Original

Dosimetric Evaluation of Volumetric Modulated Arc Therapy (VMAT) and Intensity Modulated Radiotherapy (IMRT) Using AAPM TG 119 Protocol

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ABSTRACT

Background: The commissioning accuracy of Volumetric Modulated Arc Therapy (VMAT) need to be evaluated.

Objective: To test and evaluate commissioning accuracy of VMAT based on the TG 119 protocols at local institution.

Material and Methods: The phantom, structure sets, VMAT and IMRT beam parameter setup, dose prescriptions and planning objectives were following TG 119 guidelines to create local treatment plans of VMAT and IMRT. The local planning results were compared with the results of TG 119. Point measurement at high and low dose regions were measured using three ionization chambers with different active volumes (CC01, CC13, FC65G). The composite dose was measured by a 2D detector array and analyzed for the percentage of points passing the gamma criteria of 3 % dose difference (DD) and 3 mm distance-to-agreement (DTA) and 2 % DD and 2 mm DTA.

Results: The local treatment plans of VMAT and IMRT capable to meet the dose goals criteria set by TG 119 except for C-shape hard. Three ionization chambers with various active volumes for point measurement showed an increase in the confidence limit (CL), the larger the active volume was found proportional to increase the value of CL. The results obtained from ion chambers CC01 and CC13 could met the dose criteria set by TG 119, but results obtained from ion chamber FC65G fail the criteria. All gamma evaluation results show more than 95% data points pass the criteria of 3% DD and 3 mm DTA and the gamma index CL results fall within the TG 119 criteria, which is below 12.4.

Conclusion: TG 119 methodology and recommendations have successfully been used to evaluate commissioning accuracy of VMAT. The CL value of the study could be used as a reference and recommendation to evaluate the accuracy and integrity of treatment planning and treatment delivery systems of VMAT and IMRT.

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Keywords

Radiotherapy, Intensity-Modulated ● Radiometry ● Phantoms ● Imaging Radiotherapy Planning ● Computer-Assisted

Introduction

Intensity modulated radiation therapy (IMRT) techniques reduce dose to critical structures compared to three dimensional conformal radiotherapy (3D CRT) while maintaining conformal and homogenous dose with target volume. IMRT is different from 2D or 3D CRT, it can deliver fields of non-uniform intensity [1]. However, in Volumetric

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Modulated Arc Therapy (VMAT) the gantry rotates around the patient while the radiation is being delivered. The dose distribution was shaped into three dynamic variables: MLC, gantry rotation speed, and dose rate. The quality of VMAT treatment delivery was comparable to IMRT with an advantage such as a shorter time and less monitor unit (MU). The initial concept of VMAT was introduced by Cedric Yu in 1995 [2]. He proposed radiation treatment delivery in rotational, while the field shapes and dose weighting are being modulated. The technology started commercials in the market when Otto introduced the concept of delivering the radiation dose in a single 360º arc [3]. Varian has progressive resolution optimizer (PRO) algorithm used in VMAT RapidArc treatment plan optimization, the process depends on constraints to planning target volume (PTV) and organ at risk (OAR). The algorithm will find the best solution for variation of dynamic variables such as dynamic MLC, gantry and dose rate, it has four phases with increasing resolution to deliver optimal dose distribution [4].

VMAT and IMRT are some of radiation therapy techniques used widely in modern radiotherapy. In order to ensure the quality and safety of these radiation therapy techniques, procedural guidelines [5], quality assurance of IMRT [6] and commissioning and QA of VMAT [7] are followed by some of the radiotherapy centers. The proposed procedure consists of three types of tests, the first is to test MLC position accuracy (picket fence test), the second is to evaluate the dose rate control with gantry rotation speed, and the last is to test MLC leaf speed control during VMAT delivery.

American Association of Physicists in Medicine (AAPM) Task Group (TG) 119 has been published as a guidance for testing IMRT commissioning. This document was published based on reports of Radiologic Physics Center (RPC), they showed around 28% of the institutions were involved in the head and neck (HN) IMRT dosimetry audit process failed. TG 119 describes confidence limit (CL) to evaluate treatment planning and treatment delivery for IMRT, it consists of two preliminary tests to check linac stability and five tests that similar to clinically cases [8]. TG 119 guidance can be used to test the VMAT technique commissioning; Mynampati applied TG 119 on VMAT and IMRT then compared with IMRT TG 119. VMAT planning shows results almost the same and it can be compared with IMRT, an average difference of planning by point dose measurement did not exceed 2% and gamma index above 96% for VMAT and IMRT. TG 119 were useful to have confidence in the new modalities such as VMAT, but they require more study from other institutions and vendors [9].

Kang evaluated patient specific quality assurance (QA) results of VMAT and IMRT following TG 119 criteria; the treatment plan evaluation VMAT is able to meet the dose goal of target volume and OARs. The evaluation of absolute and relative dose measurement, VMAT results indicate the value of point dose measurement below 3% and gamma index above 97% [10]. Wen evaluated overall accuracy of VMAT RapidArc and IMRT treatment delivery for both flattening filter-free (FFF) and with flattening filter (FF) based on report of TG 119. The CLs value for both techniques were below the baseline in compared to TG 119 report [11]. Thomas reported TG 119 test tool useful in order to assess the adequacy of VMAT and IMRT commissioning, it is also useful to gain confidence for physicists in the clinic while using a new modality such as VMAT and IMRT. The planning results show the dose constraint based on the measurements, clearly the CLs were well within the baseline specified in TG 119 [12]. The purpose of our study was to test and evaluate commissioning accuracy of VMAT, IMRT treatment planning and dose delivery using AAPM TG

119 recommendations, also generate confidence limits for local institutions.

Material and Methods

TG 119 recommendations were followed in the selection, scanning phantom, treatment planning, and treatment delivery. A solid water phantom with dimensions L x W x H (30 x 30 x 20 cm^3) was set up to measure a point dose at 10 cm depth from the surface; it is shown in Figure 1, ionization chambers were put in the center of the phantom and it was scanned in CT simulator. A two-dimensional detector array MatriXX Evolution with MultiCube phantom in a sandwich position were also scanned for planar dose measurements. The phantom was scanned using Philips Brilliance CT Big Bore 16 slices (Philips Healthcare, USA). Both of phantom images were exported directly to the TPS Eclipse to be contoured for structure target (PTV) and organ at risk (OAR); TG 119 provides structure set and it can be imported to the phantom.

Varian treatment planning system Eclipse (v11.0.47) and linear accelerator Clinac iX D-2300CD with 120 Millennium MLC (Varian Medical Systems, USA) were used in this study. All VMAT and IMRT treatment plans using 6 MV beam, Anisotropic Analytical Algorithm (v11.0.31) were used for 3D dose distributions calculation with 2.5 cm calculation

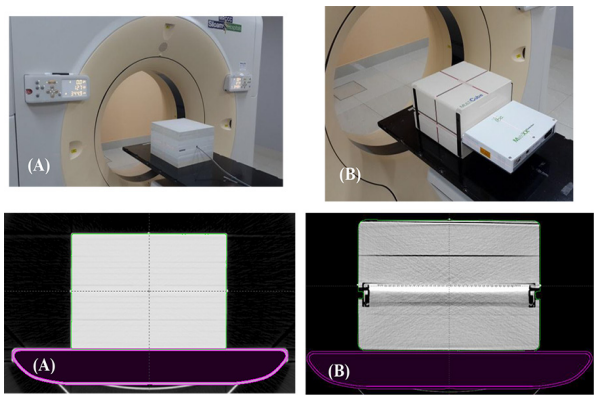

Figure 1: (A) Solid water phantom and CT scan image (B) MatriXX and CT scan image.

grid size. Equipment used during measurement were an ion chamber with 3 different volumes, electrometer Dose1, 2D array MatriXX Evolution, and a water phantom (IBA Dosimetry, Germany). The AAPM TG 119 problem set consists of two preliminary tests and five commissioning tests that resemble five clinical cases.

Figure 2 shows an illustration of preliminary tests P1 and P2. Preliminary tests P1 consist of a simple AP-PA open field of 10 x 10 cm with a prescribed dose of 2 Gy at the isocenter of solid water phantom. Preliminary tests P2 consisting of a series of AP-PA open fields in different sizes are used to creating a stair-step dose pattern, with dose ranging from 40 cGy

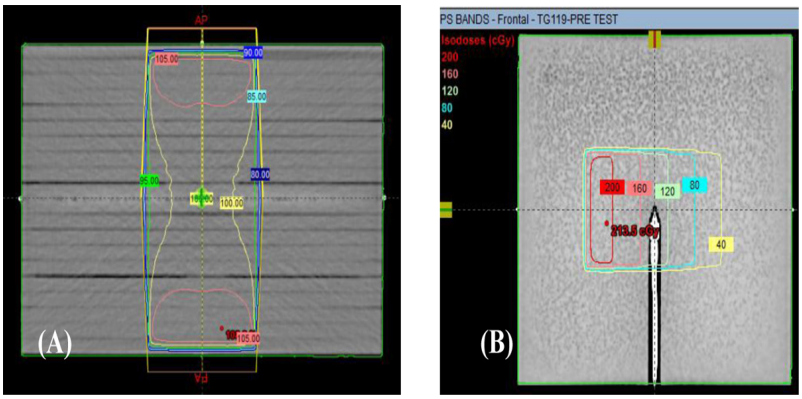

Figure 2: Illustration of Preliminary (A) test P1 and (B) test P2.

to 200 cGy and point dose measurements are made at isocenter using ionization chambers.

Figure 3(A) shows the multi-target structures, which consist of three cylindrical targets that were stacked along the axis of rotation, each target with a length of approximately 4 cm and diameter 4 cm. Each of these targets has a different dose objective. Figure 3(B) demonstrates the mock prostate structures. The prostate structure is approximately ellipsoidal, with posterior concavity, with right-left (RL), anterior-posterior (AP), and superior-inferior (SI) dimensions of 4.0 x 2.6 x 6.5 cm^3, respectively. The prostate PTV is defined as a uniform expansion of 0.6 cm around the prostate. The rectum is a cylinder with diameter of 1.5 cm, and the bladder is 5.0 x 4.0 x 5.0 cm^3 in the RL, AP, and SI dimensions, respectively.

Figure 3(C) shows the mock head and neck (H&N) structures, which consists of a large central PTV with parotid glands on both side and a spinal cord. The structures for H&N case were first drawn on a scanned of an anthropomorphic phantom and then transferred to the rectangular phantom, the gap between the PTV and the spinal cord is 1.5 cm. Finally, Figure 3(D) shows the C-shape structures, which consist of two structures, an outer target with radius of 3.7 cm and a central core with a 1 cm radius, the gap between the two structures is 0.5 cm.

A number of dose objectives or goals for each commissioning test were provided in TG 119. The first specific aim of this work was to develop VMAT and IMRT plans for the TG 119 structure sets. The dose objectives provided in TG 119 were used as guidelines in the treatment planning process in order to create plans that had complexity and modulation similar to the TG 119 institutions' plans. Table 1 lists of the numbers and arrangements beam for each commissioning test, for IMRT following the recommendations in TG 119, while for VMAT 2 arc is more easier to meet

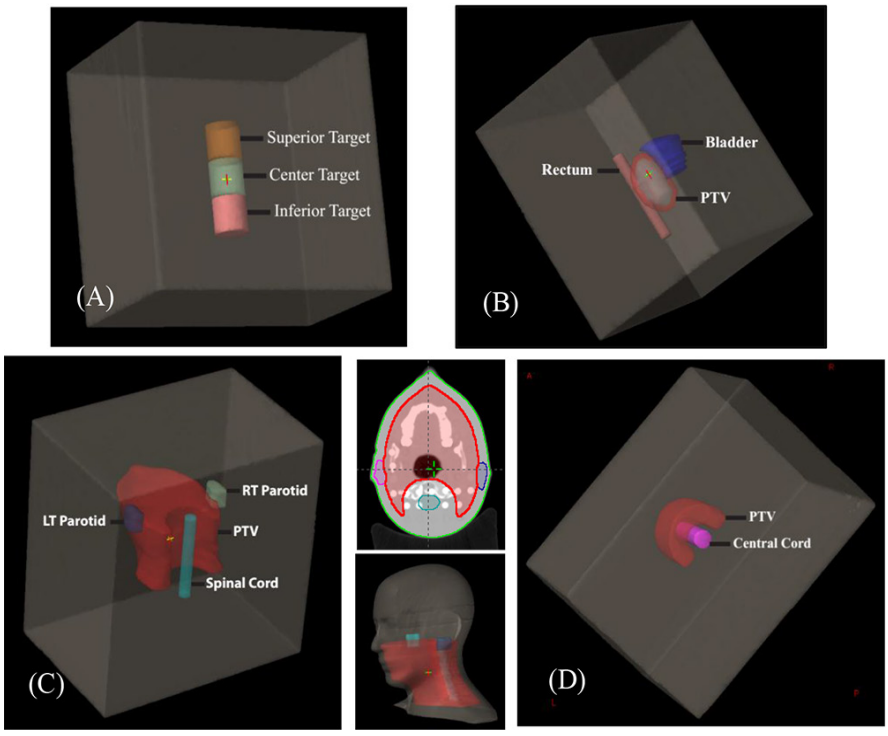

Figure 3: Mock of (a) multi target, (b) prostate, (c) head and neck, and (d) C-shape structures in Eclipse.

Table 1: Beam parameter setup for VMAT and IMRT.

	Number of beam/arcs	Beam arrangement	Collimator Angle	Prescribe dose (Gy)	Dose per fraction (Gy)
IMRT					
Multitarget	7	50° from anterior	5°	50	2
Prostate	7	50° from anterior	5°	80	2
Head and neck	9	40° from anterior	0°	50	2
C-Shape	9	40° from anterior	5°	50	2
VMAT					
Multitarget	2	CCW 179-181, CW 181-179	15°	50	2
Prostate	2	CCW 179-181, CW 181-179	30°	80	2
Head and neck	2	CCW 179-181, CW 181-179	30°	50	2
C-Shape	2	CCW 179-181, CW 181-179	30°	50	2

the dose goal criteria.

Local VMAT and IMRT treatment planning results were compared with TG 119 dose goal criteria to obtain the ratio between local treatment planning and TG 119. Conformity and the homogeneity index are two analysis tools were used to evaluate dosimetric comparison of VMAT and IMRT plans. Conformity Index (CI) equal to 1 corresponds to the ideal dose coverage or high conformity. Homogeneity Index (HI) corresponds to uniformity of the absorbed-dose distribution within the target volume, usually the PTV as indicated in Equation (1), where $D_{2\%}$ is near-maximum, $D_{95\%}$ is near-minimum, and $D_{50\%}$ is median absorbed doses [13].

$$CI = \frac{Vol\ 95\%coverage\ dose}{Vol\ PTV} \quad HI = \frac{D_{2\%} - D_{98\%}}{D_{50\%}} \quad (1)$$

TG 119 protocol recommended using ionization chamber and planar dose measurements to have point dose for 2D array. Three ionization chambers, each one with an active volume of 0.01, 0.13, and 0.65 cm^3 (IBA dosimetry, Germany) calibrated by Secondary Standard Dosimetry Laboratory (SSDL) BATAN, were listed in Table 2. The dosimeter was used to perform a point dose measurement, a volume of 0.01, 0.13, and 0.65 cm^3 chamber selected to measure a dose point. IAEA TRS 398 protocol was used for measuring dose at a certain depth, phantom with a thickness of 20 cm and the ionization chamber has been placed at a 10 cm depth from the phantom surface, positioned at the isocenter of the linear accelerator with SAD 100 cm. The readings of detector were corrected for polarity effects, ion recombination, pressure and room temperature. Point dose measurements were taken at two regions, high and low dose region. Point dose measure-

Table 2: Technical specifications of the ionization chambers used in the study.

Ionization chamber	FC65G, S/N: 2311	CC13, S/N: 9692	CC01, S/N: 9755
Active volume	0.65 cm^3	0.13 cm^3	0.01 cm^3
Polarizing voltage	300 V	300 V	300 V
Wall material	Aluminum + Graphite	Shonka	Steel + Shonka

ment was performed to measure the composite dose of VMAT and IMRT treatment delivery of five tests commissioning TG 119. Point doses were analyzed by using the Equation (2) where $D_{measured}$ was measured dose, D_{plan} is a planned dose, and $D_{prescrip}$ was a prescription dose. The dose differences are indicated as the ratio of dose subtraction between planned and measured dose to prescribed dose instead of the predicted local dose.

$$dose\ diff = \frac{D_{measured} - D_{plan}}{D_{prescrip}} \quad (2)$$

MatriXX Evolution 2D array detector, MultiCube phantom, and OmniPro IMRT software were used to measure composite planar dose distribution and to compare it with a planar dose of the treatment planning. Gamma index analysis was established for composite planar dose distribution. The gamma index technique, which is the standard method for planar dose verification in IMRT QA, calculates the quantity gamma for each point of interest using preselected dose difference (DD) and distance to agreement (DTA) criteria and then uses the gamma value to determine the outcome (pass-fail) of the IMRT QA. Gamma index was examined for the composite planar dose distribution, the criteria were set for 3 % DD, 3 mm DTA and 2 % DD, 2 mm DTA for IMRT (7 field and 9 field) and VMAT treatment delivery (2 arc).

In addition, the confidence limit (CL) was used as recommended and defined by TG 119. In TG 119, the 95% CL were established by fitting the gamma passing rate results to an assumed Gaussian distribution, then calculating the limit in which about 95% of all datasets fall within. New clinics can use TG 119 as a reference while commissioning their own IMRT program by using the aggregate gamma passing rates from multiple clinics and their associated 95% CLs. The CL is the sum of the absolute value of the average differences and the standard deviation of the differences multiplied by a factor of 1.96 as indicated in Equation (3)

$$CL = |mean| + 1.96SD \quad CL = |100 - mean| + 1.96SD \quad (3)$$

Results and Discussions

The VMAT and IMRT dose distribution for the multi target, prostate, head and neck, and C-shape cases were shown in Figure 4. It is shown that dose distribution in 95 % isodose line between VMAT and IMRT is comparable, whereas IMRT produce more dose distribution in 30 % isodose line than VMAT.

VMAT and IMRT treatment planning dose

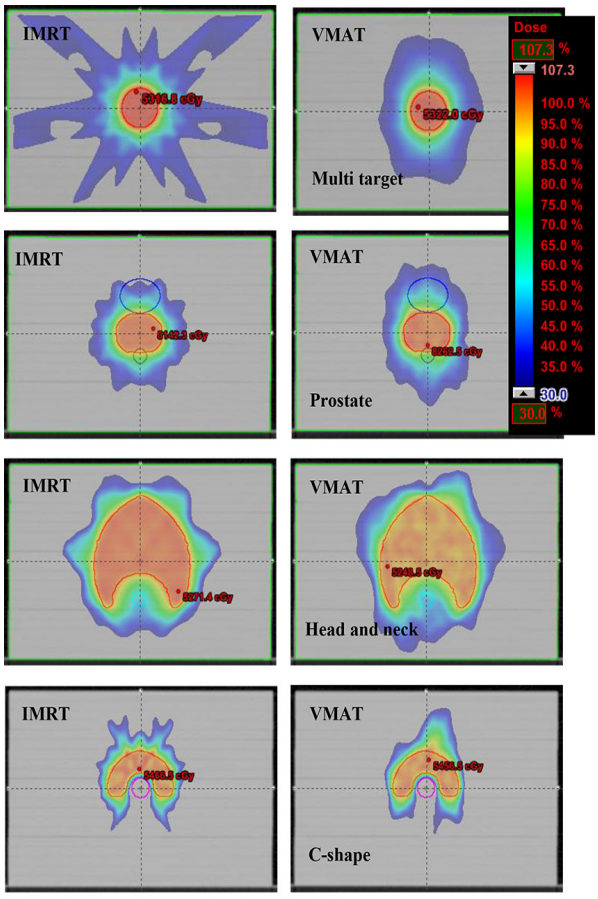

Figure 4: VMAT and IMRT dose distributions for all test commissioning.

results for five clinical tests were tabulated in Table 3. The table demonstrates that VMAT and IMRT treatment planning system for four clinical tests were capable to meet the dose goals criteria set by TG 119 except for C-shape hard. For C-shape hard case, IMRT PTV D_{10}, Core D_{10}, and VMAT Core D_{10} dose criteria could not be achieved in a local clinic as per TG 119 protocol. Since the beginning the plan goal for Core D_{10}<1000 set by TG 119 would not probably be achievable, it is for testing a treatment planning system being

Table 3: VMAT and IMRT treatment plan dose goals results .

Test/Planning parameters	Volume (cm^3)	Plan goal (cGy)	IMRT Mean (cGy)	VMAT Mean (cGy)	AAPM TG 119 Mean (cGy)	IMRT/ TG 119	VMAT/ TG 119
Multi Target							
Central D_{99}	51.6	>5000	5023 ± 3	5038 ± 23	4955 ± 162	1.01	1.02
Central D_{10}		<5300	5286 ± 5	5279 ± 4	5455 ± 173	0.97	0.97
Superior D_{99}	51.4	>2500	2514 ± 13	2527 ± 1	2516 ± 85	1.00	1.00
Superior D_{10}		<3500	3431 ± 11	3422 ± 44	3412 ± 304	1.01	1.00
Inferior D_{99}	51.5	>1250	1374 ± 3	1344 ± 57	1407 ± 185	0.98	0.96
Inferior D_{10}		<2500	2250 ± 18	2445 ± 24	2418 ± 272	0.93	1.01
Prostate							
PTV Prostate D_{95}	107.9	>7560	7663 ± 36	7838 ± 17	7566 ± 21	1.01	1.04
PTV Prostate D_5		<8300	8129 ± 10	8144 ± 38	8143 ± 156	0.97	1.00
Rectum D_{30}	20.71	<7000	6266 ± 44	6308 ± 49	6536 ± 297	1.00	0.97
Rectum D_{10}		<7500	7284 ± 27	7331 ± 43	7303 ± 15	1.01	1.00
Bladder D_{30}	63.59	<7000	4624 ± 62	5103 ± 67	4394 ± 878	0.98	1.16
Bladder D_{10}		<7500	5913 ± 64	6375 ± 97	6269 ± 815	0.93	1.02
Head and Neck							
PTV D_{90}	721.01	5000	5072 ± 6	5037 ± 9	5028 ± 58	1.01	1.00
PTV D_{99}		>4650	4856 ± 7	4880 ± 22	4704 ± 52	1.03	1.04
PTV D_{20}		<5500	5247 ± 5	5195 ± 5	5299 ± 93	0.99	0.98
Cord maximum	19.18	<4000	3887 ± 4	3877 ± 34	3741 ± 250	1.04	1.04
Parotid LT D_{50}	10.21	<2000	1927 ± 3	1874 ± 29	1798 ± 184	1.07	1.04
Parotid RT D_{50}	9.98	<2000	1943 ± 2	1878 ± 6	1798 ± 184	1.08	1.04
C-shape easy							
PTV D_{95}	283.91	5000	5016 ± 4	5012 ± 7	5010 ± 17	1.00	1.00
PTV D_{10}		<5500	5351 ± 2	5340 ± 5	5440 ± 52	0.98	0.98
Core D_{10}	31.54	<2500	2237 ± 22	2234 ± 21	2200 ± 314	1.02	1.02
C-shape hard							
PTV D_{95}	283.91	5000	5057 ± 32	5024 ± 3	5011 ± 165	1.01	1.00
PTV D_{10}		<5500	5596 ± 53	5447 ± 4	5702 ± 220	0.98	0.96
Core D_{10}	31.54	<1000	1558 ± 19	1420 ± 4	1630 ± 307	0.96	0.87

pushed very hard. In each of table, D_{XX} designates the minimum absorbed dose received by XX% of the total volume of interest, D30 of the rectum = 70 Gy. It means that 30% of the rectum volume receives at least 70 Gy. This is determined from the cumulative DVH and can be read off the cDVH.

Figure 4 shows axial plane dose distributions of VMAT and IMRT plans for multi target, prostate, head and neck, and C-shape cases. The dose distributions were 30% from total dose.

Table 4 shows comparison of VMAT and IMRT plan parameter results. It consists of conformity and homogeneity indexes, number of beams, total monitor units (MU), and MU ratio of different test cases planned for both modalities. Conformity index for VMAT and IMRT were comparable for multi-target and c-shape hard test, IMRT conformity index are higher than VMAT in prostate and c-shape easy test, the value is 0.980, 1,193 and 1.160, 1.349 for IMRT and VMAT, respectively. VMAT conformity index is higher than IMRT in the last test, with a value of 1,128 and 1,198. Homogeneity indexes (HI) show comparable results for all clinical tests, for all five test cases the HI shows value close to zero. HI indicates the ratio between the maximum and minimum dose in the target volume and the lower value indicates a more homogenous dose distribution within the target volume.

Total monitor unit (MU) comparison between volumetric modulated arc therapy and intensity-modulated radiation therapy treatment plans was made for all test cases. VMAT plans resulted in fewer MUs with the quality of treatment planning being similar or even better than IMRT for all test cases except in prostate case. Total MU for IMRT plan of all test cases were 532, 469, 1374, 1174 and 1464 for multi target, prostate, head and neck, C shape from easy one to hard respectively, while the total monitor unit in VMAT were 372, 560, 497, 902 and 985, respectively. If the total MU of VMAT plans becomes the reference; the ratios of total MU for both of plans were 1.43, 0.84, 1.76, 1.30, and 1.49 respectively for all test cases. The complexity of the plan was found to be proportional to the total MU ratio, but the increase number of total MU was lower in VMAT plan compared to IMRT plan.

The Linear accelerator output calibration for 6 MV energy was performed following IAEA TRS 398, the deviation value between the measurement and the reference value was 0.36 %. That value was within the acceptable tolerance, according to AAPM TG 142 the deviation tolerance for Linac output is 2 % [14]. The result from 6 MV output calibrations can be used for implementing VMAT and IMRT treatment plan.

Tables 5 and 6 show dose point measurements and dose variations results between

Table 4: The results of treatment plan comparison between VMAT and IMRT.

	Multi target		Prostate		Head and neck		C-shape easy		C-shape hard	
	IMRT	VMAT	IMRT	VMAT	IMRT	VMAT	IMRT	VMAT	IMRT	VMAT
Conformity index	1.357	1.372	0.980	1.160	1.198	1.128	1.193	1.349	1.355	1.400
Homogeneity index	0.042	0.047	0.074	0.055	0.067	0.073	0.113	0.090	0.154	0.133
Number of beams	7	2	7	2	9	2	9	2	9	2
Dose per fraction	200	200	200	200	200	200	200	200	200	200
Total MU	532	372	469	560	1374	497	1174	902	1464	985
MU ratio	1.43	1	0.84	1	1.76	1	1.30	1	1.49	1

Table 5: The point dose measurements for preliminary test P1.

Test	Ion chamber	Planned dose (cGy)	Measured dose (cGy)	Dose variation
P1	CC01	200	201.93	0.0096
	CC13	200	202.39	0.0120
	FC65G	200	202.78	0.0139

Table 6: The point dose measurements for preliminary test P2.

Test	Location	Planned dose (cGy)	CC01		CC13		FC65G	
			Measured dose (cGy)	Dose variation	Measured dose (cGy)	Dose variation	Measured dose (cGy)	Dose variation
P2	1st band left of isocenter	40	40.71	0.0178	40.08	0.0019	40.09	0.0022
	2st band left of isocenter	80	80.78	0.0098	80.02	0.0002	80.15	0.0019
	Pita 3 di isocenter	120	121.39	0.0116	120.65	0.0054	120.83	0.0069
	1st band right of isocenter	160	161.23	0.0077	159.96	-0.0003	160.19	0.0012
	2nd band right of isocenter	200	202.32	0.0116	200.72	0.0036	200.78	0.0039
	Mean dose variation			0.0117		0.0022		0.0032

planned and measured dose for preliminary test P1 and P2 using three different ion chambers: CC01, CC13, and FC65. The three chambers demonstrate dose variation below 2%. The range of dose variations in test P2: bands from - 0.03 % to 1.78 %, meanwhile the mean dose variations are 1.17 %, 0.22 % and 0.32 % for CC01, CC13, and FC65 respectively. Both of these preliminary tests revealed that the non-IMRT system was commissioned with adequate accuracy.

Tables 7 and 8 demonstrate dose point measurements, mean dose variations, standard deviation, and confidence limit results at high dose and low dose area of five clinical test cases for VMAT and IMRT using ionization chambers CC01, CC13, and FC65G. The prescription dose at isocenter is 200 cGy per fraction for all targets. Table 7 shows the maximum dose variations at high dose area for IMRT are 0.87 %, -0.52 %, 0.06 % and minimum dose variations of -0.04 %, -1.1 %, -1.14 % for ion chambers CC01, CC13, FC65G were measured, respectively. The means of the dose variations of CC01, CC13 and FC65G for IMRT are 0.33 %, -0.75 %, -0.44 and standard deviations of all these measurements are 0.37 %, 0.23 %, 0.48 %, respectively. The confidence limit (CL) values related to these mean and standard deviations are 0.0106, 0.0119, and 0.0137 for CC01, CC13, and FC65G chamber respectively. For VMAT, high dose area measurements show maximum dose variations of 1.03 %, -0.003 %, -0.34 % and minimum dose variations of -0.05, -1.23, -0.157 for CC01, CC13, and FC65G chamber respectively. The confidence limit (CL) values for VMAT are 0.0147, 0.0171, and 0.0208 for CC01, CC13, and FC65G, respectively.

Table 8 corresponds to doses variation, stan-

Table 7: VMAT and IMRT doses variation, standard deviation, and CL at high dose area.

Test	Location	IMRT			VMAT		
		CC01	CC13	FC65G	CC01	CC13	FC65G
Multi target	Isocenter	0.00003	-0.0052	0.0006	-0.0003	-0.0003	-0.0137
Prostate	Isocenter	-0.0004	-0.0060	-0.0013	0.0091	-0.0123	-0.0157
Head and neck	Isocenter	0.0087	-0.0069	-0.0030	0.0052	-0.0110	-0.0125
C shape (easy)	2.5 cm anterior to isocenter	0.0047	-0.0082	-0.0067	0.0103	-0.0073	-0.0053
C shape (hard)	2.5 cm anterior to isocenter	0.0035	-0.0110	-0.0114	-0.0005	-0.0017	-0.0034
	Mean of dose variations	0.0033	-0.0075	-0.0044	0.0048	-0.0065	-0.0101
	Standard deviation σ	0.0037	0.0023	0.0048	0.0051	0.0054	0.0054
	CL = |mean| + 1.96 σ	0.0106	0.0119	0.0137	0.0147	0.0171	0.0208

Table 8: VMAT and IMRT doses variation, standard deviation, and CL at low dose area.

Test	Location	IMRT			VMAT		
		CC01	CC13	FC65G	CC01	CC13	FC65G
Multi target	4 cm inferior to isocenter	0.0041	-0.0042	-0.0110	0.0086	-0.0041	-0.0206
Prostate	2.5 cm posterior to isocenter	0.0072	-0.0146	-0.0154	0.0006	0.0142	0.0331
Head and neck	4 cm posterior to isocenter	0.0048	-0.0066	-0.0264	0.0055	-0.0049	-0.0082
C shape (easy)	Isocenter	0.0067	-0.0030	-0.0029	0.0007	0.0089	0.0007
C shape (hard)	Isocenter	0.0043	-0.0044	-0.0077	0.0072	-0.0047	-0.0057
	Mean of dose variations	0.0054	-0.0065	-0.0127	0.0045	0.0019	-0.0002
	Standard deviation σ	0.0014	0.0047	0.0089	0.0037	0.0090	0.0201
	CL = |mean| + 1.96 σ	0.0082	0.0158	0.0302	0.0117	0.0195	0.0396

dard deviation, and CL at the low dose area. The location of low dose area measurement for multi target structure sets is 4 cm inferior to the isocenter, for prostate, head and neck structure low dose area measurement are at 2.5 cm and 4 cm posterior to the isocenter, whereas the low dose area measurement for C shape easy and hard structure sets are located at isocenter. For IMRT measurements at low dose area the CL are 0.0082, 0.0158, and 0.0302, whereas for VMAT CL are 0.0117, 0.0195, and 0.0396 for ion chamber CC01, CC13, FC65G respectively.

Three ionization with various active volumes showed an increase in the CL, the larger the active volume of ion chamber was found proportional to increase the value of CL. For the target and avoidance structure, CC01 reveals the lowest CL (0.82 %, 1.06 % for IMRT and 1.17 %, 1.47 % for VMAT), whereas FC65G has the highest CL (3.02 %, 1.37 % for IMRT and 3.96 %, 2.08 % for VMAT) in low dose and high dose gradient regions. TG 119 recommended that the confidence limit value for

this was 4.7 %, local CLs were within 0.047. Even though FC65G CL within TG 119 limit, there is dose variation in low dose area more than 3 % beyond the expectations set by TG 119. This volume effect of the FC65G chamber or Farmer chamber could lead to inaccurate conclusions upon clinical verification of VMAT and IMRT treatment planning, one of the causes is the lack of spatial resolution of the detector used [15].

Tables 9 and 10 show the composite gamma index analysis for all different test cases planned for both modalities in high dose and low dose area, measured a 2D array MatriXX Evolution, phantom multi cube, and analyzed OmniPro-I'MRT software, the composite gamma index analysis are compared between VMAT and IMRT in Figure 5. The table contains test name, location, and % pass rate of gamma analysis for VMAT and IMRT for each test commissioning. The mean percentage of 3 %/3 mm and 2 % DD/2 mm DTA criteria for IMRT are 98.59, 95.21 (high dose area) and 97.28, 90.75 (low dose area). The standard deviations of the gamma analysis for IMRT are 1.16, 3.53 (high dose area) and 1.63, 2.28 (low

Table 9: Gamma evaluation for VMAT and IMRT at high dose area.

Test	Location	3%, 3 mm gamma pass		2%, 2 mm gamma pass	
		IMRT	VMAT	IMRT	VMAT
Multi target	Isocenter	99.23	99.80	97.42	98.77
Prostate	Isocenter	99.04	99.62	97.31	98.42
Head and neck	Isocenter	99.44	99.57	96.81	96.30
C shape (easy)	2.5 cm anterior to isocenter	96.59	99.14	89.05	95.33
C shape (hard)	2.5 cm anterior to isocenter	98.65	98.77	95.46	95.50
	Overall mean	98.59	99.38	95.21	96.86
	Overall Standard deviation σ	1.16	0.42	3.53	1.63
	CL = |mean| + 1.96 σ	3.68	1.44	11.71	6.33

Table 10: Gamma evaluation for VMAT and IMRT at low dose area.

Test	Location	3%, 3 mm gamma pass		2%, 2 mm gamma pass	
		IMRT	VMAT	IMRT	VMAT
Multi target	4 cm inferior to isocenter	95.63	98.26	89.80	94.00
Prostate	2.5 cm posterior to isocenter	95.43	97.20	89.96	94.24
Head and neck	4 cm posterior to isocenter	98.71	98.66	88.89	94.04
C shape (easy)	Isocenter	97.87	98.76	90.42	94.92
C shape (hard)	Isocenter	98.75	96.69	94.71	93.14
	Overall mean	97.28	97.91	90.75	94.07
	Overall Standard deviation σ	1.63	0.92	2.28	0.64
	CL = |mean| + 1.96 σ	5.93	3.89	13.71	7.18

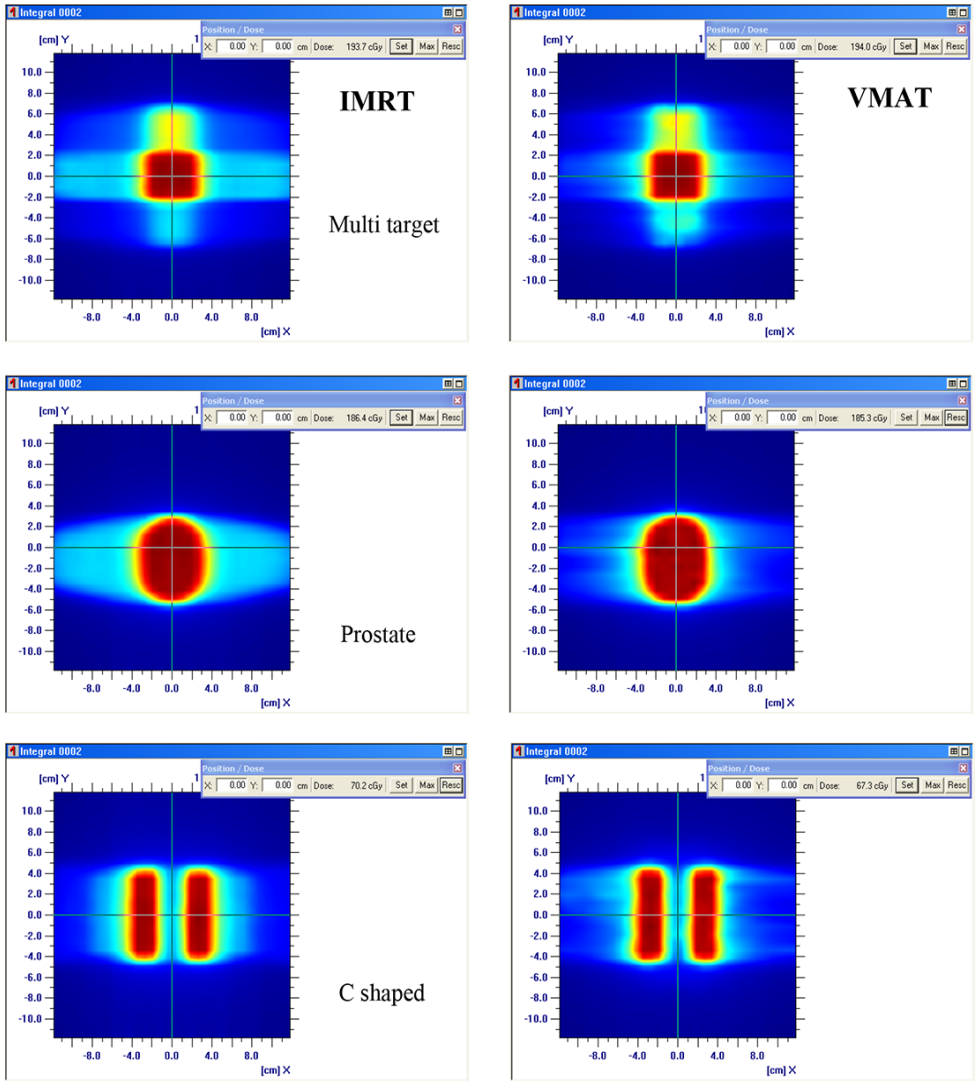

Figure 5: The comparison between the gamma index map of the dose distribution for VMAT and IMRT.

dose area). The corresponding CLs are 3.68, 11.71 (high dose area) and 5.93, 13.71 (low dose area). For VMAT CL of gamma evaluation with the same IMRT analyzing, criteria are 1.44, 6.33 (high dose area) and 3.89, 7.18 (low dose area).

All gamma evaluation results show more than 95% data points pass the criteria of 3% DD and 3 mm DTA, but for more tight criteria 2 % DD and 2 mm DTA IMRT at the low dose area fail to meet the criteria. For the same 3 %, 3 mm criteria TG 119 result value is 12.4 (i.e. 87.6 % dose point pass the criteria) as a base line. Both of them were in line with the study of Kang et al., Wen et al., and Thomas et al. [10-12] that the AAPM TG 119 can be implemented on commissioning VMAT.

Conclusion

Comparing VMAT and IMRT by AAPM TG 119 protocol along with points and composite dose measurements demonstrates adequate accuracy in delivering treatments. The ionization chamber that is smaller than a Farmer type

recommended by TG 119 with 0.01 cm^3 and 0.13 cm^3 for IMRT point dose measurement shows the confidence limit value of below 4.2 % and dose difference 3 %, while the Farmer type chamber could not meet dose criteria of 3 % dose difference. The two-dimension detector array shows CL gamma index with criteria of 3 % / 3 mm which is below 12.4 that is a limit set of TG 119 .

The CL value from the result of measurements could be used as a reference and recommendation to evaluate the accuracy and integrity of treatment planning and treatment delivery systems of VMAT and IMRT. Planning target set by TG 119 was helpful to determine baseline IMRT commissioning and it was useful for testing of new modalities such as VMAT before clinical implementation. This study focused to develop CL to evaluate the accuracy of VMAT commissioning and increase the confidence in the implementation of complex techniques.

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Conflict of Interest

None

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