Comparative Study of Fluence Distribution and Point Dose Using Arc-check and Delta⁴ Phantoms

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Abstract

The study aims to assess the fluence distribution and point dosage between two phantoms for patient-specific quality assurance on the Tomotherapy system. This was a retrospective study conducted on 15 patients who had radiation using the Helical Tomotherapy Machine (Radixact, Accuray Inc.). We used two phantoms to quantify the fluence produced by the treatment planning system (TPS) and recorded from the machine. The ArcCHECK (Sun-Nuclear) has 1386 diodes placed in a cylindrical configuration. The minimal resolution for this was 7 mm. The second was Delta^4, supplied by ScandiDos. It has 1069 diode detectors arrayed in a crossed orthogonal configuration with a minimum resolution of 5 mm. All patient plans were transferred to these phantoms to validate the accuracy of treatment plan delivery. We used SunCHECK and ScandiDos Delta^4 software to compare the fluence produced by the TPS with the fluence measured by the equipment. In ArcCHECK, we used an external ionization chamber, cc13 (IBA dosimetry), whereas in Delta^4,we employed a central diode detector to quantify point dosage. The mean and standard deviation of the gamma pass percentage with ArcCHECK were 98.3 ± 0.8%, with an average point dose deviation of ± 0.94%. The mean and standard deviation of the gamma pass percentage using Delta^4 was 99.1 ± 1.6%, while the average point dose deviation was ± 0.60%, both of which were well within the 3% tolerance employing the two phantoms.

Keywords: Arc-check, delta^4, fluence maps, patient specific quality assurance, point dosimetry

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Introduction

Radiation therapy has been a crucial and effective treatment option for cancer patients for a considerable period.[1] It is used for both palliative and curative treatments, making accurate dose delivery critically important. As treatment techniques advance, such as intensity-modulated radiation therapy (IMRT) and volumetric-modulated arc therapy (VMAT), conformal dosing becomes increasingly critical, as these methods exhibit higher dose conformity compared to three-dimensional (3D)-conformal radiotherapy.[2,3] To achieve conformal dosing, which involves delivering the maximum dose to the tumor tissue while minimizing the dose to neighboring normal tissues, a well-defined patient-specific quality assurance (PSQA) process is essential before treatment administration.[4-6] This ensures that the planned and delivered doses align accurately. Several factors contribute to potential flaws in radiation delivery for cancer treatment.[7-9] These factors include issues with multi-leaf collimator (MLC) leaf end modeling, penumbra effects from MLC and beam shaping devices, interleaf effects from MLCs, MLC transmission, scattering, backscattering from the LINAC head, nonaligned beam profiles, and output factors for small field sizes. Spatial and dosimetric variability in radiation delivery can result from variations in MLC leaf acceleration and deceleration, gantry rotation stability, couch sag and motion, and other factors that impact beam symmetry, flatness, and dose per unit time. In addition, unpredictability may arise from phantom material, detector stability, detector sensitivity, phantom positioning using lasers, and errors in selecting techniques or acceptance criteria for gamma analysis. Gamma analysis is a method used to assess the accuracy of dose distribution between calculated and measured fluence.[10] To ensure patient safety and treatment efficacy, institutions establish tolerance and action thresholds. Tolerance limits

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define the normal operating range, accounting for random errors, while action limits represent deviations that may jeopardize patient safety. Regular monitoring of QA trends is crucial to ensure that treatment machines are functioning correctly. This study focuses on a comparative analysis of two different phantoms utilized for PSQA. The first phantom studied was the Delta4, which utilizes an array detector to assess the dose delivered to the patient during treatment. It excels in providing valuable information on the dose distribution across the target area and surrounding normal tissues. The Delta4 phantom demonstrates the lowest mean percentage point dosage discrepancy between treatment planning system (TPS) computed and observed point dose values, with a standard deviation of <2%.[11] This impressive accuracy establishes its reliability as a PSQA tool. In contrast, the second phantom, the ArcCHECK, also aims to validate patient treatment plans but primarily focuses on providing exit dosage information.[12] While it offers valuable insights into certain aspects of the treatment process, it lacks the comprehensive patient-specific gamma passing data provided by the Delta4. The Delta4's[13] ability to furnish gamma passing information on the organs at risk for individual patients further highlights its superiority over the ArcCHECK phantom.[14,15]

This comparative study aims to rigorously evaluate the performance of the ArcCHECK and Delta4 phantoms in measuring fluence distribution and point dose. By analyzing data from multiple treatment plans and delivery techniques, the study will assess the accuracy, reliability, and clinical utility of each phantom. The findings from this study will contribute to a better understanding of the optimal use of these QA tools, ultimately supporting the continuous improvement of radiation therapy practices.

Materials and Methods

For this study, we included 15 patients (eight patients of head-and-neck site and seven patients of pelvic site), who received radiotherapy treatment on the Radixact Helical Tomotherapy Machine (Accuray, Inc.). For the radiotherapy dose planning, the Precision-V3.3.1.3 TPS was used (Accuray Precision V 3.3.1.3[2]). For measuring the fluence, we used two phantoms, as shown in Figure 1. The specifications of both phantoms are shown in Table 1.

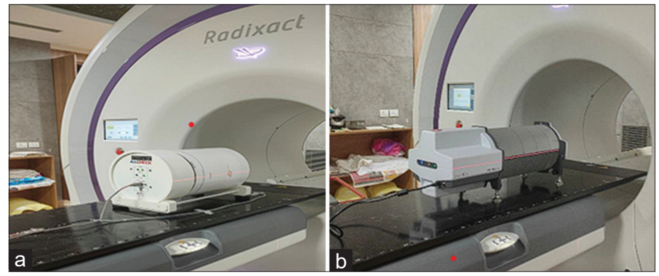

Figure 1: (a) ArcCHECK, (b) Delta4

Table 1: The specifications of Arc-Check and Delta4 phantom

	Arc-Check[16] (Sun Nuclear)	Delta4phantom[17] (ScandiDos)
Detector type	Diode (type 3-silicon diode)	Diode (p type-silicon)
Resolution (mm)	7	5
Number of detectors	1386	1069
Detector arrangement	Cylindrical	Crossed orthogonal
Detector stability (6 MV-FFF) (%/kGy)	0.5	0.1

The workflow of the PSQA is shown in Figure 2. For PSQA, the medical physicist first creates a treatment plan for the patient, specifying the dose and location of radiation beams to be delivered. Both arrays of detectors were placed in the patient's treatment area one by one. These detectors are typically placed on a flat surface and positioned according to the treatment plan. The helical tomotherapy machine was used to deliver the radiation beams according to the treatment plan. The detectors measure the dose of radiation delivered at various points in the treatment area. The data collected by the detectors were recorded by the above-mentioned software and analyzed to ensure that the dose of radiation delivered was consistent with the treatment plan. The data were analyzed and interpreted to ensure that the delivered dose was within an acceptable range. If the delivered dose was not within an acceptable range, the treatment plan may need to be adjusted.

Results

The gamma index[10,18] is a widely used quantitative metric in the field of radiation therapy for assessing the agreement between the calculated and measured dose distributions. It plays a crucial role in PSQA, ensuring the accuracy and precision of radiation treatment plans. The gamma index analysis involves comparing the dose distribution calculated by the TPS with the dose distribution measured using a verification device, such as a dosimeter or an array detector.[19] It quantifies the agreement between these two distributions by evaluating the spatial correlation of dose points based on specified criteria. In its simplest form, the gamma index calculation involves two main parameters: The dose difference criteria (ΔD) and the distance-to-agreement (DTA) criteria. The dose ΔD represent the allowable difference in dose between the TPS and measured doses at each point, while the DTA criteria specify the spatial tolerance within which the doses are considered in agreement. Commonly used values for these criteria are 3% for dose difference and 3 mm for DTA. The gamma index is typically expressed as a two-dimensional map or a 3D plot, with pass regions indicated by a gamma value of ≤1, representing good agreement between calculated and measured doses. The gamma index is particularly useful in assessing complex treatment techniques, such as IMRT and VMAT, which involve highly modulated dose distributions. While the gamma index is a valuable tool for QA, it is essential to select appropriate criteria based on clinical needs and equipment capabilities.

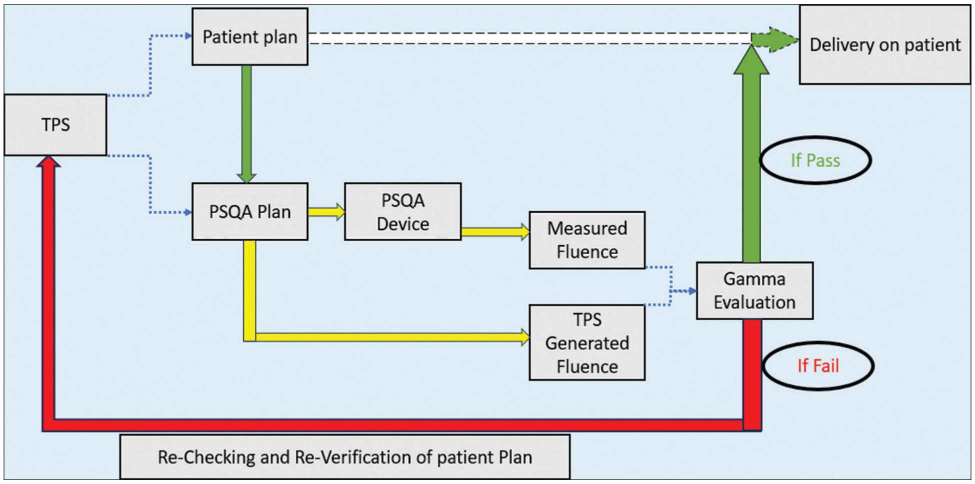

Figure 2: The block diagram for patient-specific quality assurance workflow. TPS: Treatment planning system, PSQA: Patient-specific quality assurance

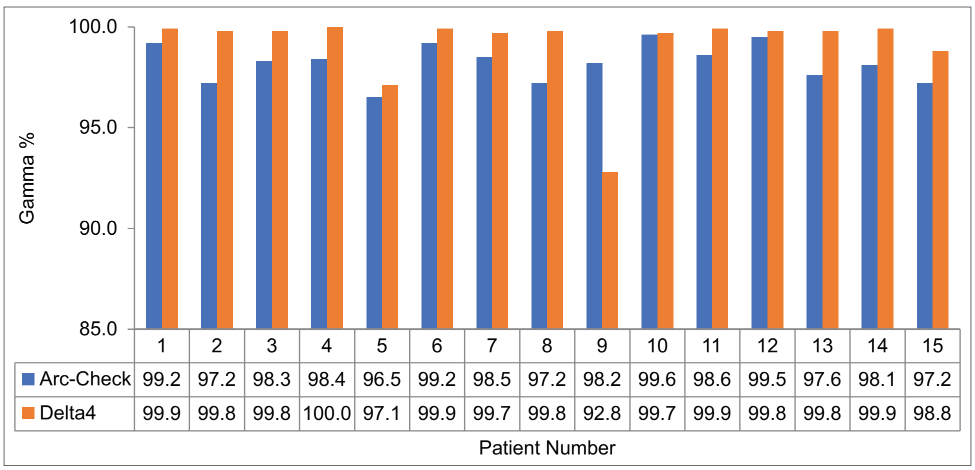

Figure 3: The gamma passing percentage using Arc-check and Delta[4] Phantoms

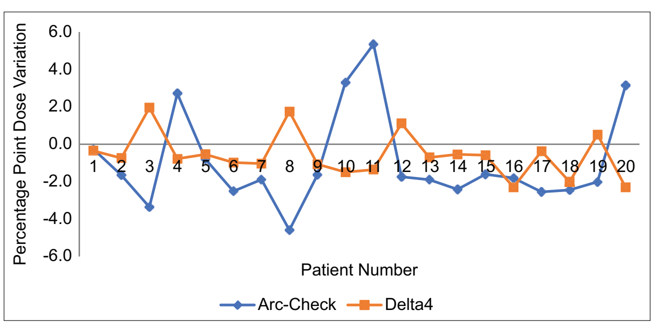

Figure 4: The point dose deviation from treatment planning system using Arc-check and Delta[4] Phantoms. TPS: Treatment planning system

For this study, we had used the criteria of 3% ΔD and 3 mm DTA.[20,21]

From this comparison, we found that the mean gamma passing[10,18] percentage using ArcCHECK was 98.2% ±0.9%, with median of 98.3% for these 15 patients. The median point dose deviation was −1.65%. The mean gamma passing percentage was 99.1 ± 1.8% using Delta4 with a median value of 99.8%. The median point dose deviation between TPS calculated and Delta4 measured was −0.71%. As we can see from the Figures 3 and 4, both the phantoms show high gamma passing rate as well as point dose, with some outliers in 2 cases. These two outliers were due to the chamber coming in the gradient region and failing to pass due to volume averaging effect.[22-24]

Conclusion

PSQA using array detectors is a crucial step in ensuring the safety and effectiveness of radiation therapy treatments. The comparative study conducted indicates that the Delta[4] array detector demonstrated the lowest mean percentage point dosage discrepancy between the TPS computed and observed point dose values. Moreover, the standard deviation associated with these differences was <2%, implying a high level of accuracy and consistency. In terms of gamma passing, the Delta[4] phantom outperformed the ArcCHECK phantom. The Delta[4] phantom provided superior gamma passing information on the OARs for individual patients, further enhancing the precision and customization of the treatment. Conversely, the ArcCHECK phantom primarily provided exit dosage information, which may be valuable for certain assessments but lacks the comprehensive patient-specific gamma passing data offered by the Delta^4 phantom. In conclusion, the comparative analysis strongly supports the use of the Delta4 array detector for PSQA in radiation therapy. Its ability to minimize dose discrepancies and provide valuable information on OARs ensures a safer and more effective treatment process, increasing confidence in the overall radiation therapy outcomes.

In conclusion, PSQA is crucial for precise and safe radiation therapy. The comparative study demonstrates that the Delta^4 phantom outperforms the ArcCHECK phantom in terms of accuracy and comprehensive dose assessment. By ensuring conformal dosing and accurate treatment delivery, the Delta^4 plays a significant role in enhancing the overall efficacy and safety of radiation therapy for cancer patients.

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Nil.

Conflicts of interest

There are no conflicts of interest.

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