Volume 21, No 4 | International Journal of Radiation Research, October 2023

Correlation analysis between 2D and 3D patient-specific quality assurance for volumetric modulated arc therapy

S. Sharma[1*], D. Sharma[1], V. Subramani[1], N. Gopishankar[1], S. Bhaskar[1], S. Pathy[1], P. Kumar[2], S. Thulkar[3], S. Chander[1]

[1]Department of Radiotherapy, Dr. B. R. A. Institute Rotary Cancer Hospital, All India Institute of Medical Sciences, New Delhi, India
[2]Department of Radiotherapy, AIIMS, New Delhi-110029, New Delhi, India
[3]Department of Radio-diagnosis, AIIMS, New Delhi-110029, New Delhi, India

► ***Original article***

Corresponding author:
Seema Sharma, Ph.D.,
E-mail: *seema_drp@yahoo.co.in*

Received: May 2022
Final revised: May 2023
Accepted: May 2023

Int. J. Radiat. Res., October 2023; 21(4): 685-691

DOI: 10.52547/ijrr.21.4.12

Keywords: *Patient specific QA, 2D measurements, COMPASS QA, Correlation analysis.*

ABSTRACT

***Background*:** Aim is to find correlation between 2D-gamma passing rate and 3D-DVH-based pre-treatment patient-specific quality assurance. ***Materials and Methods*:** 21 head and neck and 21 pelvis patients, treated with volumetric modulated arc therapy (VMAT) were selected for this study. All patients were planned with Elekta VersaHD linear accelerator using Monaco (5.11) treatment planning system. 2D-planar dose measurements were performed with IBA-I'matriXX evolution detector-array using My-QA-Patients software. For 2D-Gamma index evaluation, 3%/3mm and 2%/2mm criteria were used. 3D-dose measurements were performed using the IBA-COMPASS system. For 3D measurement, Monaco and COMPASS doses were compared in terms of percentage dose differences to PTV and organs at risk. For PTV D95, D2, and D50 (dose received by 95%, 2%, and 50% volume), similarly for OARs D2 and D50 were noted. 3D Gamma index was also noted. Correlation coefficient and its corresponding two-tailed p-value (≤0.05, for statistically significant) were calculated for 2D-gamma passing rate and 3D Gamma index & percentage dose differences of 3D-DVH based metrics (Monaco calculated versus COMPASS measured). Strength of correlation will be considered weak or strong based on the r -value. ***Results*:** 2D-Gamma index passing rate was 98.6±1.8%, 92.1±7.1% and 98.5±1.3%, 93.5±4.4% for head-neck and pelvis patients (3%/3mm, 2%/2mm criteria) respectively. Percentage dose-differences for PTV D95, D2, D50 for head-neck and pelvis were: 4.22±2.09%, 4.25±2.23%, 3.93±1.59 & 0.60±1.96%, 1.53±1.64%, 1.59±1.20% respectively. Spine and brainstem D2 were -0.84±6.10%, 0.77±2.70%, bladder and rectum D50 were 3.75±3.31%, -2.19±3.60%. ***Conclusion*:** No strong correlation was observed between the 2D Gamma passing rate and 3D measurements.

INTRODUCTION

Rotational IMRT; Intensity-Modulated Arc Therapy (IMAT) was first proposed by Yu *et al.* (1995) [1]. IMAT allows treatment delivery with continuous MLC movement and rotating gantry motion. For the Elekta machine, IMAT is called volumetric modulated arc therapy (VMAT). VMAT allows for highly conformal dose distribution with sharp dose gradients for complex target volumes with concave surfaces. Improvement in patient planning and delivery techniques (i.e. IMRT/VMAT) doesn't come without risk. IMRT/VMAT requires extensive verification measurements to ensure that the treatments are delivered correctly (Ibbott *et al.* 2008, Ezzell *et al.* 2009) [2, 3]. The American Association of Physicists in Medicine (AAPM) guidance document (AAPM TG-120) on IMRT points out the requirement for patient-specific IMRT QA [4]. The European Society for therapeutic Radiology and Oncology (ESTRO) guideline for the verification (ESTRO -2008) of IMRT states that Special hardware and software are necessary for the planning and delivery of IMRT. Furthermore, the routine clinical use of this complex treatment modality required an extensive, time-consuming, acceptance testing, commissioning, and quality assurance (QA) program [5]. Modern radiotherapy practice which involves highly complex and automated processes for planning and delivery raises issues for quality assurance and motivates the development of more modern and sophisticated approaches for the quality control program for our clinical radiotherapy treatment methods (Fraass *et al.* 2008) [6].

The objective of patient-specific pre-treatment quality assurance is to compare the planned and the delivered treatment plan, for doing that many methods are followed for two-dimensional (2D) and three-dimensional (3D) dose verification. For 2D planar dose measurement, measured and planned dose fluence were compared using the gamma index, but the 2D planar comparison is limited to one plane,

and the gamma index pass rate does not give any clinically relevant information. Interpretation of the gamma passing rate in terms of a clinical point of view was difficult. In 3D patient-specific quality assurance, planned and delivered doses can be compared in terms of dose volume histogram (DVH). DVH does not have spatial information and also all the area in the patient is not contoured therefore one may miss the error if occurred in normal tissue using DVH based evaluation method. Carrasco *et al.* [7] performed both 2D and 3D dose verification and found that the 2D gamma passing rate is not able to detect the dose errors which were introduced intentionally, to check the sensitivity of QA. Similarly, Zhen *et al.* [8] and Nelms *et al.* [9] observed that there is no correlation between 2D gamma pass rate and clinically relevant dose error. Both 2D and 3D QA methods have their merits and demerits. Performing both 2D and 3D QA for all the patients in a busy clinic is not possible. We have tools for performing both 2D and 3D patient-specific quality assurance, and the same detector is used for both 2D and 3D measurement, and if any correlation is found between the two methods then one type of measurement can be skipped. Therefore we have designed a study to establish the correlation between 2D and 3D pre-treatment quality assurance in our setup.

MATERIALS AND METHODS

Twenty-one (21) head & neck and 21 pelvis patients, treated with volumetric modulated arc therapy (VMAT) were selected for this study. All the patients were planned with 6MV X-rays using Versa HD (Elekta Medical System, Sweden) linear accelerator having 160 multileaf collimators (MLC), 0.5cm leaf width at isocenter. All the patients were planned with conventional fractionation ranging from 1.8Gy to 3.0Gy per fraction, with some patients having two or more planning target volumes (PTV) planned with simultaneous integrated boost (SIB) technique. Treatment planning and dose calculation were done using Monaco 5.11 treatment planning system (Elekta Medical System, Sweden) having a Monte Carlo dose calculation algorithm. All the patients were planned with single or dual arc, based on clinical requirements. During dose calculation and optimization, statistical uncertainty for Monte Carlo dose calculation was 1.0% per calculation and maximum segment width was kept at 1.0cm, the number of control points were ranging from 150 to 200 and the dose calculation grid was 0.3cm. Plan evaluation was done using a dose volume histogram (DVH) in terms of the dose-to-planning target volume (PTV) and organ at risk (OARs), monitor units required to deliver one fraction was also noted and MU/cGy was calculated to observe the plan complexity.

2D measurement

2D planar dose measurements were performed with I'matriXX evolution (IBA, Germany) 2D detector array using My QA Patients (IBA, Germany) software. I'matriXX evolution is a detector array having 1020 parallel plate ionization chambers, the spacing between the detectors is 0.76cm and the maximum field size which can be measured with the I'matriXX is 24x24cm^2. I'matriXX for 2D dose measurement is used with Multi-cube lite ((IBA, Germany) plastic phantom, I'matriXX can be sandwiched using multi-cube plates at different depths, present study we have kept the I'matriXX at 11.0cm depth and source to surface distance (SSD) was kept at 89.0cm. I'matriXX evolution uses a gantry angle sensor for angular response correction at the time of actual gantry angle measurement. All the measurements were performed for a true composite dose at the actual gantry angle (gantry, collimator, and couch as per plan). Once the plan is approved, the plan fluence was exported to I'matriXX phantom (along with Multi -cube), and, a QA plan was generated. I'matriXX measured and TPS calculated dose planes (coronal) were compared using gamma index analysis [10, 11]. For 2D global gamma index evaluation 3%/3mm and 2%/2mm criteria were used and the threshold was set as 10%. 2D-measurement setup is shown in figure -1(a).

3D measurement

3D dose measurements were performed using COMPASS system ((IBA, Germany). COMPASS is software, which is used in combination with the I'matriXX evolution detector array. I'matriXX is attached to the LINAC gantry head using a gantry mount which is calibrated for source to surface distance (SSD) of 100.0cm. 3D-measurement setup is shown in figure-1(b). After approval of the treatment plan, RT Plan, RT Dose, RT Structure set and CT images were exported from Monaco TPS through DICOM and imported in COMPASS. All the plans were measured with COMPASS, COMPASS is using collapsed cone convolution algorithm to calculate the measured fluence and reconstruct the final dose distribution on CT images [12]. The dose volume histogram generated from the reconstructed dose (measured dose) and computed by the treatment planning system (Monaco) was compared in terms of doses to planning target volume (PTV) and organs at risk. For PTV $D_{95\%}$, $D_{2\%}$, and $D_{50\%}$ (dose received by 95%, 2%, and 50% volume), similarly for OARs serial structure $D_{2\%}$ and parallel structure $D_{50\%}$ was noted. The percentage dose difference between TPS calculated and COMPASS measured doses was calculated using the formula, shown in equation 1.

$$\% \text{ dose difference} = \frac{DCOMPASS - DTPS}{DTPS} X\ 100 \quad (1)$$

Where; *DCOMPASS* is COMPASS reconstructed dose and *DTPS* is TPS calculated dose.

For 3D gamma (global) calculation using COMPASS percentage of pixels having gamma greater than 1 (failed pixel) was calculated, for the patient body (irradiated volume) the passing percentage pixel was derived by subtracting failed pixel from 100 (100 - pixel greater than 1). 3D gamma criteria were kept as 3%/3mm, 2%/2mm.

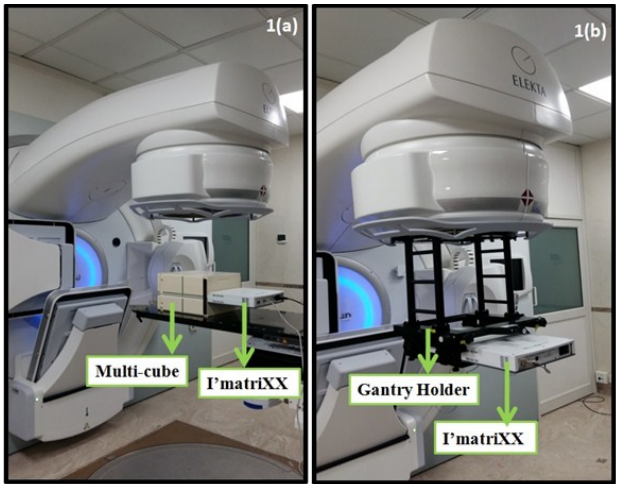

Figure 1. Showing the **1(a)** 2D measurement setup **1(b)** 3D measurement setup along with gantry mount.

Statistical analysis

To check the normality of the data, the Shapiro-Wilk test was used with a p-value of 0.05. Shapiro Wilk normality test can be used if the dataset is less than 50 because the present study n is 21. For correlation analysis of the data, the Pearson correlation coefficient or Spearman correlation coefficient was calculated based on the normality of distribution. Pearson correlation is a measure of linear correlation between two variables; data should be normally distributed to apply the Pearson correlation analysis. On the other-hand Spearman correlation measure the strength of monotonic relationship between paired data. If both the group in the data follows the normal distribution then the Pearson correlation coefficient was calculated otherwise Spearman correlation coefficient was calculated. The strength of the correlation between two data sets can be explained by the value of the correlation coefficient. The correlation coefficient range and its explanation are as follows: (i) 0.00 – 0.19: very weak correlation (ii) 0.20- 0.39: weak correlation (iii) 0.40-0.69: moderate correlation (iv) 0.70-0.79: strong correlation and (v) 0.80-1.00: very strong correlation. None of the evaluated data groups for correlation followed the normal distribution; therefore in the present study, the Spearman correlation coefficient was calculated.

RESULTS

The results of treatment plan evaluation and quality assurance are summarized in table-1.

Table 1. Showing the results of treatment plan evaluation and quality assurance.

Results of QA Test & plan evaluation	VMAT H&N Patients N=21	VMAT Pelvis Patients N=21
% 2D-Gamma pass rate ± standard deviation (3% / 3mm criteria)	98.6±1.8%	98.5±1.3%
% 2D-Gamma pass rate ± standard deviation (2% / 2mm criteria)	92.1±7.1%	93.5±4.4%
% 3D-Gamma pass rate ± standard deviation (3% / 3mm criteria)	94.7±5.6%	99.5±0.7%
% 3D-Gamma pass rate ± standard deviation (2% / 2mm criteria)	87.9±10.3%	94.4±5.5%
MU / cGy	3.55±1.4	3.40±1.0
PTV $D_{95\%}$ (Monaco versus COMPASS measured)	4.22±2.09%	0.60±1.96%
PTV $D_{2\%}$ (Monaco versus COMPASS measured)	4.25±2.23%	1.53±1.64%
PTV $D_{50\%}$ (Monaco versus COMPASS measured)	3.93±1.59%	1.59±1.20%
Spine $D_{2\%}$ (Monaco versus COMPASS measured)	-0.84±6.10%	-
Brainstem $D_{2\%}$ (Monaco versus COMPASS measured)	0.77±2.70%	-
Bladder $D_{50\%}$ (Monaco versus COMPASS measured)	-	3.75±3.31%
Rectum $D_{50\%}$ (Monaco versus COMPASS measured)	-	-2.19±3.60%

2D-gamma index passing rate was 98.6±1.8%, 92.1±7.1% and 98.5±1.3%, 93.5±4.4% using 3%/3mm, 2%/2mm criteria for head-neck and pelvis patients respectively. Similarly, the 3D-gamma index passing rate was 94.7±5.6%, 87.9±10.3%, and 99.5±0.7%, 94.4±5.5% for head-neck and pelvis patients respectively. Head-neck patients showed a lower 3D-gamma passing rate compared to 2D-gamma, because some pixels failed in the build-up region (some head-neck patient's PTV were superficially located), whereas pelvis patients showed higher 3D gamma compared to its 2D gamma results. Some head-neck patients included in the study had single PTV, therefore not required much-complicated planning parameters (i.e. control points, number of arcs) and can be planned with less MU/cGy. In the present study we did not group the data based on the complexity of the plans only we have classified based on treatment site may be that is why the average MU/cGy did not show much difference for head-neck and pelvis patients respectively. Percentage dose-differences for PTV D_{95}, D_2, and D_{50} for head-neck were: 4.22±2.09%, 4.25±2.23%, and 3.93±1.59 which were higher with high standard deviations compared to the pelvis.

Some head and neck patients for which PTVs were located superficially showed higher dose differences between Monaco calculated and COMPASS measured. Monaco is using Monte-carlo dose calculation algorithm whereas COMPASS is reconstructing the

measured dose by applying the feedback (difference between predicted and measured dose) to the predicted response based on measurement data. Even though plans were acceptable based on 2D measurements but 3D DVH-based evaluation for head & neck PTVs showed higher variation. COMPASS is overestimating the dose in the build-up region compared to Monaco for our setup. Therefore, the results of 3D DVH-based evaluation with COMPASS for superficially located targets or OARs should be verified independently with the suitable detector for defining acceptable limits (tolerances). Pelvis percentage doses difference for PTV D_{95}, D_2, D_{50} were 0.60±1.96%, 1.53±1.64%, 1.59±1.20% respectively. For Spine and brainstem D_2 were -0.84±6.10%, 0.77±2.70%, bladder and rectum D_{50} were 3.75±3.31%, -2.19±3.60%. As per results obtained in the present study, COMPASS measurements for pelvis PTV and OARs showed good agreement with Monaco TPS. The 2D and 3D gamma for a representative patient is shown in figure- 2.

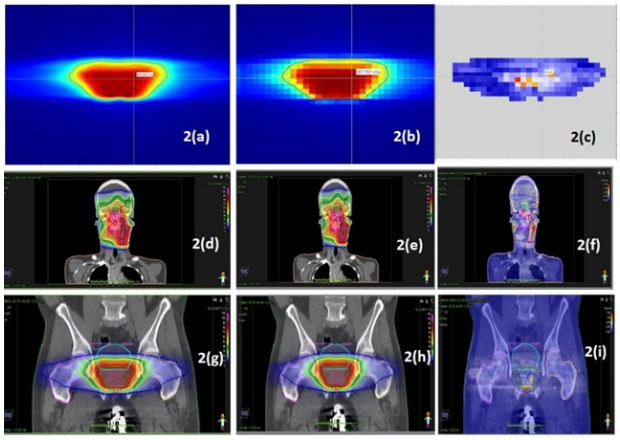

Figure 2. Showing the coronal view of **(a)** 2D planned fluence **(b)** 2D measured fluence **(c)** 2D Gamma index **(d)** 3D planned dose distribution for head & neck representative patient **(e)** 3D measured dose distribution for head & neck representative patient **(f)** 3D Gamma index **(g)** 3D planned dose distribution for pelvis representative patient **(h)** 3D measured dose distribution for pelvis representative patient and **(i)** 3D Gamma index.

Results of correlation analysis between 2D & 3D gamma pass rates were shown in table-2. The correlation coefficient (their corresponding p-value) for head and neck patients between 2D & 3D gamma were 0.618 (p=0.003) and 0.616 (p=0.003) for 3%/3mm and 2%/2mm criteria respectively. Correlation analysis showed no strong correlation between 2D and 3D gamma for head and neck patients. On the other hand, for pelvis patients, correlation coefficients were 0.363 (p=0.106) and 0.729 (p=0.000) for 3%/3mm and 2%/2mm criteria respectively. Results of correlation analysis between MU/cGy and 2D/3D gamma pass rate were shown in table-2. A weak correlation was observed between MU/cGy and 2D/3D gamma for head and neck patients, on the contrary, pelvis patients showed a strong correlation between MU/cGy and 3D gamma. In the present study, we have analyzed both 3%/3mm and 2%/2mm criteria, to understand the influence of different gamma criteria on 2D and 3D measurement correlation analysis, even though evaluating with different criteria is just an interpolation of calculated and measured data. For pelvis patients correlation coefficient between 2D and 3D gamma (3%/3mm) was 0.363 whereas for 2%/2mm it was 0.729, so the correlation coefficient is changing with the change in gamma criteria. Similarly, correlation analysis between MU/cGy and 2D gamma for pelvis patients showed a better correlation (0.756) for 2%/2mm compared to 3%/3mm.

Table 2. Showing the correlation analysis between 2D & 3D Gamma pass rate and correlation between MU/cGy and Gamma pass rate.

Correlation analysis between 2D and 3D Gamma pass rate using Spearman Correlation coefficient (r)				
Treatment Site	**2D-Gamma & 3D-Gamma** 3%/3mm		**2D-Gamma & 3D-Gamma** 2%/2mm	
	r	p	r	p
H & N	0.618	0.003	0.616	0.003
PELVIS	0.363	0.106	0.729	0.000

Correlation analysis between MU/cGy and Gamma pass rate								
Treatment Site	**2D-Gamma**				**3D-Gamma**			
	3%/3mm		**2%/2mm**		**3%/3mm**		**2%/2mm**	
	r	p	r	p	r	p	r	p
H & N	0.252	0.270	0.425	0.055	0.376	0.093	0.331	0.143
PELVIS	0.357	0.112	0.756	0.000	0.952	0.000	0.885	0.000

Results of correlation analysis between % DVH Difference (Monaco calculated versus COMPASS measured) and 2D /3D gamma pass rate were summarized in table 3.

Table 3. Showing the correlation analysis between % DVH Difference (Monaco calculated versus COMPASS measured) and 2D /3D Gamma pass rate.

Correlation analysis between % DVH Difference (Monaco calculated versus COMPASS measured) and 2D and 3D Gamma pass rate using Spearman Correlation coefficient (r)								
	2D-Gamma				**3D-Gamma**			
	3%/3mm		2%/2mm		3%/3mm		2%/2mm	
	r	p	r	p	r	p	r	p
	Treatment Site H & N							
PTV $D_{95\%}$	0.416	0.061	0.525	0.014	0.294	0.197	0.230	0.316
PTV $D_{2\%}$	0.278	0.223	0.438	0.047	0.257	0.262	0.238	0.299
PTV $D_{50\%}$	0.072	0.758	0.214	0.351	0.134	0.563	0.092	0.691
Spine $D_{2\%}$	0.102	0.677	0.202	0.406	0.007	0.977	0.023	0.926
Brainstem$D_{2\%}$	0.431	0.051	0.290	0.202	0.162	0.484	0.158	0.494
	Treatment Site PELVIS							
PTV $D_{95\%}$	0.511	0.018	0.736	0.000	0.684	0.000	0.629	0.002
PTV $D_{2\%}$	0.387	0.083	0.622	0.003	0.807	0.000	0.835	0.000
PTV $D_{50\%}$	0.327	0.148	0.637	0.002	0.785	0.000	0.741	0.000
Bladder $D_{50\%}$	0.039	0.866	0.318	0.161	0.592	0.005	0.590	0.005
Rectum $D_{50\%}$	0.130	0.575	0.566	0.008	0.542	0.011	0.340	0.132

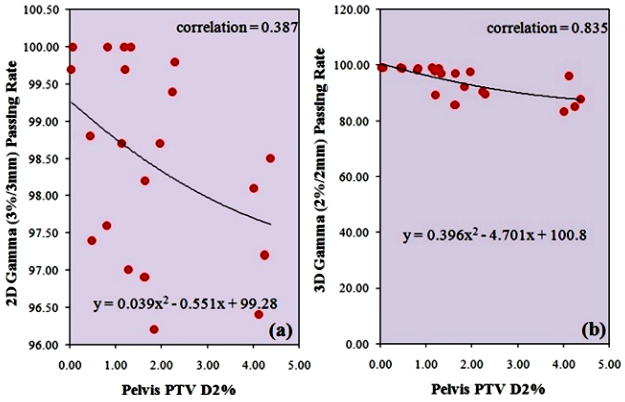

Figure 3. Showing the graphical representation of weak and strong correlation curve 3(a): between pelvis PTV D2% and 2D-Gamma (3%/3mm). 3(b): between pelvis PTV D2% and 3D-Gamma 2%/2mm respectively. Correlation analysis for head-neck patients, between % DVH Difference (for PTV and OAR) and 2D/3D-gamma (3%/3mm & 2%/2mm) showed a weak correlation. For pelvis patients, Correlation analysis between % DVH Difference and 2D/3D-gamma (3%/3mm & 2%/2mm) showed a weak correlation but PTV D95 showed a strong correlation (r=0.736) with 2D gamma (2%/2mm). In addition to that, pelvis PTV D2 and PTV D50 showed a strong correlation (r > 0.70) with 3D gamma for both 3%/3mm and 2%/2mm criteria. A graphical representation of correlation analysis results between % DVH and 2D /3D gamma pass rate is shown in figure-3(a&b).

DISCUSSION

2D-gamma passing rates for both head & neck and pelvis patients were observed almost similar (same order). Head & neck patients showed lower 3D-gamma passing rates because most of the head & neck patients' PTVs were contoured close to the skin and COMPASS dose reconstruction (measured dose) showed variation with Monaco may be due to their different dose estimation approaches in the build-up region. Head & neck PTVs showed a higher % variation in DVH parameters compared to the pelvis.

2D gamma pass rate tells only about the percentage of pixels passing in one plane, other planes may show different gamma results based on dose gradient and complexity involved with that plane, which is why single-plane gamma analysis results not correlating well with overall 3D gamma. Pulliam *et al.* (2014) compared the 2D and 3D gamma analysis for 50 IMRT plans and observed that the 3D gamma analysis showed 2.9% more pixel passing than the 2D gamma, author also emphasized accounting for inherent dosimeter difference used for 2D and 3D measurements [13]. The present study showed an overall weak correlation between 2D and 3D gamma passing rate for head & neck patients, contrary to the above pelvis patients 2D and 3D gamma (2%/2mm) showed a strong correlation, the reason for getting a strong correlation may be because the high passing rate of 2D/3D gamma and delivered dose distribution not varying much with a change in plane. A similar study by Kim *et al.* (2017), studied the correlation between 2D and quasi-3D gamma passing rates for 20 patients treated with VMAT. 2D and quasi-3D measurements were performed with radiochromic film and COMPASS respectively. Study results showed a statistically significant (r=0.564, p=0.012) moderate correlation between 2D and quasi-3D gamma passing rate for the VMAT group [14]. Wu *et al.* (2012) studied the 3D gamma analysis for IMRT/VMAT pre-treatment QA, 2D measurements were performed with Mapcheck and the 3D dose was reconstructed from EPID images. The author found that Υ_{PTV} (gamma PTV) was more than 90% for VMAT cases and no statistically significant correlation was observed between Υ_{PTV} and 2D gamma [15]. Further Rajasekaran *et al.* (2014) investigated the correlation between 2D and 3D gamma, for that author evaluated the 150 previously treated VMAT plans measured with Octavius 4D system and found that the average 2D and 3D gamma for coronal were 94.81%±2.12% and 95.90±1.57% respectively, the author also concluded that there is no correlation or notable pattern between 2D and 3D gamma [16].

For 2D measurements, the phantom (multi-cube + I'matriXX) is kept on the couch. Angular corrections (range 0.943 to 1.064) were applied in 2D measurements using a gantry angle sensor based on the beam incidence angle on the detector plane. While for, the 3D measurements detector is attached to the gantry and always perpendicular to the beam, and the gantry angle was measured independently by the gantry angle sensor (tolerance of 0.8 degrees) to assign the measured segments as per their respective gantry angles. If the difference is more than 0.8 degrees between the planned and measured gantry angle then COMPASS will not be able to assign the segments for that angle and could not reconstruct the dose.

The present study showed a weak to moderate correlation between 2D gamma passing rate and DVH -based percentage dose error except for PTV D95 (2%/2mm) which showed a strong correlation (r=0.736). 3D gamma pass rate and DVH-based % dose error showed a weak correlation for head & neck patients, whereas pelvis patients resulted in a weak to strong correlation. Correlating the percentage of pixel passing in 2D or 3D gamma with percentage dose variation in DVH matrices of PTV/ OAR is not justified, because how dose variation in dose received by 2% or 95% volume of any structure can be correlated with whole plane or volume. Maybe structure-by-structure dose variation will correlate with the 3D gamma of that structure, not with the overall 3D Gamma. Yi *et al.* (2017) also tried to understand the correlation between 2D gamma and percentage dose error of DVH metrics and found that the individual volume-based 3D percentage gamma

pass rate had more correlation with DVH-based 15% dose error metrics compared with global percentage gamma [17].

The study conducted by Jin *et al.* (2014), evaluated the correlation between 2D gamma passing rate and DVH-based percentage dose error. For doing so author analyzed the 20 nasopharyngeal patients treated with simultaneous integrated boost VMAT, 2D and 3D measurements were done with Arccheck and 3DVH software, and results showed a lack of correlation between 2D gamma passing rate and DVH -based percentage dose error [18].

Stasi *et al.* (2012) analyzed the 27 prostate cases and 15 head & neck cases treated with IMRT to study the predictive power of conventional 2D QA and DVH based % dose error. As per Stasi *et. al.*'s study gamma passing rate did not show good agreement with DVH-based percentage dose error, and the correlation between them was also weak (<0.8). Stasi *et al.* calculated the Pearson correlation and the author considered >0.8 as a strong correlation [19]. Visser *et al.* (2014) evaluated the DVH-based treatment plan verification along with the 2D gamma passing rate for head & neck IMRT cases and found that all plans showed a gamma passing rate of around 99.7%, study concluded as DVH based verification improve the insight in dose delivery and distinguished the role of medical physicist and radiation oncologist for quality assurance [20].

In another study by Guo *et al.* (2023), the author studied the influence of different spatial resolutions of various detectors and established the correlation between them [21]. Low *et al.* (2018) in a retrospective study of patient-specific quality assurance explored the use of dose volume histogram (DVH) metrics and found that the results complement the point dose and 2D gamma measurements [22]. Pal *et al.*'s (2021) study on, 2D planar versus 3D planar measurement showed a significant degree of correlation but less correlation was observed between 2D/3D planar and 3D volumetric pass rates [23].

CONCLUSION

Correlation analysis between 2D and 3D measurements showed no systematic pattern, at one or two instances correlation is high but overall weak to moderate correlation was seen, even though a similar detector was used for both 2D and 3D measurements. In addition to that, no strong correlation was seen between 2D/3D gamma passing rate and percentage dose differences of 3D-DVH-based pre-treatment quality assurance using COMPASS. Because no strong correlation was seen between the two methods, therefore one measurement result cannot predict (estimate) the results of another type of measurement.

Compliance with ethical standards

***Conflict of interest*:** The authors declare that they have no conflicts of interest.

***Ethical approval*:** This article does not contain any studies with human participants or animals performed by any of the authors.

Ethical approval from the institutional research committee has been taken to use the patient's CT data. IESC/T-246/21.06.2014, approval letter dated 30.09.2014.

***Informed consent*:** Informed consent was obtained from all participants included in the study.

***Funding*:** Nil.

Author contributions: S.S. conceived and designed the study. S.S., D.S., V.S., N.G., S.B., S.P., P.K., S.T., S.C., all the authors have helped in collecting and analysing the data, writing and correcting the manuscript.

REFERENCES

1. Yu CX (1995) Intensity-modulated arc therapy with dynamic multileaf collimation: an alternative to tomotherapy. *Phys Med Biol, **40**(9): 1435-1449*.
2. Ibbott GS, Followill DS, Molineu A, *et al.* (2008) Challenges in credentialling institutions and participants in advanced technology multi-institutional clinical trials. *Int J Radiat Oncol Biol Phys, **71**: S71–S75*.
3. Ezzell GA, Burmeister JW, Dogan N, *et al.* (2009) IMRT commissioning: Multiple institution planning and dosimetry comparisons, [a report from AAPM Task Group 119]. *Med Phys, **36**(11): 5359:5373*.
4. Low DA, Moran JM, Dempsey JF, *et al.* (2011) Dosimetry tools and techniques for IMRT. *Med Phys, **38**(3): 1313-1338.* [A Report from AAPM TG-120].
5. Alber M, Broggi S, De Wagter C, *et al.* (2008) Guidelines for the verification of IMRT. [*ESTRO BOOKLET* NO. *9]*
6. B. A. Fraass (2008) Errors in radiotherapy: motivation for the development of new radiotherapy quality assurance paradigms. *Int J Radiat Oncol Biol Phys, **71**(1): S162-5*.
7. Carrasco P, Jornet N, Latorre A, *et al.* (2012) 3D DVH-based metric analysis versus per-beam planar analysis in IMRT pretreatment verification. *Med Phys, **39**(8): 5040-5049*.
8. Zhen H, Nelms BE, Tome WA (2011) Moving from gamma passing rates to patient DVH-based QA metrics in pretreatment dose QA. *Med Phys, **38**(10): 5477-5489*.
9. Nelms BE, Zhen H, Tomé WA (2011) Per-beam, planar IMRT QA passing rates do not predict clinically relevant patient dose errors. *Med Phys, **38**(2): 1037-1044*.
10. Low DA, Harms WB, Mutic S (1998) A technique for the quantitative evaluation of dose distributions. *Med Phys, **25**(5): 656-661*.
11. Low DA and Dempsey JF (2003) Evaluation of the gamma dose distribution comparison method. *Med Phys, **30**(9): 2455-2464*.
12. Narloch N (2013) On the clinically relevant detector resolution and error detection capability of COMPASS 3D plan verification [white paper]. Schwarzenbruck, Germany: IBA Dosimetry GmbH.
13. Pulliam KB, Huang JY, Howell RM, *et al.* (2014) Comparison of 2D and 3D gamma analyses. *Med Phys, **41**(2): 021710-1-6*.
14. Kim JI, Choi CH, Wu HG, *et al.* (2017) Correlation analysis between 2D and quasi-3D gamma evaluations for both intensity-modulated radiation therapy and volumetric modulated arc therapy. *Oncotarget, **8**(3): 5449-5459*.
15. Wu C, Hosier KE, Beck KE, *et al.* (2012) On using 3D γ-analysis for IMRT and VMAT pre-treatment plan QA. *Med Phys, **39**(6): 3051-3059*.
16. Rajasekaran D, Jeevanandam P, Sukumar P, *et al.* (2014) A study on the correlation between 2D and 3D gamma evaluation metrics

in patient-specific quality assurance for VMAT. *Med Dosim,* ***39****(4): 300-308*.

17. Yi J, Han C, Zheng X, *et al. (2017) Individual volume-based 3D gamma indices for pretreatment VMAT QA. J Appl Clin Med Phys,* ***18****(3): 28-36.*
18. Jin X, Yan H, Han C, *et al. (2015) Correlation between gamma index passing rate and clinical dosimetric difference for pre-treatment 2D and 3D volumetric modulated arc therapy dosimetric verification. Br J Radiol. 88(1047):20140577-1-8.*
19. Stasi M, Bresciani S, Miranti A, *et al.* (2012) Pretreatment patient-specific IMRT quality assurance: a correlation study between gamma index and patient clinical dose volume histogram. *Med Phys,* ***39****(12): 7626-7634*.
20. Visser R, Wauben DJ, de Groot M, *et al.* (2014) Evaluation of DVH-based treatment plan verification in addition to gamma passing rates for head and neck IMRT. *Radiother Oncol,* ***112****(3): 389-395*.
21. Guo Y, Hu J, Li Y, *et al.* (2023) Correlation between patient-specific quality assurance in volumetric modulated arc therapy and 2D dose image features. *Scientific Reports,* ***13****: 4051*.
22. Low C, Toye W, Phung P, Huston C (2018) Patient-specific quality assurance protocol for volumetric modulated arc therapy using dose volume histogram. *Med Phys,* ***43****(2)*.
23. Pal B, Pal A, Bag S, *et al.* (2021) Comparative performance analysis of 2D and 3D gamma metrics for patient-specific QA in VMAT using Octavius 4D with 2D-Array 1500. *Physica Medica,* ***91****: (18-27)*.