International Journal of Research in Medical Sciences
Shukla AK et al. Int J Res Med Sci. 2023 Apr;11(4):1160-1164
www.msjonline.org
pISSN 2320-6071 | eISSN 2320-6012
DOI: https://dx.doi.org/10.18203/2320-6012.ijrms20230854

Original Research Article

Comparison of 2D and 3D gamma evaluation method in patient specific intensity-modulated radiotherapy quality assurance

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Received: 07 March 2023
Revised: 21 March 2023
Accepted: 22 March 2023

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ABSTRACT

Background: In this study we have compared 2D and 3D gamma pass percentage for a variety of acceptance criteria for 40 step-and-shoot IMRT (intensity-modulated radiotherapy) plans.
Methods: Treatment planning was done for 40 patient including head and neck, abdomen and pelvis simulated on the Siemens Healthcare GmBH CT simulator with images of 3 mm slice thickness using treatment planning system (TPS) (Monaco Version 5.11.03, Elekta medical system) using Monte Carlo algorithm. The gamma evaluation was done using PTW VeriSoft 8.1 which allowed us to perform 2D and 3D gamma index calculation, slice-by-slice comparison of measured and calculated dose distributions, measured dose was compared against the calculated DICOMRT dose on the OCTAVIUS 3D phantom from TPS.
Results: The average 3D and 2D gamma passing in coronal planes were 96.61±0.45% and 96.27±0.78% for 5 mm/5% criteria, 93.74±4.17% and 91.9±4.88% for 3 mm/3% criteria, 85.83±7.58% and 82.41±8.06% for 2 mm/2% criteria and 62.8±9.42% and 59.18±9.52% for 1 mm/1% criteria respectively for all cases. The average gamma passing rate for 3D gamma analysis was 0.35%, 1.97 %, 3.97% and 5.78% higher when compared with 2D coronal planar analyses for 5 mm/5%, 3 mm/3%, 2 mm/2% and 1 mm/1% DTA criteria respectively.
Conclusions: It is concluded in the study that 3 D gamma passing rate is higher compared to 2D gamma passing for head and neck, abdomen and pelvis cases.

Keywords: IMRT QA, 2D gamma, 3D gamma, PSQA

INTRODUCTION

Intensity-modulated radiotherapy (IMRT) is a highly conformal treatment modality which delivers precise radiation to tumor while minimizes radiation dose to surrounding tissue. IMRT requires precise dose verification due to the increased complexity compare to three-dimensional conformal radiotherapy.[1-5] Traditionally IMRT patient specific quality assurance (PSQA) is done using point dose measurement using ionizing chamber with electrometer and fluence dose measurement in 2 dimensional planer with film dosimetry or 2D array of detectors.[6,7] A very common method to quantitatively compare measured and treatment planning system (TPS) calculated dose fluence is the calculation of gamma index. The gamma method is useful in measuring distance to agreement (DTA) in high gradient region, and sensitive to dose differences between calculated and measured plan.[8,9]

Several methods and detectors are available to perform pretreatment verification. Due high spatial resolution in

the sub-mill metric range filmsare ideal for the 2D fluence measurements, but they require multiple works like to generate film densitometric calibration curve, film processing and evaluation, which becomes time consuming process.[10]

Alternative to the film, various 2D detector methods are commercially available for patient specific IMRT QA which are mainly 2 dimensional matrices.[11,12]

However, 3-dimensional gamma analysis is advancement in IMRT verification. It is extension of another dimension of 2D gamma analysis. It allows evaluating the entire volumetric patient dose distribution.[13-15]

In the present study we have compared 2D and 3D gamma pass percentage for a variety of DTA acceptance criteria for 40 step-and-shoot IMRT plans. All IMRT plans were clinically approved.

METHODS

The study was conducted for 40 patients including head and neck, abdomen and pelvis from January 2022 to February 2023. All patients were selected for the study which were planned for the IMRT treatment. The immobilization cast prepared for each patient to reduce patient movement during radiotherapy of head and neck, abdomen and pelvis cases. The CT simulation was done on the Siemens Healthcare GmBH (Somatom confidence RT pro) CT simulator with images of 3 mm slice thickness. The IMRT planning was done using Monte Carlo algorithm used with TPS (Monaco Version 5.11.03, Elekta medical system). After clinically validation of IMRT plans QA plans were generated. Each of these plans was recalculated on the OCTAVIUS phantom with same parameters and same algorithm, which was simulated on the same CT scanner with a slice thickness of 3 mm and was subsequently referred to as QA plans. Individual patient plans were exported to the MOSAIQ (Elekta medical system) and executed for each gantry angle on the OCTAVIUS assembly. The Verisoft (version 8.1, PTW Dosimetry, Freiburg, Germany) software was then used to evaluate the QA plans as well as the completed plans.

The step-and-shoot IMRT plans data was collected using the PTW OCTAVIUS system comprising the OCTAVIUS Phantom with OCTAVIUS detector 1500 and Detector Interface 4000.

The OCTAVIUS phantom is an octagonal solid body phantom with an opening for inserting the detector array. The phantom is constructed of polystyrene (density 1.04 g/cm^3) with 320 mm in diameter 320 mm length.

The octagonal phantom geometry allowed flexible adaptions of the measurement setups to clinically relevant beam directions. An integrated air cavity ensured uniform directional dose response at arbitrary gantry angles during measurements with PTW OCTAVIUS detectors.

The OCTAVIUS Detector 1500 detector array for dose measurement and the Detector interface 4000 comprise a multichannel dosimeter for dose and dose rate measurement.

The OCTAVIUS Detector 1500 is a two-dimensional detector array consisting of 1405 vented ionization chambers with a 27×27 cm^2 active area. Each detector is 4.4 mm×4.4 mm×3 mm (0.06 cm^3) in size, with a spacing of 7.1 mm between two detectors from centre to centre, with the effective reference point of measurement 0.75 cm below the surface of the array. The detector array has an interface between the detector array and the measuring and analysis software on the PC.

The dosimetric measurements in this investigation were performed by placing the beam's central axis travelling through the central ion chamber of the OCTAVIUS detector 1500 at 6 cm depth from the phantom's surface at predesigned place. The detector array measurement results were acquired for the various gantry angles in the patient plan, which are then linearly interpolated to a predetermined dose grid (~1 mm) and supplied into the verisoft 8.1 software for gamma analysis.

Gamma evaluation method was used to compare the planned dose distribution in TPS and delivered dose distribution. Gamma method is useful in measuring DTA in a high gradient region, and sensitive to dose differences between calculated and delivered plan. The DTA was taken for study was 5 mm distance with 5% dose, 3 mm distance with 3% dose, 2 mm distance with 2% dose and 1 mm distance with 1% dose. The Gamma pass percentage was calculated using VeriSoft 8.1 which allowed us to perform 2D and 3D gamma index calculation, slice-by-slice comparison of measured and calculated dose distributions, measured dose was compared against the calculated DICOMRT dose on the OCTAVIUS 3D phantom from TPS.

RESULTS

All IMRT patient specific QA plans were delivered on OCTAVIUS phantom with 2D array of detectors. the TPS calculated and measured fluence were compared in coronal plane the 2D and 3D using Gamma analysis method using Verisoft 8.1 software. Figure 1 shows 3D gamma analysis window of a typical IMRT QA plan in coronal plane.

Table 1 shows the average 2D and 3D planar gamma passing rate with standard deviation for all the QA plans in coronal planes. The average 3D and 2D gamma passing in coronal planes were 96.61±0.45% and 96.27±0.78% for 5 mm/5% criteria, 93.74±4.17% and 91.9±4.88% for 3 mm/3% criteria, 85.83±7.58% and 82.41±8.06% for 2 mm/2% criteria and 62.8±9.42% and

59.18±9.52% for 1 mm/1% criteria respectively for all cases.

Figure 2 shows graphical representation of 2D and 3D gamma passing for head and neck cases which depicts 3D gamma pass percentage is higher compared to 2D gamma.

Similarly Figure 3 and 4 represent the 2D and 3D gamma passing for abdomen and pelvis cases respectively.

Table 1: Average 2D and 3D planar gamma passing rate with standard deviation.

Site	Acceptance criteria (mm/%)	% gamma passing 3D coronal	% gamma passing 2D coronal	% difference
Head and neck	5/5	99.82±0.36	99.59±0.64	0.23
	3/3	96.29±3.8	94.42±4.55	1.95
	2/2	87.83±7.06	84.23±7.67	4.09
	1/1	62.55±9.08	58.96±9.46	5.75
Pelvis	5/5	99.9± 0.12	99.64±0.26	0.26
	3/3	95.62±4.19	93.74±1.97	1.96
	2/2	87.48±9.00	84.48±3.43	3.42
	1/1	62.7±11.56	59.02±5.87	5.86
Abdomen	5/5	99.11±1.08	98.27±1.70	0.84
	3/3	92.37±7.69	90.07±7.79	2.49
	2/2	82.7±1.32	78.2±10.24	5.44
	1/1	54.53±9.84	50.1±7.20	8.12
All	5/5	96.61±0.45	96.27±0.78	0.35
	3/3	93.74±4.17	91.9±4.88	1.97
	2/2	85.83±7.58	82.41±8.06	3.97
	1/1	62.8±9.42	59.18±9.52	5.78

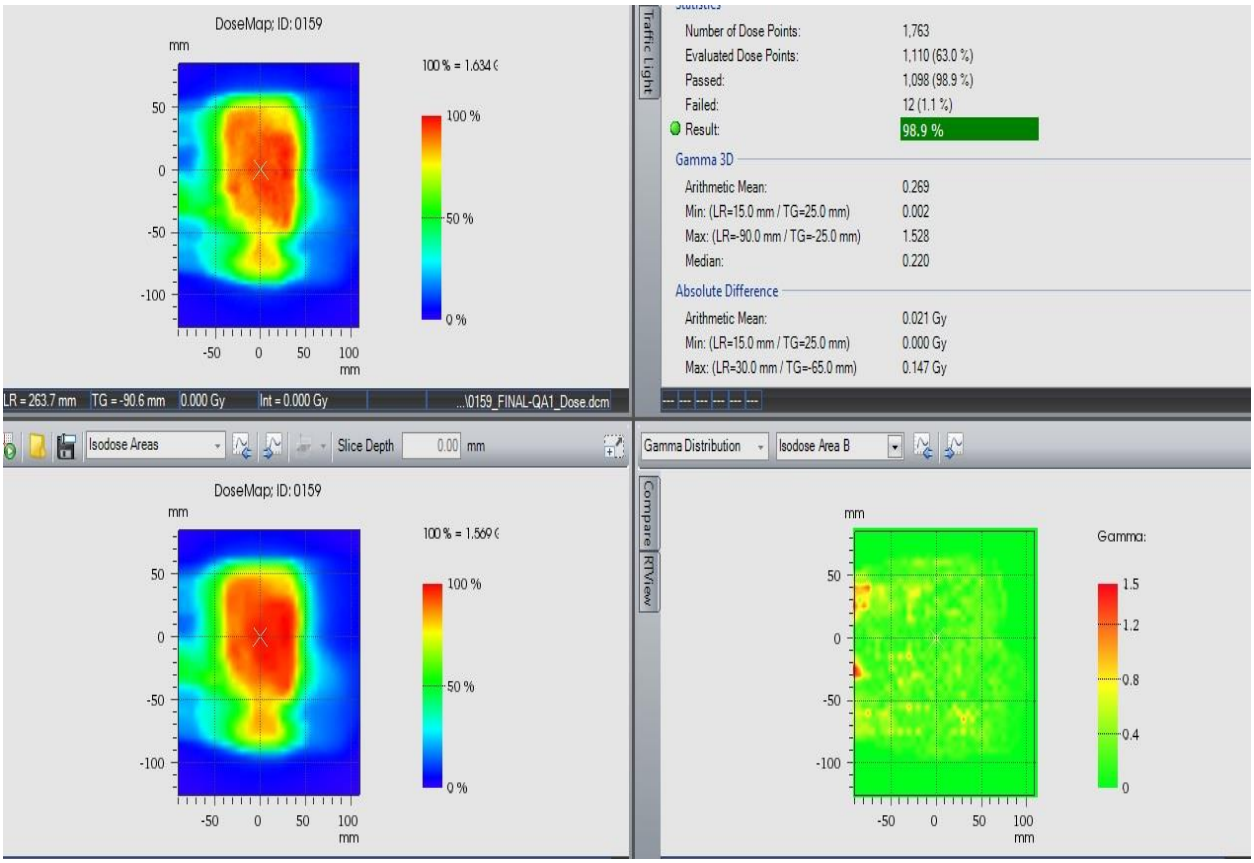

Figure 1: 3D gamma analysis window of a typical IMRT QA plan in coronal plane.

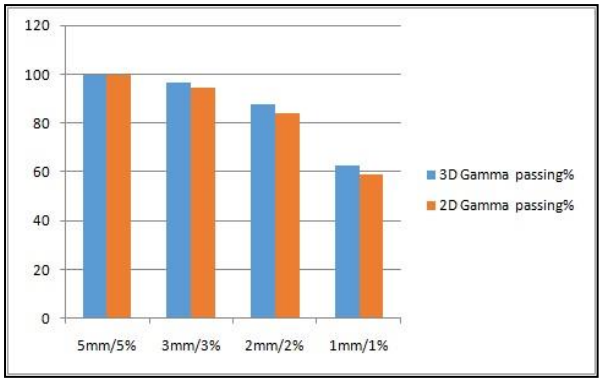

Figure 2: Graphical representation of 2D and 3D gamma passing for head and neck cases.

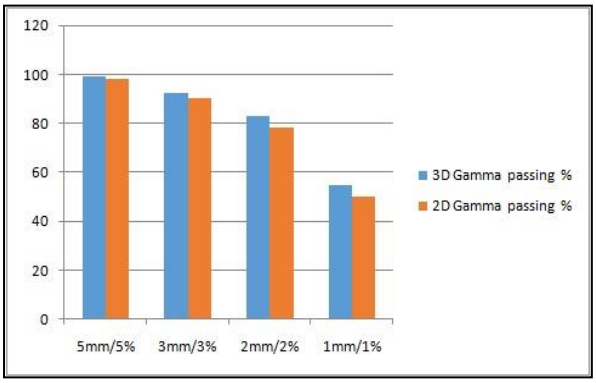

Figure 3: Represent the 2D and 3D gamma passing for abdomen.

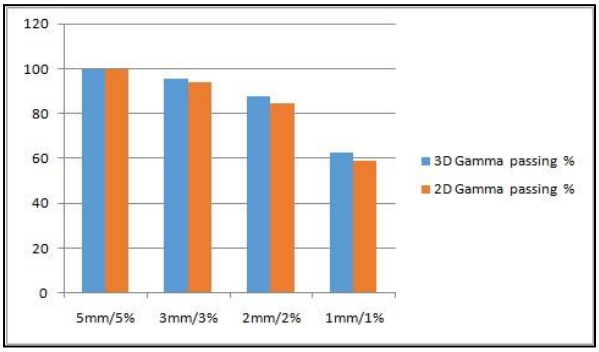

Figure 4: Represent the 2D and 3D gamma passing for pelvis.

Figure 5 represents the average gamma pass percentage for 2D and 3D gamma for all the QA plans. Which clearly shows that 3D gamma pass percentage is more compared to 2D gamma. The average gamma passing rate for 3D gamma analysis was 0.35%, 1.97%, 3.97% and 5.78% higher when compared with 2D coronal planar analyses for 5 mm/5%, 3 mm/3%, 2 mm/2% and 1 mm/1% DTA criteria respectively. The difference in pass percentage increase as DTA criteria becomes stringent.

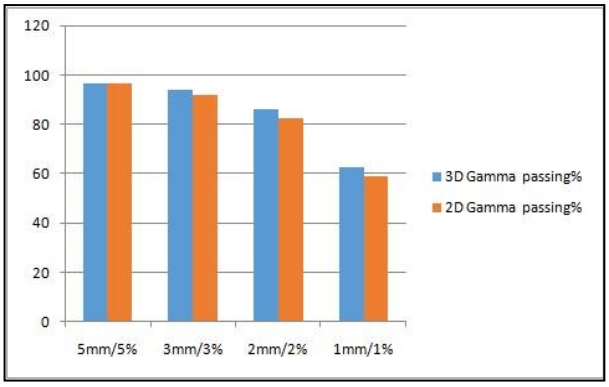

Figure 5: Average gamma passing in percentage for 2D and 3D gamma for all the QA plans.

The p values of head and neck cases was found statistically significant (≤0.05) for all gamma passing DTA (5 mm/5%, 3 mm/3%, 2 mm/2% and 1 mm/1%) criterias. The p values of other sites abdomen and pelvis were not found to be statistically significant (≥0.05).

DISCUSSION

In present study we compared variety of DTA criteria and found that 3D gamma pass percentage always resulted in higher passing rate than 2D gamma pass percentage. Same pattern was followed for all head and neck, abdomen and pelvis cases. The average difference between the 3D and 2D gamma passing percentage results were increased as DTA criteria became stringent. The gamma analysis was kept for global settings. The difference in results were found statistically significant ($p \leq 0.05$) of head and neck cases for all gamma passing DTA criteria. while for other sites abdomen and pelvis difference were not found to be statistically significant ($p \geq 0.05$). Rajasekaran et al had done study for 2D and 3D gamma for volumetric-modulated arc therapy (VMAT) in local and global settings and shown that there was no correlation between volumetric 3D and planar (2D and 3D) gamma analysis passing rates however esophagussite plans gave higher global gamma analysis passing rates.[16] Pulliam et al done a study on 2D and 3D gamma analysis which also showed that gamma pixel passing rate for 3D was 2.9% higher.[17]

The 2D array of detectors had finite size of ion chambers which caused volume-averaging effect. It should be properly taken in to account when planar dose distribution was measured and compared with TPS calculated fluence. If size of ion chamber of 2D array was same or comparable to ion chamber used for beam data commissioning the gamma pass percentage was high as both TPS calculated and 2D array measured suffer same volume averaging effect.[18]

This effect can be overcome with films measurements due high spatial resolution, but it was a time consuming and laborious process as it required film processing or scanning, evaluation and to generate calibration curve.[19]

CONCLUSION

It is concluded in the study that 3D gamma passing percentage is higher compared to 2D gamma passing for head and neck, abdomen and pelvis cases. For all gamma passing DTA criteria's 5 mm/5%, 3 mm/3%, 2 mm/2% and 1 mm/1% the 3D percentage gamma passing was higher compared to 2D gamma passing rate. The difference was statistically significant (≤0.05) only for head and neck cases. However, for other sites in study, abdomen and pelvis, difference was not found to be statistically significant (≥0.05) for all gamma passing criteria.

Funding: No funding sources
Conflict of interest: None declared
Ethical approval: Not required

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Cite this article as: Shukla AK, Bhamra HK, Rathore NK, Patidar AK, Verma A, Rajpurohit VS, et al. Comparison of 2D and 3D gamma evaluation method in patient specific intensity-modulated radiotherapy quality assurance. Int J Res Med Sci 2023;11:1160-4.