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Implementation of AAPM TG-218 for Patient Specific Quality Assurance (PSQA) in The Case of Thoracic Target Region using IMRT Radiotherapy Technique with EPID aSi-1200

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Abstract

The implementation of Patient-Specific Quality Assurance (PSQA) is crucial for ensuring the accuracy and safety of Intensity-Modulated Radiation Therapy (IMRT). This study evaluates the application of AAPM TG-218 recommendations in PSQA for thoracic region treatment using the IMRT technique. The study compares two PSQA methods, Perpendicular Composite (PC) and Perpendicular Field-by-Field (PFF), using Electronic Portal Imaging Device (EPID). Measurements were conducted on 10 IMRT patients using a Varian TrueBeam Linac and Eclipse TPS. The Gamma Index (GI) analysis with criteria 3%/3 mm, 3%/2 mm, and 2%/2 mm was used to assess dose distribution accuracy. The results indicate that the average Gamma Passing Rate (GPR) for 3%/2 mm criteria exceeded 95%, which is appropriate with AAPM TG-218 standards. However, stricter criteria (2%/2 mm) did not reach the minimum recommended values. The study suggests that PSQA using EPID with the PFF method under rotational gantry conditions is the most suitable approach for thoracic IMRT treatment verification. The local standardization recommendations from the results of this study can be used as a reference for determining methodological standards in cases of the thoracic region in the IMRT technique to increase efficiency in clinical applications with similar PSQA dosimetry.

Introduction

The patient specific quality assurance (PSQA) program is critical in successfully implementing intensity modulated radiation therapy (IMRT). PSQA is a pretreatment quality assurance (QA) procedure aimed at verifying the accuracy of dose calculation performed by the Treatment Planning System (TPS). Ideally, PSQA should be conducted before the implementation of the radiotherapy treatment plan on the patient. This process serves as a quality assurance measure to ensure the conformity of the radiotherapy plan and to detect potential errors that may occur during irradiation. By performing PSQA, the accuracy of the delivered dose can be verified, ensuring that it aligns with the intended treatment procedure [1].

AAPM TG-218 recommends that the Tolerance Limit (TL) and Action Limit (AL) for the measurement results be set at 95% and 90% respectively at the 3%/2 mm GI variation with a threshold of 10%. Values exceeding the tolerance limit indicate potential deviations in the performance of a device or process. An investigation should be conducted if results fall outside the tolerance limit, followed by problem identification and necessary corrective actions. Corrections should be implemented before reaching the minimum threshold of the AL. It is important to note that the complexity of treatment planning is one of the factors influencing the AL value. For instance, differences in complexity exist between cervical, thoracic, and head-and-neck cases [2]. Thoracic malignancies pose distinct challenges for PSQA, particularly due to tissue heterogeneities and target motion along the radiation beam path [3].

Measurement evaluation to assess the difference between measurement results and TPS calculations can be applied using Gamma Index (GI) analysis, which is a standard procedure for PSQA [4]. The quantitative results of dose distribution evaluation using GI can serve as a standard for agreement [5]. The Gamma Passing Rate (GPR) value, based on the Dose Difference (DD)/Distance-to-Agreement (DTA) criteria, can indicate the system's responsiveness in detecting errors. A low GPR value signifies a high sensitivity of the GI measurement system to errors. The parameter known as DD testing assesses the agreement between two dose distributions in regions with dose gradients. DTA refers to the nearest point in the dose distribution appropriate to the reference dose location [6]. The GI criterion of 3%/3 mm is the most used standard referring to the AAPM TG-119 recommendation, while the 3%/2 mm criterion is recommended by AAPM TG-218. A more stringent parameter for evaluating the GPR is 2%/2 mm [7].

Standardization and consistency in PSQA practice to improve the efficiency and effectiveness of clinical implementation, especially in the case of thoracic target region radiotherapy, as a local standard in radiotherapy facilities is essential. This study seeks to evaluate the PSQA method that can be applied, it is hoped that several priority options for the PSQA method will be obtained according to the conditions at the radiotherapy facility where this study is conducted. Comparison of PSQA results on different methods is necessary before establishing a recommended local PSQA protocol [1]. PSQA data acquisition method for Electronic Portal Imaging Device (EPID) can be performed using the Perpendicular Field-by-Field (PFF) and Perpendicular Composite (PC) approaches. The PFF method aims to obtain the dose distribution for each field separately, allowing for individual dose distribution analysis [8]. The PC method offers the advantage of better clinical representation of the total dose distribution received by the patient, as well as a shorter PSQA duration since all dose data are combined in one step [9].

This study is the first implementation study where this research was conducted to determine the protocol for standardization of local procedures referring to the recommendations of AAPM TG 218. The use of the 3%/2 mm GI criterion is the best choice according to the TG-218 recommendations and Linac capability. However, the importance of this research must still be carried out to be more convincing that the study can be recommended as a local standardization of PSQA on IMRT techniques in the place where this research takes place. This study applied variations of the PSQA method, especially PC and PFF on EPID, especially in planning IMRT for the thoracic region. This PSQA evaluation aims to determine the most efficient local PSQA method recommendations for clinical applications using the EPID dosimetry. The PC and PFF methods for EPID can be implemented in static gantry and rotational gantry conditions. The results of the PSQA evaluation are expressed quantitatively in the form of GPR, which is obtained by comparing the variation of the GI criteria based on the variation of DD and DTA of the methods used in this study. Based on research conducted by Perbangkara et al (2016), a study has been conducted using 5 subjects in thoracic region cases compared to 2 radiotherapy centers. In this study, 10 subjects were used, but with variations in the projection of the PSQA method. In this study, it is expected to provide evaluation and recommendations of PSQA results on the IMRT technique with a variety of PSQA methods, namely PC and PFF with EPID dosimetry. The results of this PSQA evaluation will be a recommendation for an efficient PSQA method for cases of thorax region when clinical use at the local level in facilities that have similar PSQA dosimetry.

Experimental Method

This study was conducted using the Varian TrueBeam Linac (Varian, California, USA) for radiotherapy planning in 10 cases targeting the thoracic region. The TPS utilized was Eclipse TPS (Varian, California, USA). The detectors used for Patient-Specific Quality Assurance (PSQA) measurements were EPID (aSi-1200, Varian, California, USA). All radiotherapy plans employed 6 MV photon beams with the IMRT technique. The type of Multi Leaf Collimator (MLC) projection used is dynamic MLC and the calculation algorithm used in TPS is the Anisotropic Analytical Algorithm (AAA). PlanQA is used to simulate planning for the original patient to be the target of EPID dosimetry. Each radiotherapy planning case will be converted into a planQA with projections of PFF on static gantry, PFF on rotational gantry, PC on static gantry and PC on rotational gantry.

Patient Selection

This study involved a total of 10 subjects, comprising 10 thoracic region cases generated using PlanQA. 10 subjects of thorax region patients will then be used as planQA with 4 different method projections. From this projection it will result in 40 planQA. Each case was selected based on the first 10 radiotherapy treatment plans for IMRT technique patients targeting the thoracic region between January and February 2024. The case selection was determined by the location of the thoracic target region rather than specific case types, as these plans share similar IMRT planning settings and exhibit minimal contouring complexity.

In terms of the number of fields, thoracic region cases in our facility are typically tested using 5 to 7 fields. The analysis of GPR results in PSQA, as well as the accuracy of TPS calculation results when applied to Linac, was carried out using variations in GI criteria of 3%/3 mm, 3%/2 mm, and 2%/2 mm as test stricter parameters with a threshold used of 10%. The gamma analysis used was global gamma using the maximum dose of the entire plan (global max dose) as a reference.

Calibration of Electronic Portal Imaging Device

This measurement has been carried out on condition that the EPID has been calibrated. Measurements were made by adjusting the unlit background image without illumination (Dark Field) and the scatter image of the arm holding the detector (Flood Field) at a field setting of 43 x 43 cm^2 [10]. Absolute measurements at 1 CU (Calibration Unit) equivalent to 100 MU were also carried out on a field area of 10 x 10 cm^2. This calibration measurement is carried out at all photon energies and at an average dose of 50 - 600 MU/min.

Tolerance limit (TL) and Action Limit (TL)

TL and AL were calculated based on the guidelines outlined in TG-218. The plans had varying levels of complexity, and each plan underwent multiple measurements to minimize potential uncertainty due to differences in conditions. This approach was applied to ensure consistency and avoid significant deviations during the evaluation process. The AL is used to set the minimum performance level of the process. There are two types of action restrictions, the first is considered an absolute recommendation and does not vary from one hospital to another. The second is determined locally in each hospital and with the analysis of available data. The local AL constraints defined in this way can be procedural, equipment, and location-specific to each institution and are calculated using the following equation [11].

$$\Delta A = \beta\sqrt{\sigma^2 + (\bar{x} - T)^2} \quad (1)$$

$$Action\ Limit = 100 - \Delta A \quad (2)$$

AL is the maximum GPR value minus the difference between *the upper* and *lower*, which is ΔA. TL functions as a warning limit. Where calculation of tolerance limit based on lower control limit value, therefore

$$\text{Tolerance Limit (TL)} = \text{Lower Control Limit} \quad (3)$$

$$\text{Lower control limit} = \text{Center line} - 2{,}660.\,\overline{\text{mR}} \quad (4)$$

$$\text{Centerline} = \frac{1}{n}\sum_1^n x \quad (5)$$

$$\text{Moving Range } \left(\overline{\text{mR}}\right) = \frac{1}{n-1}\sum_{i=2}^{n}|x_i - x_{1-1}| \quad (6)$$

where $\bar{x}$ is the average of PSQA data, n is the number of individual PSQA data, σ^2 is variations of PSQA data, T represents the ideal value (set at 100), β is a constant with a value of 6.0. and x is the PSQA value of each individual. Moreover, evaluation criteria were established using the mean value center line (CL), and GPR as parameters [12].

Patient-Specific Quality Assurance tools

Varian TrueBeam is a US-made linac machine from Varian Medical Systems that has a photon energy of 6 MV, 6 MV Free Flattening Filter, and 10 MV [13]. TrueBeam (TB) has a millennium multi leaf collimator (MLC) specification with 20 leaves in the center with a width of 0.5 cm and 20 peripheral leaves with a width of 1 cm with an enhanced dynamic slice. TB is equipped with MV imaging with photon energy of 2.5 MV [14]. PSQA measurements were conducted using the PortalVision™ aSi-1200 on a Linac TrueBeam (Fig. 1), an advanced digital megavolt

imager featuring a 1280 × 1280 pixel matrix array, an active detection area of 43 cm × 43 cm, and a pixel size of 0.34 mm × 0.34 mm [15].

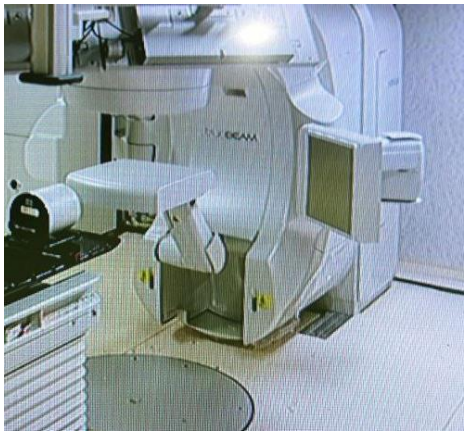

Figure 1. Linac TrueBeam with EPID aSi 1200 perpendicular to the radiation beam source

Patient-Specific Quality Assurance Measurements

The PSQA measurement evaluation was applied to validate the dose distribution of the TPS under various conditions, including the IMRT technique. The TPS fluence (fluence map) was compared with actual measurement results to ensure the agreement between treatment planning and delivery [16]. The GI calculation was used to analyze PSQA measurement results with EPID for radiotherapy planning. AAPM TG-218 was used as a reference for GI calculation. The recommendation for the DD and DTA criteria is 3%/2 mm, and the dose threshold is 10% of the maximum dose to exclude noise areas or low doses. The 3%/3 mm criterion is also applied, as it is the previous standard used on TG-119 for clinical practice. The GI calculation for PSQA using EPID was conducted using the PFF and PC methods, both of which were evaluated under static and rotational gantry conditions [17]. Fig.2 showed the interface of Portal Dosimetry analysis software, which consisted of profiles along collimator axes, histogram dose difference, respectively, predicted dose, blended dose, and portal dose.

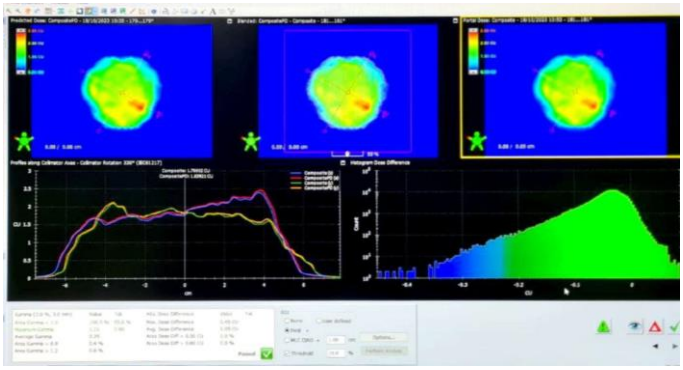

Figure 2. Portal Dosimetry interface view when displaying PSQA calculation results

Result and Discussion

The average measurement results of GPR, action limit, and tolerance limit from PSQA results are shown in Table 1 to Table 4. Table 1 shows the average GPR results for each method variation and GI variation exceeding 95% above the recommendation of AAPM TG-218. There are differences in each method variation and GI, but still below 1% of the total data. At the recommended global GI parameter of 3%/2 mm averaging, IMRT engineering radiotherapy planning in cases in the thoracic region can apply the global standard recommended by TG-218. An interesting thing is shown in the GI parameter data of 2%/2 mm in each method variation, indicating that the Linac TrueBeam at the test facility can apply stricter parameters.

Table 1. The average of GPR results from methods variation of PSQA and GI criteria 3%/3 mm, 3%/ 2 mm, and 2%/ 2mm.

Method	3%/3 mm	3%/2 mm	2%/2 mm
EPID PC Rotation	99.56 ± 0.81 %	99.20 ± 0.75 %	97.54 ± 1.84 %
EPID PFF Rotation	99.22 ± 1.07 %	98.91 ± 1.23 %	97.30 ± 2.16 %
EPID PC Static	99.52 ± 0.80 %	99.50 ± 1.15 %	97.58 ± 1.83 %
EPID PFF Static	99.27 ± 1.12 %	98.83 ± 1.15 %	97.09 ± 1.57 %

Table 2 shows the AL and TL results of the 3%/3 mm GI criteria in each method variation on the EPID. The 3%/3 mm GI criterion parameter is a widely used criterion for commissioning PSQA dosimetry before being used for clinical purposes recommended by AAPM TG-119 [18]. Quantitatively, measurements using the EPID with the PC method showed higher AL and TL values than the PFF method on the 3%/3 mm criteria, namely 97.58% and 94.47%, while the PC on the rotation gate was 97.17% and 94.37%. Similar data are also shown in the 3%/2 mm criteria shown in Table 3 with AL and TL being 97.28% and 93.41% for PC rotation gantry conditions, while in PC static gantry conditions are 96.54% and 92.45%, respectively. This is because the PC method can cover possible errors in the dose delivery from a beam field. Errors from each beam field can be covered due to the superposition of other beam distributions. However, the PC method provides an overall combined dose distribution from each radiation field, approaching the actual conditions in the patient [19].

Table 2. Tolerance limit and action limit results on GI criteria 3%/ 3 mm

Method	Tolerance Limit	Action Limit
	3%/3 mm	**3%/3 mm**
EPID PC Rotation	97.58 %	94.47%
EPID PFF Rotation	96.36%	92.04%
EPID PC Static	97.17%	94.37%
EPID PFF Static	96.04%	92.00%

Table 3. The Results of Tolerance and Action Limit on GI criteria 3%/2 mm

Method	Tolerance Limit	Action Limit
	3%/2 mm	**3%/2 mm**
EPID PC Rotation	97.28%	93.41%
EPID PFF Rotation	96.35%	90.13%
EPID PC Static	96.54%	92.45%
EPID PFF Static	95.81%	90.13%

Measurements using the PFF method under static and rotational gantry conditions showed lower AL and TL results than PC because the PFF method allows error detection in each IMRT planning field and identifies mechanical errors such as MLC misalignment or jaw positioning errors [8]. Overall, the average PSQA, AL and TL data for variations of the PSQA method and GI criteria of 3%/3 mm and 3%/2mm are still above the standards recommended in AAPM TG-218, namely AL and TL of > 95% and > 90%. In stricter test parameters with variations in GI criteria of 2%/2mm as in Table 4, it shows that it does not meet the TG-218 recommendations. In terms of the average results of PSQA data acquisition, the GPR value decreases with the increasingly stringent GI criteria used. This shows that the 2%/2 mm GI criterion detects more responsive errors [20]. The GI criteria of 2%/ 2 mm showed results below the recommended AL and TL, with a change in the tightness of the DD value of 2%. A change in the DD criterion of 2% from 3%, identified a difference in dose at the time of the implementation of radiotherapy planning in linac. This shows that the level of complexity of the target area of the thoracic region is very likely to occur in dose differences between TPS planning and when irradiation in Linac. The results of the AL and TL under the AAPM TG-218 standard indicate that there is a high probability of planning inconsistency with clinical actions, so further investigation is required such as alleged MLC errors, algorithm errors, less perpendicular gantry movement, or other mechanical errors at the time of measurement, if the 2%/2 mm criterion is to be applied as the local standard. Calibration errors or measurement inaccuracies can be the main factors in the dropping AL and TL values, but in this study, we have tried to minimize this by calibrating the EPID dosimetry to the Linac condition at the

time of measurement. This is in line with research from Yu et al., 2019 which showed a failure rate on the GI criterion of 2%/ 2 mm. Of course, the local standard AL and TL of 2%/2 mm is expected to be applied, this is because the accuracy of the dose difference between TPS and when applied to the linac is more assured of accuracy and precision before being applied to radiotherapy irradiation to the patient [21].

Table 4. The Results of Tolerance and Action Limit on GI criteria 2%/2 mm

Method	Tolerance Limit	Action Limit
	2%/2mm	2%/2mm
EPID PC Rotation	90.54%	81.55%
EPID PFF Rotation	91.92%	79.19%
EPID PC Static	92.47%	81.79%
EPID PFF Static	93.04%	80.18%

EPID has a higher resolution, making it more sensitive to small dose variations and providing more accurate error detection. This study shows that the AAPM TG-218 recommendation can be applied to IMRT planning for thoracic region cases on the TrueBeam Linac in the radiotherapy facility where this study was tested. Measurement time efficiency can be achieved by establishing standardization, method consistency, and type of detector used in PSQA practice in radiotherapy facilities. EPID offers higher time efficiency due to its integration with Linac [22]. EPID is directly integrated with the linac, allowing data acquisition during PSQA data acquisition without additional settings required [23]. EPID can detect position and dose errors because it has a high resolution, making it suitable for PSQA measurements for any method [24]. PSQA using EPID is more recommended in clinical use with many patients in a facility, but it is necessary to know the consistency of the PSQA taking method using EPID as a local standard in a radiotherapy facility. PSQA using the PFF method under rotation gantry conditions with a GI criterion of 3%/2 mm using EPID can be recommended as the main choice in PSQA measurements in the thoracic region to detect errors when planning is applied to the Linac. However, measurements using the PC method on EPID can also be an option based on the results of this study data, because it has a measurement difference of less than 1% compared to PFF. Measurements using the PC method are not recommended because they can cover up errors that may occur during irradiation but can still be used if the detectors available at a facility do not allow for PFF evaluation. Determining the 3%/2 mm criterion as a stricter GI criterion standard than 3%/3 mm is recommended in cases of thoracic regions such as breast cancer because it is more sensitive to smaller dose and geometry differences [25]. The stricter GI criterion of 2%/2 mm still does not reach the minimum AL and TL values recommended by AAPM TG-218, but stricter criteria such as 2%/2 mm can be used as an additional parameter to analyze the possibility of more subtle errors [26].

Conclusion

PSQA results in thoracic cases with variations of the PSQA method using EPID showed that the average GPR, AL, and TL calculations reached the minimum criteria recommended by AAPM TG-218. At the recommended GI criteria of 3%/2 mm, TL and AL values were obtained of >95.81% and >90.13%. PSQA measurements using EPID using the PFF method with the gantry rotation method can be the main choice and local standard for PSQA measurements. Determining the 3%/2 mm criterion as a stricter GI criterion standard than 3%/3 mm is recommended in thoracic cases such as breast cancer. The 2%/2 mm GI criterion in this study showed an average GPR above 95%. However, the TL and AL calculations produced values below the universal standard recommended by AAPM TG-218. This study shows that the global recommendations from TG-218 can be applied as recommendations for standardizing the PSQA method and local GI criteria at this study site for thoracic cases.

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