Iranian Journal of Medical Physics

ijmp.mums.ac.ir

Comparison of Patient-Specific Quality Assurance of 6 MV and 10 MV VMAT plan at Isocenter using Improved Gamma Evaluation Algorithm

Jitendra Nigam[1*], Piyush Kumar[2], P.P. Singh[1]

1. Department of Physics, Invertis University, Bareilly, (U.P.), India
2. Department of Radiation Oncology, SRMS Institute of Medical Sciences, Bareilly, (U.P.), India

ARTICLE INFO

Article type:
Original Paper

Article history:
Received: Aug 06, 2021
Accepted: Feb 14, 2022

Keywords:
Radiation Dosimetry
Portal Imaging
High Energy Radiotherapy
Linear Accelerator

ABSTRACT

Introduction: To compare Patient-Specific Quality Assurance (PSQA) of 6 MV and 10 MV Volume Modulated Arc Therapy (VMAT) plans performed with Electronic Portal Imaging Device (EPID) kept at Isocenter 100 cm (Source to Imager Distance (SID)) using an Improved Gamma Evaluation algorithm.
Material and Methods: Previously treated patients with 6 MV IMRT for Pelvic cancers were planned, on Eclipse TPS, with 6 MV and 10 MV photon beams using VMAT technology. The PSQA was performed using EPID and investigated the effect on Area Gamma, Maximum Gamma & Average Gamma.
Results: The mean Area Gamma passing rate (%GP±Standard Deviation(σ)) for 6 MV was 97.06±3.70, 95.42±5.31, 90.93±7.29, 86.55±9.10 and for 10 MV 97.14±6.08, 95.8±8.47, 94.62±9.45, 91.97±13.50 using the criteria 3%/3 mm, 3%/2 mm, 2%/3 mm, 2%/2 mm respectively. Similarly, for mean Maximum Gamma value for 6 MV was 2.50±0.89, 2.72±0.94, 3.32±1.13, 3.56±1.02 and for 10 MV 2.17±0.62, 2.42±0.72, 2.84±0.90, 3.26±0.94 respectively. For mean average gamma, value for 6 MV was 0.36±0.09, 0.42±0.10, 0.45±0.12, 0.53±0.13 and for 10 MV was 0.27±0.16, 0.32±0.19, 0.34±0.20, 0.41±0.24.
Conclusion: There is a marked difference between Area Gamma Passing Rate of 6 MV and 10 MV photon beam. The gamma criteria of 3%/2 mm with a 5% Threshold limit and 95% Area Gamma Passing Rate can be used for PSQA using EPID at Isocenter for 6 MV and 10 MV photon beam. There is no marked significant difference in values of mean Maximum Gamma and mean Average Gamma for 6 MV and 10 MV photon beams PSQA.

► *Please cite this article as:*
Nigam J, Kumar P, Singh PP. Comparison of Patient-Specific Quality Assurance of 6 MV and 10 MV VMAT plan at Isocenter using Improved Gamma Evaluation Algorithm. Iran J Med Phys 2022; 19: 282-289. 10.22038/IJMP.2022.59535.2001.

Introduction

Intensity Modulated Radiotherapy (IMRT) and Volume Modulated Arc Therapy (VMAT) are some advanced treatment technologies used to deliver radiation therapy treatment to cancer patients. In advanced radiation therapy, dose delivery is more precise and conformal to the target volume. This is achieved by treatment planning on advanced computer systems, and treatment delivery is performed through a linear accelerator (LINAC). The LINAC is supported by many electronic circuits and devices like Computer Systems, Imaging and Dosimetry devices, and other peripheral devices that help accurately deliver treatment. But in spite of lots of checks, it is possible that during delivery of radiation treatment, there are chances that due to incorrect data transfer, hardware or software failure, treatment may not be accurately delivered as planned by the computer system.

To rule out these types of situations, the Patient-Specific Assurance (PSQA) is performed by using various Quality Assurance (QA) devices like Gel dosimeters, Ionization Chambers, Radio chromic Films, 2D Array Detectors, and 3D Array Detectors [1]. Professional associations such as the American Association of Physicists in Medicine (AAPM) and The Netherlands Commission for Radiation Dosimetry have issued guidance documents on patient-specific quality assurance related to IMRT and VMAT [2-5].

There was a comparison of different types of QA devices conducted by multiple authors [6-8].

In TrueBeam, Varian Medical System provided Electronic Portal Imaging Device (EPID). EPID serves two purposes. First, it is used for Imaging, and Second, it is used for Portal Dosimetry. The EPID uses Amorphous Silicon flat panel detector to compare of 2D dose distribution – TPS computed and measured doses. There are many studies performed in relation to characteristics, dose-response, and calibration of EPID [9-11]. The modification in the detector from aS500, aS1000, to aS1200 leads to change in various properties of the detector. Also, various authors still

*Corresponding Author: Tel: +919457087277; Email: jnbarc37@yahoo.com

have debated using the same detectors for PSQA for IMRT [12-15] and VMAT [16-18].

As proposed by Low DA, and et al in 1998, Gamma Analysis was a milestone in PSQA [19-21] The Gamma Analysis Tool is a comparison of two dose distributions. Portal Dosimetry uses Improved Gamma Evaluation to perform Gamma Analysis.

The present study created the VMAT plans using 6 MV and 10 MV photon beams for various pelvic malignanc dose calculated by Eclipse TPS was compared with the dose measured by the EPID using Improved Gamma Evaluation Algorithm in portal dosimetry.

Materials and Methods

Patient Selection

Twenty-five (25) patients treated with IMRT using 6 MV photon beam and diagnosed with Pelvic Malignancies were included in the present study.15 female and 10 male patients were included in the study. The average age of patients was 56.6 years. The patients included in the study were suffering from cancer of the anorectum (Number of patient-1), cervix (12), endometrium (2), prostate (4), rectum (2), urinary bladder (4).

Linear Accelerator

The TrueBeam 2.5 Linear Accelerator is supplied and installed by Varian Medical Systems, Palo Alto, California, USA. The energy used in the present study is 6 MV and 10 MV photon energy.

Multi-Leaf Collimator

The Multi-Leaf Collimator (MLC) used is Millennium MLC – 120 Leaves (120MLC- Radiation Oncology Version). There are Two Banks - A & B. Each Bank with 40 inner leaf widths of 0.5 cm and 20 outer leaf widths of 1.0 cm at SSD 100 cm.

Electronic Portal Imaging Device (EPID)

The EPID is attached to TrueBeam. In the present study, the EPID was used as Quality Assurance Dosimeter. The EPID is an Amorphous Silicon aS1000 Type Flat panel detector. The Active Matrix size of EPID is 30 cm X 40 cm (768 pixels X1024 pixels). The size of each pixel is 0.39 mm X 0.39mm.

Treatment Planning System (TPS)

The TPS used is Eclipse Ver 13.6. The Calculation Model AAA_13.6.23, Photon Optimizer PO_13.6.23, and Portal Dose Image Prediction PDIP_13.6.23 with 2.5 mm Resolution in Normal Mode was used for Planning and Optimization.

Pre-Selection Steps

For every patient, the CT scan was done, and thereafter the patient data was imported into Eclipse TPS using DICOM Mode. The contouring of Target Volume and Organ at Risk was done by Radiation Oncologists. Treatment planning using Inverse Planning IMRT was done. The patient was shortlisted, satisfying the planned criteria, and treated with 6 MV using IMRT and suffering from Pelvic Malignancy. For these patients using the inverse planning technique, the VMAT plans were generated using 6 and 10 MV photon beams.

Creation of Verification Plan using PDIP Algorithm

For the generated plans, using the portal Dose Image Prediction (PDIP) algorithm, the verification plans were created for PSQA. This algorithm does not consider the patient and the treatment couch while creating the verification plan. For each 6 MV and 10 MV VMAT plans, separate verification plans were created, keeping Source-Imager Distance (SID) (IEC 61217) to 100 cm. The Field Geometry was not set to zero. The beams were tested at the actual treatment angle. The same Tolerance Table was used as was used in the original treatment plan. All the beams were kept in the same verification plan (plan generation mode). This verification plan was recalculated without a patient for all the planned fields at the actually planned gantry angle. In the scheduling workspace, the plan was scheduled and integral images were added to each beam. Before delivery, the plan was approved and was delivered in QA mode on a TrueBeam treatment machine. Before every PSQA, the EPID was warmed with 1000 MU by opening the Field Size to 30 cm X 40 cm. The EPID was kept at 100 cm for all readings. During PSQA, the couch was entirely outside the beam, and EPID was directly facing the collimator. After the performance of PSQA on EPID, the fluence maps were saved to the system. Portal Dosimetry in Eclipse was used for PSQA using Gamma Analysis with Improved Gamma Evaluation. Selecting the appropriate course and plan, the PSQA was performed. Each field separately is aligned to the reference image. The composite image was created by selecting all the separately aligned images. The composite image was used for the evaluation of the plan. The predicted plan and measured plan were compared using Improved Gamma Evaluation, as shown in Figure 1. The doses calculated by Eclipse TPS were compared with the doses measured by the EPID using Gamma Analysis with Improved Gamma Evaluation method. There were two sets of readings for VMAT plans. One for 6 MV and another for 10 MV VMAT plans. Under each set, the gamma analysis was performed using the criteria 3%/3 mm, 3%/2 mm, 2%/ 3mm, and 2%/2 mm. The threshold value of 5% was used. No Normalization and No corrections were introduced in the results to correct the value. Further, two other parameters, Maximum Gamma (γ_{max}), and Average Gamma (γ_{ave}) were also evaluated in the present study.

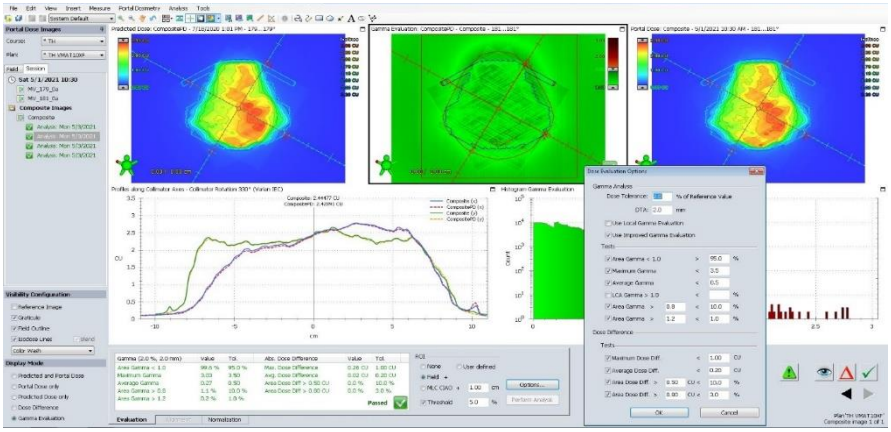


Figure 1. EPID Gamma Evaluation & Settings using Portal Dosimetry. Evaluation table at the bottom centre shows gamma evaluation results. Inset shows settings used for Gamma Evaluation

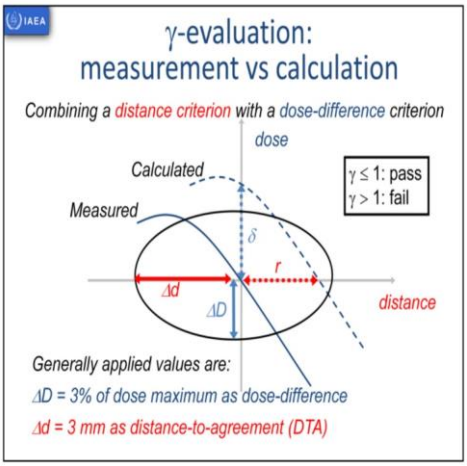
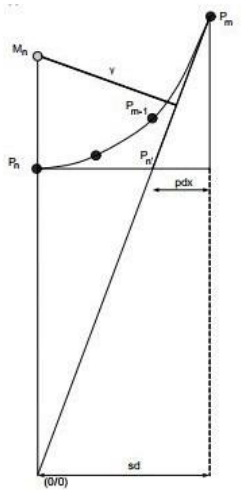


Figure 2. Gamma Evaluation (Source: IAEA Presentation)



Abbreviation	Description
M_n	Acquired pixel at position n.
P_n	Predicted pixel at position n.
$P_{n'}$	Point with coordinates $[P_{m-1}(x), P_n(y)]$.
P_m	Predicted pixel at currently observed shell, at position m.
P_{m-1}	Predicted pixel at position m-1.
pdx	Distance of two predicted pixels (= pixel size of predicted pixels).
sd	Shell distance, $P_m(x) - P_n(x)$.

Figure 3. Improved Gamma Algorithm (Source: Portal Dosimetry Manual, Varian Medical Systems)

Dose Analysis

Gamma Analysis or Gamma Evaluation or γ-evaluation, or gamma index analysis are different types of names used for Gamma evaluation. The method was introduced by Low, and et al [19-21]. It combines distance criteria with dose difference criteria. The distance criteria are expressed as Distance-to-agreement (DTA) in mm, while the dose-difference is expressed as Dose Maximum (ΔD) in percentage %. It compares the two-dose distributions. The ΔD is important in low-dose gradient regions, while the DTA in mm provides information in high-dose gradient regions. The gamma index analysis produces Gamma Value. The points lying inside the ellipse with axes having the criteria values

have a gamma value refer to Figure 2. If the Gamma Value $\gamma \leq 1$, it denotes the pass of the test, and If the Gamma value is $\gamma > 1$, it denotes the failure of the test. Gamma Passing Rate (%GP) is the passing points, in terms of percentage, in the gamma distributions.

Improved Gamma Algorithm

The original algorithm used to calculate the gamma evaluation searched for the best gamma value only at the integer pixel positions around the given source pixel. Due to this, the gamma value may be overestimated at that point. To overcome this limitation, an improved Gamma calculation algorithm has been developed refer to Figure 3. It is based on the neighbor search algorithm as described in Calculation of Gamma Evaluation with an extension to interpolate between neighboring predicted points. This algorithm has an upper bound for the underestimation or overestimation of gamma, which is the distance between two predicted pixels (pdx). The typical error is much smaller than this upper bound.

Statistical analysis

To compare 6 MV and 10 MV psqa results, Pearson correlation coefficient was calculated using online website https://www.statskingdom.com/correlation-calculator.html. The Pearson correlation coefficient (r) measure linear association between two variables. Thereafter the p value for different parameter was calculated using r value. The p value is shown in the Table 1.The p-value <0.05 were considered statistically significant in present study. Except for 2%/3 mm Area Gamma, all the p-value are statistically significant.

Results

The individual observations are shown in Figures 4 to 15. The results are tabulated in Table 1.

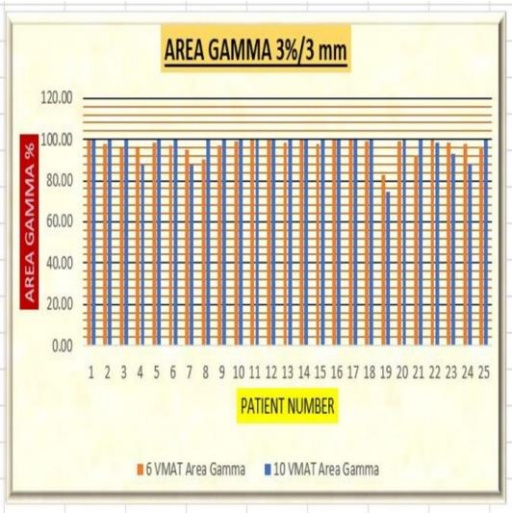


Figure 4. Individual Patient Response Area Gamma 3%/3 mm

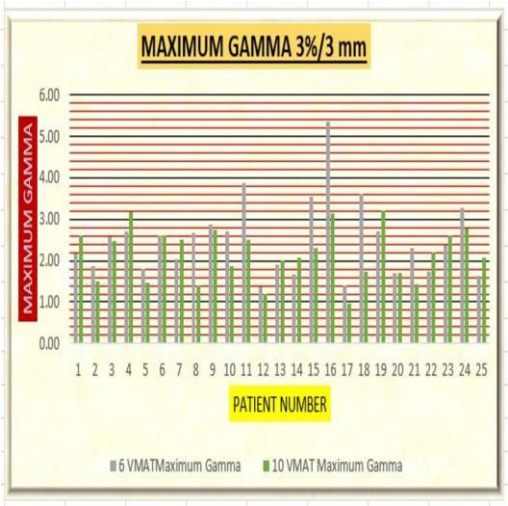


Figure 5. Individual Patient Response Maximum Gamma 3%/3 mm

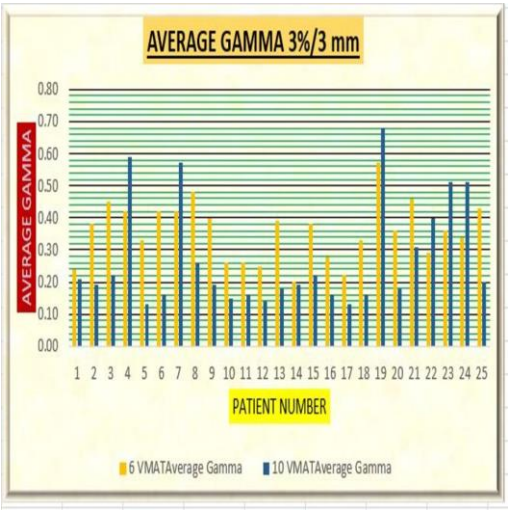


Figure 6. Individual Patient Response Average Gamma 3%/3 mm

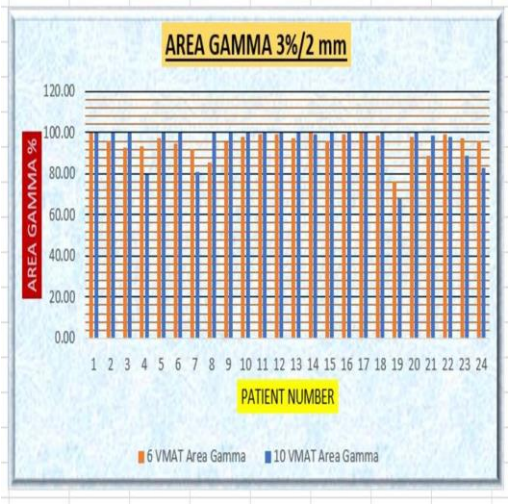


Figure 7. Individual Patient Response Area Gamma 3%/2 mm

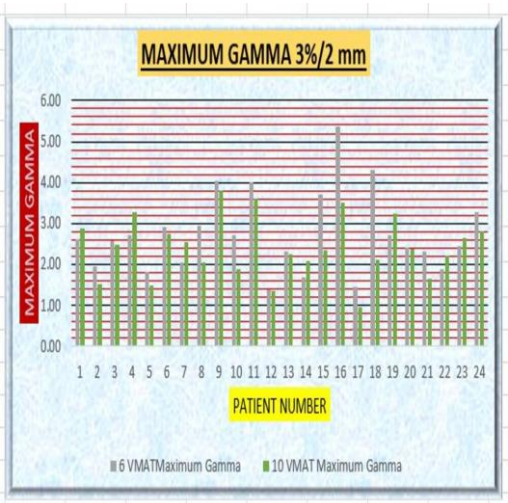


Figure 8. Individual Patient Response Maximum Gamma 3%/2 mm

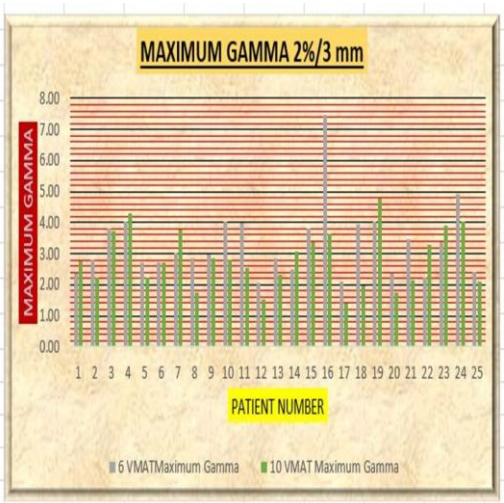


Figure 11. Individual Patient Response Maximum Gamma 2%/3 mm

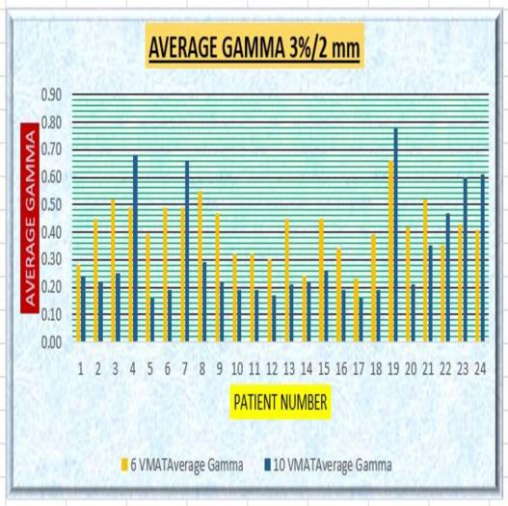


Figure 9. Individual Patient Response Average Gamma 3%/2 mm

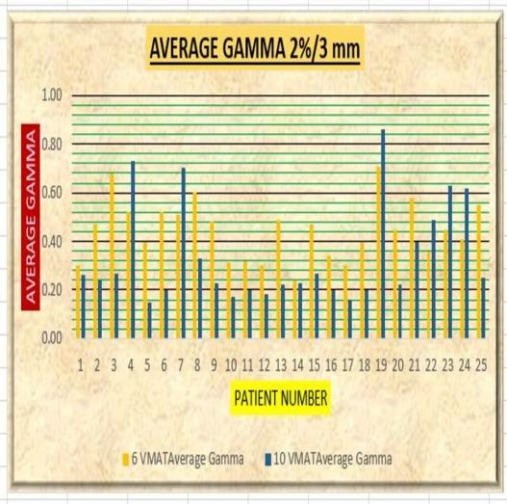


Figure 12. Individual Patient Response Average Gamma 2%/3 mm

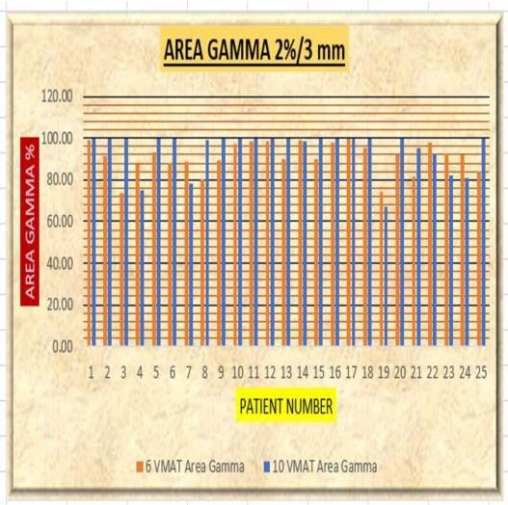


Figure 10. Individual Patient Response Area Gamma 2%/3 mm

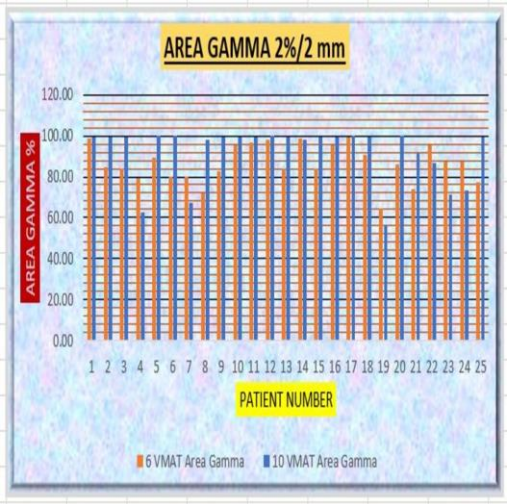


Figure 13. Individual Patient Response Area Gamma 2%/2 mm

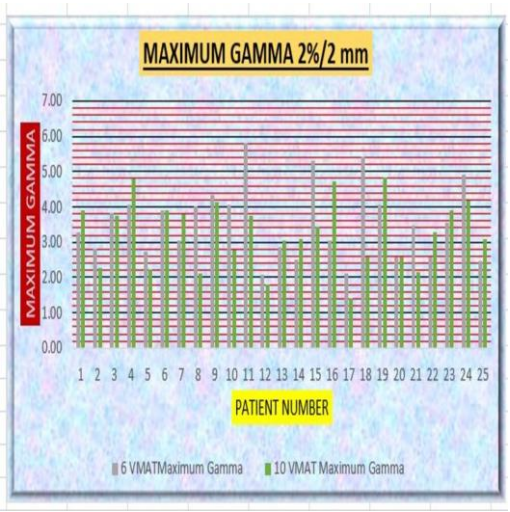


Figure 14. Individual Patient Response Maximum Gamma 2%/2 mm

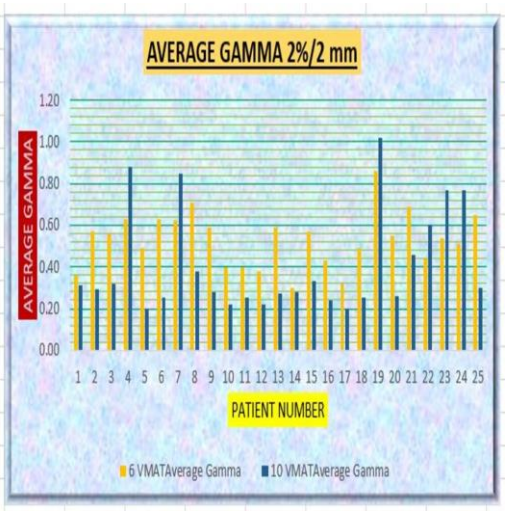


Figure 15. Individual Patient Response Average Gamma 2%/2 mm

Table 1. Statistical Data for Gamma Criteria and Parameter Studied

Gamma Criteria	Parameter (Tolerance)	Figure	VMAT 6 MV Mean ± Standard Deviation	VMAT 10 MV Mean ± Standard Deviation	Difference between Mean (6 MV-10 MV)	P value
3%/3 mm	Area Gamma (Tolerance:95%)	Figure 4	97.06±3.70	97.14±6.08	-0.08	0.0002464
	Maximum Gamma (Tolerance:3.5)	Figure 5	2.50±0.89	2.17±0.62	0.33	0.00506
	Average Gamma (Tolerance:0.50)	Figure 6	0.36±0.09	0.27±0.16	0.09	0.0115
3%/2 mm	Area Gamma (Tolerance:95%)	Figure 7	95.42±5.31	95.8±8.47	-0.38	0.0009537
	Maximum Gamma (Tolerance:3.5)	Figure 8	2.72±0.94	2.42±0.72	0.30	0.0002366
	Average Gamma (Tolerance:0.50)	Figure 9	0.42±0.10	0.32±0.19	0.10	0.01161
2%/3 mm	Area Gamma (Tolerance:95%)	Figure 10	90.93±7.29	94.62±9.45	-3.69	0.06748
	Maximum Gamma (Tolerance:3.5)	Figure 11	3.32±1.13	2.84±0.90	0.48	0.007124
	Average Gamma (Tolerance:0.50)	Figure 12	0.45±0.12	0.34±0.20	0.11	0.02145
2%/2 mm	Area Gamma (Tolerance:95%)	Figure 13	86.55±9.10	91.97±13.50	-5.42	0.02534
	Maximum Gamma (Tolerance:3.5)	Figure 14	3.56±1.02	3.26±0.94	0.30	0.0433
	Average Gamma (Tolerance:0.50)	Figure 15	0.53±0.13	0.41±0.24	0.12	0.008555

Discussion

The present study demonstrated that EPID could be used for the verification of VMAT plans. The time taken to perform PSQA was reasonable. The comparison of results of 6 MV and 10 MV psqa shows that there is a marked difference in the value of Area Gamma as the PSQA was moved towards the strict criteria. The p-value is statistically significant for Area Gamma with Gamma criteria of 3%/3 mm (p-value=0.0002464), 3%/2 mm (p-value=0.0009537) and 2%/2 mm (p-value=0.02534). There was little difference in the mean values of Maximum Gamma and Average Gamma for various Gamma Criteria but in each case, the p-value is statistically significant as shown in the Table 1. Also, from the results, it could be observed that as Gamma criteria were moved to more strict criteria, the Value of Area Gamma %GP decreased for both the beam energies.

Zijtveld, and et al. [22] reported for 3%/3 mm criteria 0.32±0.10(γ_{ave}) while in the present study for (γ_{ave}) was 0.36±0.09 using 6 MV photon and 0.25±0.40(γ_{ave}) using 10 MV photon in VMAT plan. The results are comparable and are in close agreement with the study of Zijtveld.

Roxby et al. [23] studied pre-treatment verification of Head and Neck IMRT plans using EPID. Authors reported results under three categories – Initial, Test, and Clinical Testing. Under Test Category, the team reported for 3%/3 mm gamma criteria with Gantry Set to 0 and using IMRT plans, and the results were 0.986 (2SD=0.027) (γ_{area}); 2.51 (2SD=1.3) (γ_{max}), and 0.14 (2SD=0.09) (γ_{ave}) without repositioning of EPID. The results in the present study were 97.06±3.70 (γ_{area}), 2.50±0.89(γ_{max}) and 0.36±0.09 (γ_{ave}) in 6 MV VMAT plans. For 2%/2 mm, Roxby et al reported that under Test, 0.987 (2SD=0.018) (γ_{area}); 3.10 (2SD=1.6) (γ_{max}) and 0.19 (2SD=0.13) (γ_{ave}) after repositing. The results

obtained in the present study using 6 MV VMAT plans for 2%/2 mm Gamma criteria are 86.55±9.10 (γ_{area}), 3.56±1.02 (γ_{max}), and 0.53±0.13 (γ_{ave}). Roxby's team repositioned the EPID to correct the value obtained, whereas, in the present study, no correction was applied. But the results in the present study are acceptable for 3%/3 mm because results are within tolerance limits, whereas for 2%/2 mm require considerable monitoring.

Matsumoto et al. [24] studied and discussed the dosimetric properties of aS1000 EPID for IMRT. The position of the EPID was kept at 105 cm. The authors reported for 3%/3 mm Gamma Criteria 1.37±0.42 (γ_{max}) and 0.26±0.11 (γ_{ave}). In the present study, the values obtained for 3%/3 mm Gamma Criteria are 2.50±0.89 (γ_{max}) and 0.36±0.09 (γ_{ave}). The position of EPID was at 100 cm. The difference in gamma values may be due to the different positions of EPID. The results were within the tolerance limit in both studies.

Jayesh K et al. [25] study reported that with EPID for 3%/3 mm criteria for 6 MV beam, the values for IMRT are 1.31±.14 (γ_{max}) and 0.31±.03 (γ_{ave}); for VMAT, the values are 1.73±0.66 (γ_{max}) and 0.48±.06 (γ_{ave}). In the present study, the corresponding results for VMAT 6 MV beam, 3%/3 mm criteria, values are 2.50±0.89 (γ_{max}) and 0.36±0.09 (γ_{ave}). As can be observed, the results are near and in an acceptable range.

Surendran, and et al. [26] compared the portal dosimetry and ImatriXX 2-D array system for IMRT and Rapid Arc PSQA. Considering the EPID results, the authors reported, that for IMRT 3%/3 mm criteria, the values are 1.72±0.20 (γ_{max}) and 0.48±0.05 (γ_{ave}), whereas, for Rapid Arc, the values are 1.72±0.29 (γ_{max}) and 0.48±0.07 (γ_{ave}). In the present study using 6 MV photon beam for VMAT plan and 3%/3 mm criteria, the corresponding values are 2.50±0.89 (γ_{max}) and 0.36±0.09 (γ_{ave}).

Mohamed, and et al. [27] performed QA for 24 patients using VMAT technology using 6 MV photon beams. The results reported by the authors for 3%/3 mm were 99.42±0.67 (γ_{area}), 2.11±0.56 (γ_{max}), and 0.19±0.05 (γ_{ave}). For 2%/2 mm criteria, the results are 94.73±6.54 (γ_{area}), 3.41±0.94 (γ_{max}), and 0.31±0.09 (γ_{ave}). In the present study, the results for the VMAT plan using 6 MV with 3%/3 mm criteria were 97.06±3.70 (γ_{area}), 2.50±0.89 (γ_{max}), and 0.36±0.09 (γ_{ave}) whereas for 2%/2 mm criteria, 86.55±9.10 (γ_{area}), 3.56±1.02 (γ_{max}) and 0.53±0.13 (γ_{ave}). As can be observed, the 2%/2 mm results are beyond acceptable limits of %GP=95% and could not be accepted for PSQA.

More, and et al. [28] discussed the dosimetric properties for IMRT in Head and Neck cases using 6 MV photon beams and performed PSQA on two different devices. More, and et al. set the Gantry to Zero degree. The authors reported EPID for 3%/3 mm Gamma Criteria, the Area Gamma 98.18%, 2.19 (γ_{max}), and 0.192±0.048 (γ_{ave}). The authors concluded from the study that there was no defined connection between Area Gamma, Maximum Gamma (γ_{max}), and Average Gamma (γ_{ave}) in planned and measured dose distributions. In the present study, it was also observed that for 6 MV and 10 MV Beam with VMAT plan, there was no relationship between Area Gamma, Maximum Gamma, and Average Gamma.

More, and et al. [29] studied pre-treatment verification with EPID and ImatriXX for patients treated through IMRT. Patients from various cancer sites were included in the study. For cancer Cervix patients with 3%/3 mm criteria, the results reported were Area Gamma 97.95%, 2.33 (γ_{max}) and 0.19 (γ_{ave}) with EPID. The Gantry was kept at 0^0. As compared, in the present study, with EPID at isocenter and gantry moving at treatment angle, the results were Area Gamma 97.06%, Max Gamma 2.5, and Average Gamma 0.36.

Recommendations

The PSQA of VMAT-treated patients can be performed with EPID using the improved Gamma evaluation algorithm. The Gamma Criteria of 3%/3 mm and 3%/2 mm with a 5% Threshold limit with a Gamma Passing Rate of 95% can be used for PSQA in VMAT-treated patients with 6 MV & 10MV. For 2%/2 mm, the Gamma Passing rate is less than 95% which is beyond the acceptable limit for PSQA and therefore requires careful considerations and clinical correlations before implementation in the clinical setup.

Conclusion

There is a marked difference between Area Gamma Passing Rate of 6 MV and 10 MV photon beam. The results demonstrated that gamma criteria 3%/2 mm with 5% Threshold limit and 95% Gamma Passing Rate can be used for PSQA using EPID at Isocenter for 6 MV as well as for 10 MV photon beam. There is no marked significant difference in values of mean Maximum Gamma and mean Average Gamma for 6 MV and 10 MV photon beams.

Acknowledgment

The authors wish to appreciate the help provided by technical staff in the collection of data at the Department of Radiation Oncology, SRMSIMS, Bareilly. And technical support is provided by service engineers of Varian Medical Systems.

References

1. Dogan N. Tools for IMRT QA. Department Of Radiation Oncology, Virginia Commonwealth University, Medical College Of Virginia Hospitals, Richmond, VA, USA. 2005 Jun 1.
2. Miften M, Olch A, Mihailidis D, Moran J, Pawlicki T, Molineu A, and et al. Tolerance limits and methodologies for IMRT measurement-based verification QA: recommendations of AAPM Task Group No. 218. Medical physics. 2018 Apr;45(4):e53-83.
3. Stralingsdosimetrie NC, Commissie N, Stralingsdosimetrie V, Stralingsdosimetrie NC. Code of practice for the quality assurance and control for intensity modulated radiotherapy. no. June. 2013 Jun.

4. Stralingsdosimetrie NC. Code of Practice for the Quality Assurance and Control for Volumetric Modulated Arc Therapy. Report. 2015 Feb;24:9-59.
5. Ezzell GA, Galvin JM, Low D, Palta JR, Rosen I, Sharpe MB, and et al. Guidance document on delivery, treatment planning, and clinical implementation of IMRT: report of the IMRT Subcommittee of the AAPM Radiation Therapy Committee. Medical physics. 2003 Aug;30(8):2089-115.
6. Son J, Baek T, Lee B, Shin D, Park SY, Park J, and et al. A comparison of the quality assurance of four dosimetric tools for intensity modulated radiation therapy. Radiology and oncology. 2015 Sep;49(3):307.
7. Sharma DS, Mhatre V, Heigrujam M, Talapatra K, Mallik S. Portal dosimetry for pretreatment verification of IMRT plan: a comparison with 2D ion chamber array. Journal of applied clinical medical physics. 2010 Sep;11(4):238-48.
8. Merheb C, Chevillard C, Ksouri W, Fawzi M, Bollet M, Toledano A. Comparison between two different algorithms used for pretreatment QA via aSi portal images. Journal of applied clinical medical physics. 2015 May;16(3):141-53.
9. Winkler P, Hefner A, Georg D. Dose-response characteristics of an amorphous silicon EPID. Medical physics. 2005 Oct;32(10):3095-105.
10. Spezi E, Lewis DG. Gamma histograms for radiotherapy plan evaluation. Radiotherapy and oncology. 2006 May 1;79(2):224-30.
11. Antonuk LE. Electronic portal imaging devices: a review and historical perspective of contemporary technologies and research. Physics in Medicine & Biology. 2002 Mar 1;47(6):R31.
12. Depuydt T, Van Esch A, Huyskens DP. A quantitative evaluation of IMRT dose distributions: refinement and clinical assessment of the gamma evaluation. Radiotherapy and oncology. 2002 Mar 1;62(3):309-19.
13. Létourneau D, Gulam M, Yan D, Oldham M, Wong JW. Evaluation of a 2D diode array for IMRT quality assurance. Radiotherapy and oncology. 2004 Feb 1;70(2):199-206.
14. Greer PB, Popescu CC. Dosimetric properties of an amorphous silicon electronic portal imaging device for verification of dynamic intensity modulated radiation therapy. Medical physics. 2003 Jul;30(7):1618-27.
15. Van Esch A, Depuydt T, Huyskens DP. The use of an aSi-based EPID for routine absolute dosimetric pre-treatment verification of dynamic IMRT fields. Radiotherapy and oncology. 2004 May 1;71(2):223-34.
16. Krishna Murthy K, Anandagiribabu A, Prasad PB, Kaviarasu K. Patient-specific quality assurance of RapidArc treatments: Portal prediction dosimetry compared with phantom studies. Biomed Imaging Interv J. 2012 Oct 1;8:e28-34.
17. Fogliata A, Clivio A, Fenoglietto P, Hrbacek J, Kloeck S, Lattuada P, and et al. Quality assurance of RapidArc in clinical practice using portal dosimetry. The British journal of radiology. 2011 Jun;84(1002):534-45.
18. Wagner D, Vorwerk H. Two years experience with quality assurance protocol for patient related Rapid Arc treatment plan verification using a two dimensional ionization chamber array. Radiation oncology. 2011 Dec;6(1):1-8.
19. Low DA, Harms WB, Mutic S, Purdy JA. A technique for the quantitative evaluation of dose distributions. Medical physics. 1998 May;25(5):656-61.
20. Low DA, Dempsey JF. Evaluation of the gamma dose distribution comparison method. Medical physics. 2003 Sep;30(9):2455-64.
21. Low DA. Gamma dose distribution evaluation tool. InJournal of Physics: Conference Series 2010 Nov 1 (Vol. 250, No. 1, p. 012071). IOP Publishing.
22. van Zijtveld M, Dirkx ML, de Boer HC, Heijmen BJ. Dosimetric pre-treatment verification of IMRT using an EPID; clinical experience. Radiotherapy and oncology. 2006 Nov 1;81(2):168-75.
23. Roxby KJ, Crosbie JC. Pre-treatment verification of intensity modulated radiation therapy plans using a commercial electronic portal dosimetry system. Australasian physical & engineering sciences in medicine. 2010 Mar;33(1):51-7.
24. Matsumoto K, Okumura M, Asai Y, Shimomura K, Tamura M, Nishimura Y. Dosimetric properties and clinical application of an a-Si EPID for dynamic IMRT quality assurance. Radiological physics and technology. 2013 Jan;6(1):210-8.
25. Jayesh K, Ganesh T, Suganthi D, Mohan R, Rakesh CJ, Sarojkumar DM, Jacob SJ. Dosimetric comparison of aSi1000 EPID and ImatriXX 2-D array system for volumetric modulated arc and intensity modulated radiotherapy patient specific quality assurance. Int J Math Comput Phys Electrical Comput Eng. 2013 Mar 27;7(3):393-4.
26. Surendran S, Rao DP, Cyriac SL. Study of feasibility of portal dosimetry in comparison with ImatriXX 2-D array system for IMRT and Rapid arc patient specific QA. IOSR-JEN. 2014;4(6):11-15.
27. Mohamed IE, Ibrahim AG, Zidan HM, El-Bahkiry HS, El-sahragti AY. Physical dosimetry of volumetric modulated arc therapy (VMAT) using EPID and 2D array for quality assurance. The Egyptian Journal of Radiology and Nuclear Medicine. 2018 Jun 1;49(2):477-84.
28. More M, Jain V, Gurjar OP. Clinical Experience of Intensity Modulated Radiotherapy Pre-Treatment Quality Assurance for Carcinoma Head and Neck Patients with EPID and IMatriXX in Rural Center. Journal of Biomedical Physics & Engineering. 2020 Dec;10(6):691.
29. More M, Jain V, Gurjar OP. Pre-treatment Verification Performed with Electronic Portal Imager Device (EPID) and IMatriXX for 204 Cancer Patients Treated with Intensity Modulated Radiotherapy (IMRT) –Phantom Based Study. Iran J Med Phys . 2021; 18: 444-451.