs or IMRT plans with more than one gantry angle, the PD system uses a dose stacking tool, superimposing the dose data to consolidate the various arcs or angles into one dose distribution.

The parameters of DD and DTA are 2%/2 mm with a threshold of 10% using an enhanced γ criterion. Passing rates are obtained under various analysis criteria by comparing the TPS-calculated dose distribution to the PD-reconstructed dose distribution.

**Figure1:** Portal Dosimetry with EPID

Twelve verification plans, which included two arcs each, were generated Eclipse Treatment Planning System. The verification of the plans was made by the use of the EPID integrated in a Varian TrueBeam linear accelerator. EPID is a flat-panel detector that, in its aS1200 version, features a 1280 × 1280 pixel array of amorphous silicon detectors. The active detection area measures 43 × 43 cm with high spatial resolution of 0.035 cm.

**Measurements:** The EPID was mounted at a calibrated distance from the source of radiation and set for integrated image acquisition during these measurements. In each verification plan, the EPID captured the dose distribution when the gantry rotated through both the clockwise and counterclockwise arcs. Details of the experimental arrangement, including placement of the EPID for arc delivery without a phantom in place, are shown in Figure 1.

**The ArcCHECK Dose Verification System**

The ArcCHECK system developed by Sun Nuclear is a 3D dose verification tool; it is intended for use in ensuring the accuracy of treatments in radiation therapy. It consists of a cylindrical phantom made of acrylic, PMMA, with a total of 1386 N-type semiconductor diode detectors. These detectors are spaced 1 cm apart, with each detector having an active area of 0.64 $mm^2$ and a volume of 0.019 $mm^3$. The system has a merge function for the extended verification range up to 36 cm to accommodate larger treatment fields with phantom positioning and dose fusion algorithms.

The ArcCHECK array is first calibrated before any plan verification. RTplan and RTdose files for 12 patient-specific IMRT/RapidArc plans, each with two arcs, are generated using CT images of the ArcCHECK phantom. These files are then imported to the ArcCHECK software, SNC Patient, which allows for planned versus measured dose distribution comparison.

During verification, the ArcCHECK phantom is placed on the treatment couch with extreme care and aligned using laser guidance. The planned treatment is delivered from the linear accelerator, and the ArcCHECK system records the dose distribution. The measured dose is compared with the planned distribution using gamma analysis with a 2%/2 mm criterion and a 10% threshold. The gamma passing rate is calculated to assess the agreement between the measured and planned dose distributions. Arc delivery setup with the cylindrical ArcCHECK phantom is shown in Fig 2.

**Figure 2:** ArcCHECK Phantom Measurements

## Results

Calculated and measured planar relative dose distributions, and absolute central axis (CAX) point doses were compared for each using profile and isodose matching methods within respective software platforms. A global gamma index ($\gamma \leq 1$) analysis was performed using a 2 mm distance-to-agreement (DTA) and 2% dose difference criterion. Results from both methods were compared.

**Figure 3:** Shows the planar dose evaluation for a representative RapidArc plan using portal dosimetry. Figure 4 presents the planar dose comparison for the same plan analyzed with the cylindrical ArcCHECK phantom and its corresponding software.

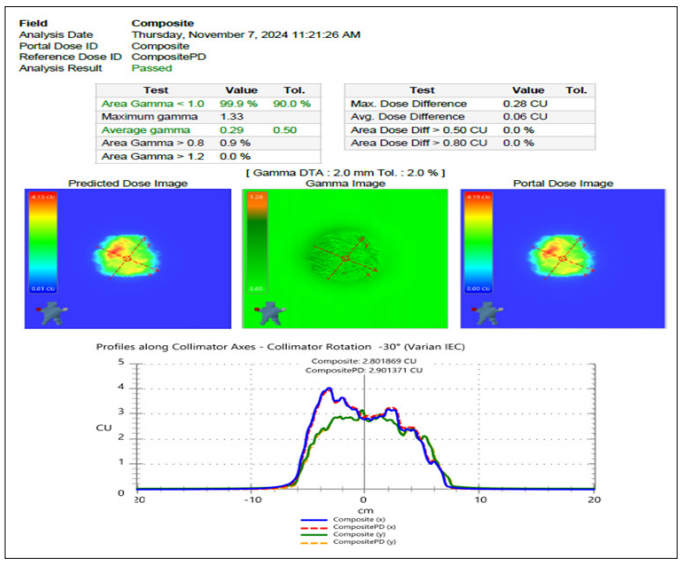


**Figure 3**

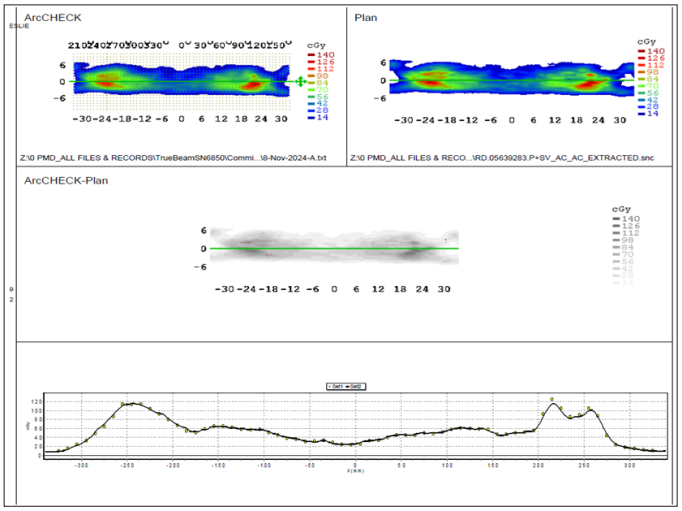


**Figure 4**

Table 1 summarizes the percentage of points with a gamma index greater than 1 ($\gamma > 1$) for the 12 patients, as well as the maximum, mean, and SD values of the calculated parameters using both QA methods. Most importantly, the CAX absolute point doses measured by both systems showed excellent agreement with the TPS-calculated doses, with a maximum deviation of less than 3%.

It suggests from the findings that, at a 2 mm DTA and 2% dose difference criterion, the percentage of discrepancies seen for portal dosimetry matches closely with that of the ArcCHECK system, indicating the dependability of both systems under clinical dose verification.

## Discussion

Delivery accuracy, planning reliability, and machine performance were evaluated by a retrospective analysis of technical and QA data from 12 patients treated with RapidArc and IMRT. The verification of the treatment plans was performed using both ArcCHECK and portal dosimetry, and all plans passed the predefined gamma evaluation criteria, indicating only minor differences between the two methods.

While portal dosimetry requires fewer resources in terms of time and materials, it demonstrated minimal deviations, likely due to the higher density and closer spacing of its detectors, as well as the precise EPID setup during treatment delivery. In this study, arc beams were directly delivered to the EPID with gantry rotation, mimicking clinical conditions and allowing for dose measurements under actual treatment parameters. However, one of the drawbacks of portal dosimetry is that it cannot give information about the gantry angle. On the other hand, the ArcCHECK system uses a cylindrical phantom with embedded point-size detectors. These detectors measure doses perpendicularly from all gantry angles, simplifying the setup process. Despite its advantages, the wider detector spacing of the ArcCHECK system may contribute to slightly higher deviations compared to portal dosimetry.

Both methods were subject to the same setup uncertainties. A uniform grid size of 0.125 mm was used for all the calculation verifications in order to be comparable. On average, portal dosimetry showed a lesser deviation compared to the ArcCHECK system. The absolute doses of measurement at the central axis for all plans from both methods were in an excellent agreement with TPS-predicted values with the highest deviation less than 3%.

**Table 1: The Percentage of Points Falling Outside the Passing Criteria (2% & 2mm), Which is Defined by γ>1 of 12 Patients, along with Maximum, Mean and SD**

| SITE | Arc Check | | | Portal Dosimetry | | |
|---|---|---|---|---|---|---|
| | □<1 | □>1 | max dose dif(%) | □<1 | □>1 | max dose dif (CU) |
| Brain | 100 | 0 | 1.5 | 100 | 0 | 1.76 |
| Neck | 97.3 | 2.7 | 1.2 | 99.3 | 0.7 | 0.24 |
| Head & neck | 97.3 | 2.7 | 2.5 | 99.8 | 0.2 | 0.25 |
| PBI | 99.2 | 0.8 | 1.72 | 99.7 | 0.3 | 0.48 |
| APBI | 97.1 | 2.9 | 0.03 | 99.2 | 0.8 | 2.01 |
| L LUNG | 97.8 | 2.2 | 2.2 | 99.9 | 0.1 | 0.28 |
| LUL Superior | 98.6 | 1.4 | 2.1 | 100 | 0 | 2.3 |
| P+SV | 98.6 | 1.4 | 0.03 | 98.3 | 0.7 | 0.42 |
| PELVIS | 99 | 1 | 1.03 | 100 | 0 | 0.5 |
| Prostate | 98.2 | 1.8 | 2.9 | 98.8 | 1.2 | 0.5 |
| Esophagus | 98.4 | 1.6 | 1.5 | 99 | 1 | 0.2 |
| Pelvis | 98.3 | 1.7 | 1.47 | 99.6 | 0.4 | 0.43 |
| MAX | | 2.9 | 2.9 | | 1.2 | 2.3 |
| Mean | | 1.68 | 0.88 | | 0.45 | 0.54 |
| SD | | 0.82 | 0.84 | | 0.40 | 0.73 |

From Table 1, it can be noticed that the number of points failing the gamma threshold (γ > 1) was less for portal dosimetry when compared to ArcCHECK system. This may be because of the closer spacing of the EPID detectors when compared to the diode detectors in the ArcCHECK system. The observed variations in error percentages between the two methods can be explained by their distinct dose reconstruction approaches: portal dosimetry relies on transmission-based measurements, while ArcCHECK employs entry/exit dose reconstruction.

**Statistical Analysis:** Data of γ passing rates are expressed as mean ± standard deviation. For data that met the normal distribution criteria, the paired-samples T-test for mean was used to evaluate the differences between two groups of ArcCHECK and PD; A p-value <0.05 is statistically significant.

**Figure 3:** Shows the γ Passing Rates Distribution of RapidArc and the IMRT Plan with Two Verification Methods with Analysis Criterion (2%/2 mm).

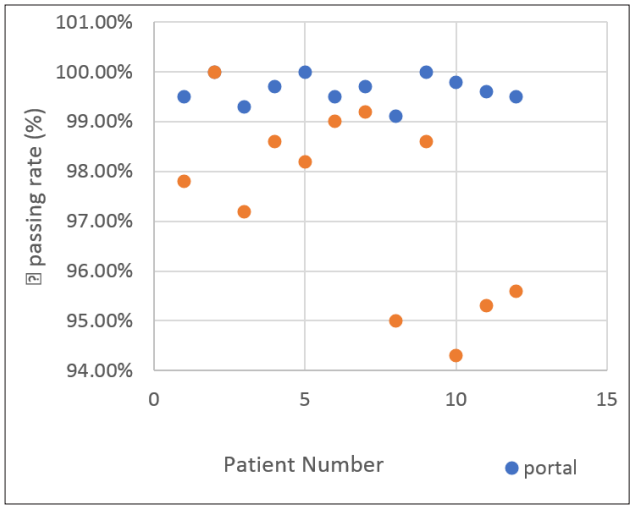


**Figure 3:** The γ Passing Rates of Rapidarc Plans with the ArcCHECK/PD Method with 2%2mm Analysis Criteria.

The average γ passing rates and the results of the difference analysis for the two verification methods with the 2%/2 mm criterion are presented in Table 4. The average γ passing rates were very high for both methods, with the PD method exceeding 98% and the ArcCHECK method maintaining values above 95%, using a 2%/2 mm criterion. Specifically, the average γ passing rates were 99.47 ± 0.53 for the PD method and 98.32 ± 0.82 for the ArcCHECK method.

**Table 4: Average γ Passing Rates (mean ±SD) with (2%/2 mm) Analysis Criterion**

| Method | 2%/2 mm |
|---|---|
| | Abdomen |
| ArcCHECK (%) | 98.32 ±0.82 |
| PD (%) | 99.47± 0.53 |
| P Value | 0.241 |

The PD method had greater efficiency compared to ArcCHECK, without the need for the phantom placement and laser alignment. Its effective verification area (43 cm × 43 cm) is greater with capability for single beam emission and providing the ability of higher spatial resolution in general. After standard calibration, PD performed excellently from dosimetric points of view. In this work, beams from the actual treatment angles were delivered using PD and ArcCHECK for dose verification purpose.

Although highly efficient, the PD method; the ArcCHECK system uses isotropic semiconductor detectors and considers the influence of the couch from the linear accelerator. This system provides a more realistic verification process closer to actual treatment conditions.

Due to the availability of only ArcCHECK and PD from the machines, this study was further restricted in verification of connection fields for γ passing rates. While both the systems performed with high γ passing rates for target volumes, dose accuracy for organs at risk was also not tested here, again a limitation.

## Conclusions

A retrospective study concerning patient-specific QA in RapidArc treatments underlined the possibilities of uncertainties and errors in dose delivery. However, it confirmed that all the deviations observed fell well within international standards and ensured the accuracy and reliability of the treatments being carried out at our center. ArcCHECK and PD systems proved to be efficient for RapidArc treatment verification; among them, PD is efficient and more precise.

The study concluded that either QA system could be used interchangeably for routine patient-specific QA, depending on machine availability. This research gave great insight into QA procedures and provided opportunities to optimize departmental workflows, staff training on best practices for RapidArc QA. These findings will support the use of a 3%/3 mm or 2%/2 mm criterion for dose verification with both ArcCHECK and Portal Dosimetry.

Conclusively, ArcCHECK and PD are suitable for dose verification of the IMRT and RapidArc plans based on the two standard clinical gamma criteria 3%/3 mm and 2%/2 mm. A variety of quality assurance and control methodologies need to be employed as a key component in treatments that vary dynamically with changing dose rates and MLC configurations continuously in a RapidArc.

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