Technical Note

Verification of Dosimetric Commissioning Accuracy of Intensity Modulated Radiation Therapy and Volumetric Modulated Arc Therapy Delivery using Task Group-119 Guidelines

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Abstract

Aim: The purpose of this study is to verify the accuracy of the commissioning of intensity-modulated radiation therapy (IMRT) and volumetric-modulated arc therapy (VMAT) based on the recommendation of the American Association of Physicists in Medicine Task Group 119 (TG-119). **Materials and Methods:** TG-119 proposes a set of clinical test cases to verify the accuracy of IMRT planning and delivery system. For these test cases, we generated two sets of treatment plans, the first plan using 7–9 IMRT fields and a second plan utilizing two-arc VMAT technique for both 6 MV and 15 MV photon beams. The template plans of TG-119 were optimized and calculated by Varian Eclipse Treatment Planning System (version 13.5). Dose prescription and planning objectives were set according to the TG-119 goals. The point dose (mean dose to the contoured chamber volume) at the specified positions/locations was measured using compact (CC-13) ion chamber. The composite planar dose was measured with IMatriXX Evaluation 2D array with OmniPro IMRT Software (version 1.7b). The per-field relative gamma was measured using electronic portal imaging device in a way similar to the routine pretreatment patient-specific quality assurance. **Results:** Our planning results are compared with the TG-119 data. Point dose and fluence comparison data where within the acceptable confident limit. **Conclusion:** From the obtained data in this study, we conclude that the commissioning of IMRT and VMAT delivery were found within the limits of TG-119.

Keywords: Intensity-modulated radiation therapy, linear accelerator, quality assurance, Task Group 119, volumetric-modulated arc therapy

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Introduction

Machine-specific and patient-specific quality assurance (QA) of radiotherapy treatment is an essential part of clinical practice to know the quality of radiotherapy given to patients, implementation of a comprehensive QA program evaluates the tolerance limits, and ensures the adequate level of quality of treatment delivered to patients. The intensity-modulated radiation therapy (IMRT), volumetric-modulated arc therapy (VMAT), or Rapidarc and intensity-modulated stereotactic radiosurgery/stereotactic radiation therapy treatments are known as modern and novel techniques in which either fixed or rotational fields are used in treatments. During the delivery of these treatments, the multileaf collimators move dynamically while the gantry may either fixed or rotated continuously with different dose rates.[1-3] In view of potential source of errors and inaccuracies involved in various stages of implementation of these treatments, periodic QA checks are required to assess their performance. Various methods involved and results obtained in the QA procedures of modern radiotherapy treatment delivery are reported by various authors.[4-7] A guidance document for IMRT commissioning has been published by the American Association of Physicists in Medicine (AAPM) Radiation Therapy Committee.[8] Task Group 119 (TG-119) of AAPM was charged with expanding the guidance document. TG-119 has focused on the problem

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of quantifying the overall performance of an IMRT system and determining the reasonable confidence limits (CLs) for assessing the adequacy of the dosimetric commissioning.[9] The guidelines established test cases to verify the overall accuracy of IMRT planning and delivery. Each test has contours of the target and critical organs drawn in a rectangular slab phantom. Each test includes a specification of dose goals for the IMRT planning and the beam arrangement to be used, and it also specifies the measurements to be taken to test the accuracy of the dose delivery and what is to be reported. TG-119 has quantified the "degree of agreement that should be expected" using the concept of "CL" to describe how closely the measurements sets are agreed with the planned values, as proposed by Venselaar *et al*.[10] and refined by Palta *et al*.[11] For the point doses, where perfect agreement produces a different ratio of 0.00, the CL is defined by the formulation of Palta *et al*. [CL=|mean| +1.96 σ] is the sum of the absolute value of the average difference and (σ) standard deviation (SD) of the differences multiplied by a factor of 1.96. This formulation is based on the statistics of a normal distribution; it is to be expected that 95% of the measured points will fall within the CL. For the gamma analysis, the perfect agreement produces passing ratio rate of 100%, the CL is defined as CL= (100−mean) + 1.96 σ, where mean is the mean percentage of points passing the gamma criteria and σ is the SD. Every institution needs to carry out these set of tests as recommended in AAPM TG-119 and use the formalism to derive the local CLs before clinical implementation. Compare the local CLs obtained by institution with the AAPM TG-119 published data. If the local CLs exceed those from AAPM TG-119, then that might be an indication that the IMRT modeling needs to be improved.

The goal of our study is to verify the dosimetric commissioning of IMRT delivery using AAPM TG-119 recommendations and further extend the TG-119 protocol for low energy (6 MV) VMAT, high-energy photon (15 MV) IMRT and VMAT delivery for the three-linear accelerator commissioned at our center.

Materials and Methods

American Association of Physicists in Medicine Task Group-119

The AAPM TG-119 planning set consisting of two preliminary tests with simple fields irradiating the phantom were created to demonstrate the reliability of the assessment system for non-IMRT dose delivery, followed by five tests of IMRT plans with increasing complexity (multitarget, mock prostate, mock head/neck, and C shape).

The multitarget case includes three cylindrical targets stacked along the axis of rotation. Each cylinder has 4 cm diameter and 4 cm length [Figure 1a]. They are to receive different doses, with the central target to receive the largest dose per fraction. The mock prostate case includes the prostate, planning target volume (PTV), rectum, and bladder. The rectum was a cylinder

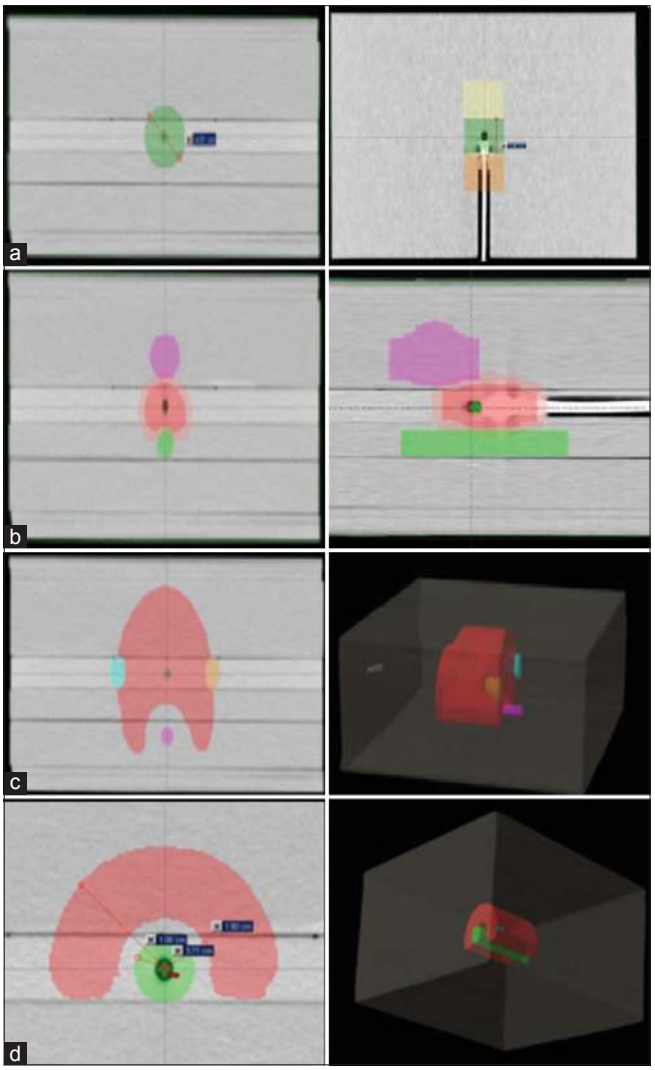

Figure 1: American Association of Physicists in Medicine Task Group-119 test structure set for (a) multitarget, (b) mock prostate, (c) mock head/neck and (d) C Shape

with a diameter of 1.5 cm. One-third of the volume of the rectum was inside the PTV of the prostate. The bladder was approximately ellipsoidal size and was centered on the superior portion of the prostate [Figure 1b]. The mock head/neck case includes the PTV, spinal cord, and both side parotids (right and left). There was a 1.5 cm gap between the PTV and the spinal cord. Both parotids are abutting the PTV [Figure 1c]. The C-shape case included a C-shape target that surrounded a central avoidance structure called core. The central core was a cylinder 1 cm in radius. The gap between the core and the PTV was 5 mm [Figure 1d]. Full description of the all the four IMRT test cases structure sets is available, with the dimensions, in AAPM TG-119 report. AAPM TG-119 defines the beam arrangement, IMRT goals, and methods to analyze the dosimetric results.

Treatment planning and quality assurance

All treatment plans and dose calculations were performed with an Eclipse treatment planning system (Version 13.5;

Varian Medical Systems, Palo Alto, CA, USA) for 6 MV and 15 MV beams for three-linear accelerator units at our center (Novalis Tx, Clinic iX and Clinac-600C). Eclipse treatment planning system (TPS) uses dose volume-optimizer algorithm for IMRT optimization for both static and dynamic IMRT. For VMAT progressive resolution optimizer algorithm was used for optimization. The analytical anisotropic algorithm was used for dose calculation with the grid size of 2.0 mm.

The first preliminary test P1 was planned to deliver 200 cGy to the mid-plane of the slab phantom by delivering two opposed anteroposterior/posteroanterior of field size 10 × 10 cm^2. The second preliminary test P2 was similar beam arrangements of the preliminary test P1, except 3 cm bands were created with asymmetric jaws to create dose gradient ranging from 40 to 200 cGy. For the preliminary test P1, central axis dose was measured with the compact ion chamber (CC13). For the preliminary test P2, we measured the doses at 5 different locations (center of the each band). For both the preliminary tests, the dose distribution on the central plane was measured with the IMatriXX 2D array ion chamber. The IMatriXX results were gamma verified with planned dose planes, and the fraction of points passing the gamma criteria was reported for 3% of dose to 3 mm distance to agreement.

For each clinical test cases, two sets of plans were generated: One with IMRT following the AAPM TG-119 guidelines which include orientation and number of gantry angles, and the other with Rapidarc (VMAT) technique for both the beam energies. For mock prostate and multi-target cases, seven static gantry angles 50° apart, and two complimentary full arcs (179.9° to 180.1° and 180.1°-179.9°) were chosen for IMRT and VMAT plans, respectively. For head/neck and C-shape tests, nine static gantry angles 40° apart for IMRT and two complimentary full arcs for VMAT were used. For all VMAT plans, we maintained the collimator angle at ±45° while, for IMRT plans, 0° collimator angle was applied throughout. For all plans, default dose calculation grid size of 2 mm was used. Dose-volume constraint and dose prescription for all plans were set according to TG-119 protocol.

In this study, we calculated conformity index (CI) and homogeneity index (HI) for all test plans using the below-mentioned formula.

(i) CI: Ratio between the volume covered by the prescribed isodose and target volume. CI = Pres Dose Volume/Total PTV Volume

(ii) HI: The dose difference normalized to dose prescription (D_{pres}) between dose covering 5% (D_5) and 95% (D_{95}) of the PTV. HI = $(D_5 - D_{95})/D_{pres.}$

To compare the local results with that of the TG, it will be necessary to analyze the data as per the TG recommendations**.** Hence, we analyzed the all test suite plans as per the recommendations of AAPM TG-119. The TG recommends to analyze the data for test suite plans in the three different QA tests, namely, point dose measurements (mean dose to the contoured ion chamber volume), Per-filed gamma analysis and composite gamma analysis.

Point dose (mean dose of the contoured chamber volume) measurements were done with compact ion chamber (CC13) placed in a SP34 solid water phantom. We have contoured the active volume on the compact chamber and found the mean dose for the calculations. For the point doses, the comparison of the measured and planned values will be done by normalizing to the prescribed dose, not the dose to a particular point. The ratio of measured and calculated dose is obtained by the formula; ratio = (measured − planned)/prescribed. After finding out the ratio, we calculated the CLs for the both techniques and energies by the formalism [CL=|mean| +1.96 σ] provided by the TG-119. Compared the results with AAPM TG-119 published data.

The per field (field-by-field) gamma measurements for the test suite plans was performed with amorphous silicon electronic portal imaging device (as1000 EPID) using portal dose image prediction software in Eclipse TPS. as1000 EPID has a 40 × 30 cm^2 detecting surface with a matrix of 1024 × 768 pixels (0.392 mm pixel pitch). All IMRT and VMAT EPID images were acquired at a source to detector distance of 100 cm with no additional buildup. The gamma evaluation was carried out between the measured and calculated fluence for the criteria of 3% dose difference and 3 mm distance to agreement in a portal dosimetry workspace of Eclipse TPS.

The composite planar dose measurements at isocenter plane/other planes were recorded using multicube phantom mounted with ImatriXX 2D array using OminiPro IMRT software for IMRT and VMAT delivery. ImatriXX is a 2D array of ion chambers, consists of 1020 ion chambers, which are arranged in 32 × 32 matrix. The sensitive area for dose measurement of 2D ion chambers array is 24 × 24 cm^2, and the space between two adjacent detectors is 7.62 mm. For both per field and composite planar dose measurements, the CLs are calculated by the formalism given in AAPM TG-119, CL= (100−mean) +1.96 σ, where mean is the mean percentage of points passing the gamma criteria, and σ is the SD. Compared the CLs with the published data of AAPM TG-119.

Results and Discussion

Quality assurance-preliminary tests

For the preliminary test P1, the measured point doses (mean dose of the contoured chamber volume) at isocenter are tabulated for both energies and three linear accelerators in Table 1. Gamma analysis was done for both the preliminary tests with the use of IMatriXX ion chamber 2D array mounted on a multicube phantom for the criteria of 3% dose difference and 3 mm distance to agreement, and the results were tabulated for the both energies in Table 1.

The ratio of point dose measurements between the TPS calculated and measured are within 1% deviation for the both energies. This showed that the absolute dose calibration in TPS is matching with machine output at the time of dose and fluence measurements. This preliminary test P1 is carried out

every time before starting any measurements (dose, fluence) for this study to make sure that the deviation of dose between the TPS and linear accelerator is <1%.

Gamma evaluation for both the preliminary tests yielded 95% of the data points having gamma values <1 for the criteria of 3% dose difference and 3 mm distance to agreement at the isocenter plane. From our results for the preliminary test, we ensured the accuracy of the planning system and dosimetric measurement devices before introducing the IMRT planning and dose measurement uncertainties.

Planning-American Association of Physicists in Medicine Task Group-119 test suites

Tables 2 and 3 show the dose-volume parameter (DVH) results for the test cases (multitarget, mock prostate, mock head/neck, and C shape) achieved in this study for 6 MV IMRT, 6 MV VMAT, 15 MV IMRT, and 15 MV VMAT delivery, respectively, for the three linear accelerators. For the 6 MV IMRT plan, DVH parameters are closely agreeing with the published data of AAPM TG-119. For 6 MV VMAT plan, DVH parameters are closely agreeing with several published data.[12,13] For 15 MV IMRT and 15 MV VMAT plan, DVH parameters are closely agreeing with the DVH results of the 6 MV IMRT and 6 MV VMAT delivery of the present study.

In this study, we calculated CI and HI for all test plans using the below-mentioned formula.

CI: Ratio between the volume covered by the prescribed isodose and target volume. The results of CI are tabulated in Table 4. CI closer to 1 is an ideal plan. From our results for the different test plans (IMRT and VMAT), mock prostate and mock head/neck test suite plans CI values are closer to 1. Multitarget and C shape plans CI values are >1.2.

HI: The dose difference normalized to dose prescription (D_{pres}) between dose covering 5% (D_5) and 95% (D_{95}) of the PTV. $HI = (D_5 - D_{95})/D_{pres.}$; the results of HI for the test plans are tabulated in Table 4. HI values closer to 0.0 are an ideal plan. Multitarget and mock prostate test plans for the energies show closest values to the HI 0.0, than the head/neck and C shape test plans.

Table 1: Test results for the preliminary test P1 and preliminary test P2

Tests	Novalis Tx	Clinac iX	Clinac-600 C
Point dose (mean dose to the contoured chamber volume) measurement at isocenter - CC13 ion chamber (Gy)			
P1: AP/PA (6 MV)	2.01	1.99	1.99
P1: AP/PA (15 MV)	2.01	2.02	N/A
Gamma values less than one at isocenter plane in percentage			
P1: AP/PA (6 MV)	95.66	95.42	95.37
P2: Bands (6 MV)	97.00	96.22	95.39
P1: AP/PA (15 MV)	96.98	96.38	N/A
P2: Bands (15 MV)	95.86	95.41	N/A

N/A: Not applicable, AP: Antero posterior, PA: Postero anterior

Point dose measurements

Point dose (mean dose for the contoured ion chamber volume) measurements were performed using CC13 compact chamber mounted on an SP34 slab phantom. The deviation of point dose measured and calculated was found for the low- and high-dose region for each test suite plans, energies, and techniques. Using these deviation values, CLs were calculated using the formalism $CL = |mean| + 1.96\ \sigma$, where mean is the mean ratio of deviation between the measured and calculated point doses σ is the SD.

Figure 2 shows the CL values for both the energies and techniques of three linear accelerators. The local CL values obtained were 0.034 and 0.037 for 6 MV and 15 MV IMRT delivery for the Novalis Tx linear accelerator. Local CL value obtained by this study closely agrees with AAPM TG-119 published value of 0.045 for the both low- and high-energy IMRT delivery. The local CL values obtained were 0.032 and 0.040 for 6 MV and 15 MV VMAT delivery for the Novalis Tx linear accelerator. Local CL value obtained by this study closely agrees with the present study IMRT CLs and the Clinac iX VMAT delivery CLs.

The local CL values obtained were 0.029 and 0.035 for 6 MV and 15 MV IMRT delivery for the Clinac iX linear accelerator. Local CL value obtained by this study closely agrees with AAPM TG-119 published value of 0.045 for the both low- and high-energy IMRT delivery. The local CL values obtained were 0.032 and 0.052 for 6 MV and 15 MV VMAT delivery for the Clinac iX linear accelerator and were in close agreement with the present study IMRT CLs and the Novalis Tx VMAT delivery CLs.

The local CL value obtained was 0.039 for 6 MV delivery for the Clinac-600C linear accelerator which was in close agreement with AAPM TG-119 published value of 0.045 for IMRT delivery. Overall, CL values are 0.035, 0.036, 0.032, 0.043 for 6 MV IMRT, 15 MV IMRT, 6 MV VMAT, and 15 MV VMAT delivery, which are in close agreement with the published AAPM TG-119 data.

Per-field measurements with electronic portal imaging device

Per-field gamma analysis was performed using as1000 EPID portal dosimetry. Using the mean and SD of gamma values of

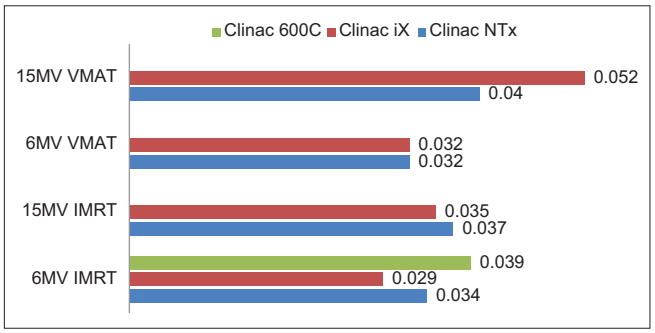

Figure 2: Confidence limit values for point dose measurements (mean dose to the contoured chamber volume) using CC13 ion chamber

Table 2: Clinical test cases - intensity modulated radiation therapy planning results for three linear accelerators

Structure	Parameters	Novalis Tx 6 MV (Gy)	Clinac iX 6 MV (Gy)	Clinac- 600C 6 MV (Gy)	Novalis Tx 15 MV (Gy)	Clinac iX 15 MV (Gy)
Multitarget						
Centre target	D99	50.06	50.00	50.00	50.00	50.00
	D10	54.53	54.22	54.54	55.36	55.20
Superior target	D99	25.80	25.57	25.80	25.78	25.65
	D10	35.72	34.40	34.86	35.79	35.00
Inferior target	D99	13.26	12.94	12.80	12.82	12.73
	D10	25.40	23.68	24.50	25.83	24.31
Mock prostate						
Prostate	D95	75.68	75.63	75.62	75.60	75.60
	D5	77.87	79.00	78.88	80.60	81.78
Rectum	D30	68.55	67.64	67.27	70.62	69.80
	D10	72.95	72.20	72.17	75.38	74.96
Bladder	D30	38.40	38.34	37.40	39.50	39.30
	D10	58.60	57.43	56.16	60.85	59.64
Mock head/neck						
PTV neck	D90	50.00	50.02	50.00	50.00	50.00
	D99	46.64	46.72	46.68	46.70	46.55
	D20	53.62	53.76	53.50	53.57	54.27
Spinal cord	Maximum	40.88	40.60	40.48	40.92	40.83
Parotid	D50	19.88	19.66	19.73	21.00	21.10
C shape hard						
PTV	D95	50.10	50.15	50.15	50.00	50.00
	D10	58.67	58.35	58.37	58.85	58.90
Center core	D5	14.40	14.80	14.72	18.12	18.25
C shape easy						
PTV	D95	50.10	50.05	50.02	50.00	50.00
	D10	56.70	56.28	56.20	57.25	56.98
Center core	D5	26.08	25.10	25.32	28.58	28.37

PTV: Planning target volume

five test suit plans, we calculated the CLs using the formula; CL= (100−mean) + 1.96 σ, where mean is the mean percentage of points passing the gamma criteria, and σ is the SD.

Figure 3 shows the CL values for both the energies and techniques of three linear accelerators. The values of local CL for 6 MV IMRT delivery for Novalis Tx linear accelerator is 4.16. This result implies that the percentage of points passing the gamma criteria is 95.8%. The local CL values were 2.71 and 3.82 for 6 MV IMRT delivery for Clinac iX and Clinac-600C, respectively. The local CL for the three linear accelerator for the 6 MV IMRT delivery results was closely matching with the published data of AAPM TG-119.

For 15 MV IMRT delivery, CL values are 3.33 and 3.65 for Novalis Tx and Clinac iX linear accelerator, respectively. The CL values for 15 MV IMRT are closely matching with the 6MV IMRT delivery of the present study.

The CL values are 2.8, 2.75, 2.90, and 2.75 for Novalis Tx 6 MV VMAT, Novalis Tx 15 MV VMAT, Clinac iX 6 MV VMAT and Clinac iX 15 MV VMAT delivery, respectively.

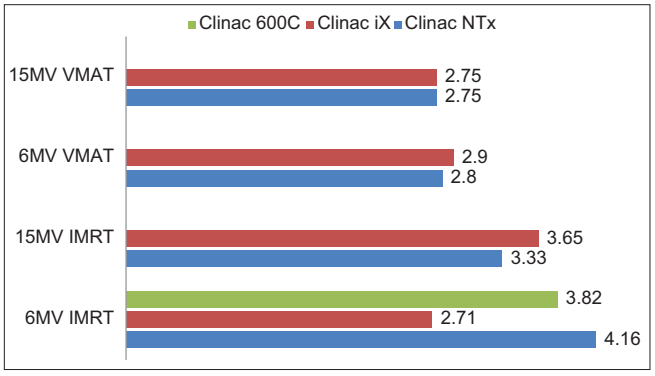

Figure 3: Confidence limit values for per field gamma analysis (3% dose difference and 3 mm distance to agreement) using electronic portal imaging device dosimetry

The CL values for VMAT are lesser than the CL value IMRT delivery. These results indicate that the pass percentage is higher in VMAT delivery compared to the IMRT delivery for per-field analysis. IMRT and VMAT plans showed similar and comparable results for all the five test cases for the three linear accelerators.

Table 3: Clinical test cases - volumetric modulated arc therapy planning results for two linear accelerators

Structure	Parameters	Novalis Tx 6 MV (Gy)	Clinac iX 6 MV (Gy)	Novalis Tx 15 MV (Gy)	Clinac iX 15 MV (Gy)
Multi target					
Centre target	D99	50.00	50.00	50.00	50.00
	D10	53.35	53.46	54.50	54.62
Superior target	D99	25.28	25.26	25.29	25.50
	D10	34.83	34.60	35.53	35.88
Inferior target	D99	12.86	12.75	13.13	12.60
	D10	24.5	24.00	26.00	25.85
Mock prostate					
Prostate	D95	75.70	75.62	75.60	75.60
	D5	78.82	77.94	81.50	81.58
Rectum	D30	68.28	67.85	69.80	70.00
	D10	72.80	72.63	75.10	75.10
Bladder	D30	38.50	38.43	40.60	41.00
	D10	59.70	58.60	58.83	60.00
Mock head/neck					
PTV neck	D90	50.00	50.00	50.00	50.00
	D99	46.73	46.85	47.80	47.66
	D20	53.25	53.48	54.33	54.30
Spinal cord	Max	39.86	39.94	40.98	41.10
Parotid	D50	19.85	19.65	21.10	21.50
C shape hard					
PTV	D95	50.08	50.05	50.00	50.00
	D10	56.85	56.78	60.00	60.30
Centre core	D5	14.45	14.95	18.22	18.78
C shape easy					
PTV	D95	50.05	50.08	50.00	50.00
	D10	56.28	56.65	57.24	57.20
Centre core	D5	25.25	25.36	27.70	27.45

PTV: Planning target volume

Composite-field measurements with IMatriXX ion chamber 2D array

Composite field measurements are performed using the IMatriXX ion chamber 2D array mounted on a Multicube phantom. The gamma deviation is found between the measured composite dose matrix at isocenter plane/different plane with the TPS calculated dose matrix. Using the gamma values at different planes, we found the CL values using the formula CL= (100−mean) + 1.96 σ, where mean is the mean percentage of points passing the gamma criteria and σ is the SD.

Figure 4 shows the CL values for both the energies and techniques of three linear accelerators. The local CL values are 2.36, 2.45, and 2.45 for Novalis Tx, Clinac iX and Clinac-600C linear accelerator 6 MV delivery, respectively. The 6 MV IMRT delivery local CL values are comparable with the published data of AAPM TG-119. For 15 MV IMRT delivery, local CL value for the both Novalis Tx and Clinac iX linear accelerator are 2.66 and 2.74, respectively. These local CL values of 15 MV IMRT delivery are closely matching the 6 MV IMRT delivery local CL of this study.

The CL values are 3.31, 3.49, 3.22, and 3.28 for Novalis Tx 6MV VMAT, Novalis Tx 15MV VMAT, Clinac iX 6 MV VMAT and Clinac iX 15 MV VMAT delivery, respectively. The local CL values for the VMAT delivery are greater than the CL values of IMRT delivery.

Conclusion

We used the AAPM TG-119 test cases to investigate the commissioning accuracy of IMRT delivery of the three linear accelerators installed at our center. The CLs obtained in our study on the dosimetric commissioning accuracy of 6 MV IMRT in the three linear accelerators were found to be well within the AAPM TG 119 recommendations. Extending this study into high-energy photon IMRT delivery, low and high energy VMAT delivery we got the similar results of CLs to that of low-energy IMRT delivery. The dosimetric commissioning accuracy of the three linear accelerators was verified and the overall results were found to be satisfactory.

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Nil.

Table 4: Conformity index and homogeneity index results for test plans

Conformity index (pres dose volume/total PTV volume)					
Test plan	**Novalis Tx (6 MV IMRT)**	**Clinac iX (6 MV IMRT)**	**Clinac-600c (6 MV IMRT)**	**Novalis Tx (15 MV IMRT)**	**Clinac iX (15 MV IMRT)**
Multi target	1.285	1.308	1.271	1.319	1.202
Mock prostate	1.001	0.959	0.960	0.993	0.961
Mock head/neck	0.973	0.973	0.944	0.963	0.928
C shape easy	1.248	1.164	1.158	1.208	1.032
C shape hard	1.137	1.102	1.095	1.129	1.101
Test plan	**Novalis Tx (6 MV VMAT)**	**Clinac iX (6 MV VMAT)**	**Clinac-600c (6 MV VMAT)**	**Novalis Tx (15 MV VMAT)**	**Clinac iX (15 MV VMAT)**
Multi target	1.124	1.160	N/A	1.093	1.117
Mock prostate	0.995	1.017	N/A	0.972	0.992
Mock head/neck	0.967	0.988	N/A	0.971	0.965
C shape easy	1.107	1.175	N/A	1.100	1.125
C shape hard	1.263	1.365	N/A	1.269	1.300
Homogeneity index $(D_5-D_{95})/D_{Pres}$					
Test plan	**Novalis Tx (6 MV IMRT)**	**Clinac iX (6 MV IMRT)**	**Clinac-600c (6 MV IMRT)**	**Novalis Tx (15 MV IMRT)**	**Clinac iX (15 MV IMRT)**
Multi target	0.056	0.058	0.057	0.068	0.063
Mock prostate	0.050	0.065	0.062	0.063	0.078
Mock head/neck	0.106	0.118	0.118	0.125	0.148
C shape easy	0.122	0.119	0.117	0.131	0.129
C shape hard	0.160	0.160	0.157	0.160	0.163
Test plan	**Novalis Tx (6 MV VMAT)**	**Clinac iX (6 MV VMAT)**	**Clinac-600c (6 MV VMAT)**	**Novalis Tx (15 MV VMAT)**	**Clinac iX (15 MV VMAT)**
Multi target	0.072	0.069	N/A	0.073	0.074
Mock prostate	0.077	0.073	N/A	0.074	0.075
Mock head/neck	0.112	0.115	N/A	0.114	0.116
C shape easy	0.136	0.144	N/A	0.144	0.141
C shape hard	0.175	0.176	N/A	0.187	0.192

N/A: Not applicable, VMAT: Volumetric modulated arc therapy, PTV: Planning target volume, IMRT: Intensity modulated radiation therapy

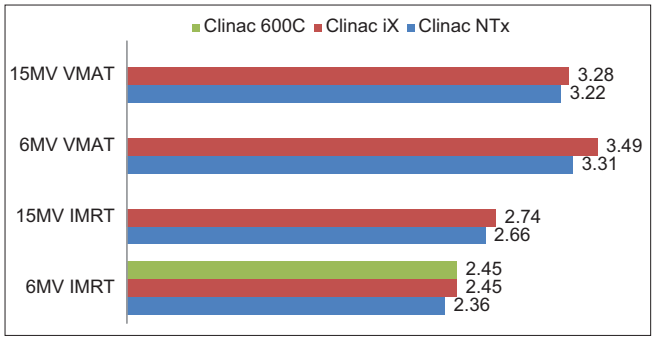

Figure 4: Confidence limit values for composite gamma analysis (3% dose difference and 3 mm distance to agreement) using IMatriXX 2D array with OmniPro intensity modulated radiation therapy software

Conflicts of interest

There are no conflicts of interest.

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