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Commissioning of 6 MV UNIQUE Performance Medical Accelerator: Dosimetric Evaluation and TPS Validation using AAPM TG -119 and IAEA CIRS Test Cases

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Abstract: ***To test the overall accuracy and quality of IMRT and VMAT plans following AAPM TG119 and IAEA test recommendation and to validate the test plans for clinical implementation by comparing the calculated and measured doses. The recommendations in AAPM TG119 include planning objectives, dose delivery and measurement conditions for different clinically relevant and common test cases of IMRT & VMAT. IAEA end-to-end audit performed on CIRS phantom to test the overall accuracy of all treatment modalities. The phantom was made to undergo similar processes to a patients undergoing radiotherapy. For cases planned with TG119 recommendation the gamma analysis and point dose measurements were performed. The mean dose observed for IMRT in point dose measurement found to be -0.08% and Confidence Limit obtained were: a) point dose measurements 0.56%b) measured gamma analysis is 4.66 c) Portal dosimetry (PD) gamma analyses is 0.12.VMAT plans shows mean dose variation for point dose measurement is 0.30%and Confidence Limit obtained were: a) point dose measurements 1.15 b) measured gamma analysis is 3.46 (1 ARC) & 3.35 (2 ARC) c) gamma analysis is 0.85 (1 ARC) & 1.36 (2 ARC). IAEA test shows maximum point dose variation 2.149 % in VMAT.***

Keywords: Confidence Limit; Point dose measurement; Gamma analysis

1. Introduction

The VARIAN UNIQUE performance equipped with millennium 120 leaf Medical Linear Accelerator Installation and commissioning were carried out in our institution. UNIQUE linac is designed to generate and deliver a single photon beam of nominal energy of 6 MV with a maximum dose rate upto 600 MU/min and was developed with a vertical standing wave linac, without bending magnet and steering coils. Radio Frequency power generation was realised by a conventional magnetron. Quality Assurance (QA) in radiotherapy treatment planning process is essential to ensure that the dose calculation is performed correctly and to minimize the likelihood of accidental exposure[1, 2]. For the purpose of acceptance testing, commissioning and QA of TPSs, the IAEA has published Technical Reports Series No. 430[3]that provides the general framework and describes a large number of tests and procedures to be considered by the TPS users. Acceptance criteria for initial machine and TPS commissioning are well established [4-6]. By "commissioning, " we mean the initial verification by phantom studies that treatments can be planned, prepared, and delivered with sufficient accuracy. Commissioning is different from per-patient phantom measurements for quality assurance purposes[7].AAPM Task Group 119 has produced quantitative confidence limits as baseline expectation values for IMRT commissioning[8]. The IAEA audit methodology verifies the chain in external beam radiotherapy workflow, from patient data acquisition to treatment planning, dose delivery and monitor unit/time (MU/time) calculation, is operable for typical treatment techniques and leads to the desired results with sufficient accuracy[9].The intensity-modulated radiation therapy (IMRT), volumetric-modulated arc therapy (VMAT), or Rapidarc are known modern and novel techniques in which either fixed or rotational fields are used in treatments. During the delivery of these treatments, the multi-leaf collimators move dynamically while the gantry may either fixed or rotated continuously with different dose rate. Volumetric Modulated Arc Therapy (VMAT) is a novel rotational delivery platform that combines of dynamic gantry rotation, variable dose rate, and MLC movement speed[10, 11]. The goal of our study is to verify the dosimetric commissioning and TPS validation of IMRT and VMAT delivery using AAPM TG -119 and IAEA thorax phantom recommendations.

2. Material and Methods

Commissioning of UNIQUE performance linear accelerator is done with the help of the PTW dosimetry system in 3-D water phantom (RFA – Phantom Therapy Beam Analyzer with in-built MEPHYSTO software). The CIRS Model 002LFC Thorax Phantom was used for IAEA end to end test. The phantom represents an average human torso and measures 30 x 30 x 30 cm and has interchangeable rod inserts to accommodate ionization chambers for point dose measurements and verification in OARs. The OCTAVIUS Rotation Unit is a cylindrical phantom with 2D Detector 729 array (27 cm x 27 cm) used for IMRT and VMAT treatment plan verification. The a-Si1000 EPID is a solid state matrix of 1024 x 768 pixels with pixel size of 0.38 mm. It provides portal images which also contains dosimetric information and can be used for both image and dose verification. The separate dose image prediction algorithm Portal Dose Image Prediction (PDIP) is part of the Eclipse treatment planning system, it converts the pixel data to absolute dose. All beam

data collection and testing were performed in accordance with the VARIAN specifications and international practice and guidelines such as AAPM Task Group TG-142[12] which provides guidelines for Quality Assurance of Medical Electron Linear Accelerators, TG-106[13]provides recommendations on commissioning equipments and measurement procedures, TG-119 provides Instructions for planning, measurement and analysis. For TPS validation and verification, contours and structure sets are downloaded from TG 119 and contoured from IAEA audit are used. The chamber used for beam data collection and dosimetric measurements are PTW Ionization Chambers Semi flex (0.125 cc) and Farmer (0.6 cc) and Parallel Plate (0.01 cc). The beam data measurement and Beam Data configuration is done as per recommendation of AAA (Anisotropic Analytical Algorithm) for photon beam in order to commissioning the Eclipse (Version 13.7) TPS (Treatment Planning System).

3. Results and Discussion

3.1 TG- 119 IMRT and VMAT commissioning test: Measurement and Analysis

The CTs and RT structure set are downloaded from AAPM TG 119 with predefined structure sets contoured on CT images. Dose prescriptions and planning objectives were followed as recommended in TG 119 report to generate the test plans in Eclipse treatment planning system. Two plans were generated using IMRT and VMAT optimization. The point dose measurements for each plan were done using an ion chamber at high dose. The evaluation of gamma criteria was set to 3% Dose Difference with 3mm Distance To Agreement for both the composite and individual fields of each plan.

IMRT plan for Multi-target, Head & Neck and Prostate structure sets was generated using 7 static fields with 50° intervals for each field while 2 VMAT plan were created with one plan in full clockwise arc from gantry angle 181.0-179.0° and collimator rotation 30° and the other plan with 2 full arcs (181.0°-179.0° clockwise arc with collimator angle 30° and 179.0°-180.0° counter clockwise with collimator angle 330°). Both IMRT & VMAT plans were generated such that the dose constraints for all Organs at Risk (OARs) and tumour are achieved as specified in TG119.For C-shape, the IMRT beam arrangement were made with 5 fields at 70° intervals and same beam orientation followed for the above Multi-target, Head & Neck and Prostate structure set plan. Figure 1& 2.shows beam arrangement and dose distribution VMAT and IMRT plans.

Table 1 shows plan evaluation comparison results of test cases multi target, prostate, head & neck and c shape of IMRT and VMAT (1 and 2 arc) plans. The conformity index (CI) of all four cases is comparable. Except for test case Multi-target, the IMRT plan conformity index is slightly higher 1.12 compared to VMAT plan with CI 1.0. Homogeneity Indexes (HI) shows comparable results for multi-target, prostate and C shape structure sets of both IMRT & VMAT plans. The HI for head & neck test case is higher than the other test cases with HI for IMRT is 0.093 and VMAT is 0.132 for one arc, 0.119 for two arcs. The MU ratio and Total MU is slightly higher for VMAT plans generated with 2 arcs compared to 1 arc except for the Head & Neck case, the MU ratio as well as the Total MU is exceptionally higher than the other test cases. This indicates that as the complexity of the plan increases, the total MU and MU ratio increases.

Several publications have been published for recommendation of point measurements and gamma analysis limits[14, 15]. Table 2shows the point dose measurements at isocentre of Multi target, Prostate, Head and Neck and C shape Structure sets for IMRT. Maximum dose variation of 0.393% and minimum dose variation of -0.049% for ion chamber measurements at isocentre for IMRT. The four measurements give a mean dose variation of -0.08%, overall standard deviation of 0.34 and CL 0.59.Dose variation is defined as (measured dose – planned dose)/(prescribed dose per fraction).In dose variation the positive sign means over dose, that is the measured dose is higher than the planned dose and negative sign means under dose.

Table 3 shows maximum dose variation of -1.496% and a minimum dose variation of -0.048% for ion chamber measurements at isocentre for VMAT planning. The mean dose variation is -0.30, overall standard deviation of 0.75 and CL 1.17.

Table 1: IMRT and VMAT plan comparison result

Comparison parameters	Multi-target			Prostate			Head & Neck			C Shape		
	IMRT	VMAT (1 Arc)	VMAT (2 Arc)	IMRT	VMAT (1 Arc)	VMAT (2 Arc)	IMRT	VMAT (1 Arc)	VMAT (2 Arc)	IMRT	VMAT (1 Arc)	VMAT (2 Arc)
Conformity index	1.12	1.00	0.96	0.99	0.98	1.01	0.81	0.72	0.93	1.00	0.92	0.95
Homogeneity index	0.070	0.071	0.076	0.074	0.063	0.051	0.093	0.132	0.119	0.055	0.074	0.064
Dose per fraction (cGy)	200	200	200	200	200	200	200	200	200	200	200	200
Total MU	360	399	494	375	448	496	866	393	369	477	484	522
MU ratio	0.90	1	1.2	0.83	1	1.10	2.20	1	0.93	0.98	1	1.07

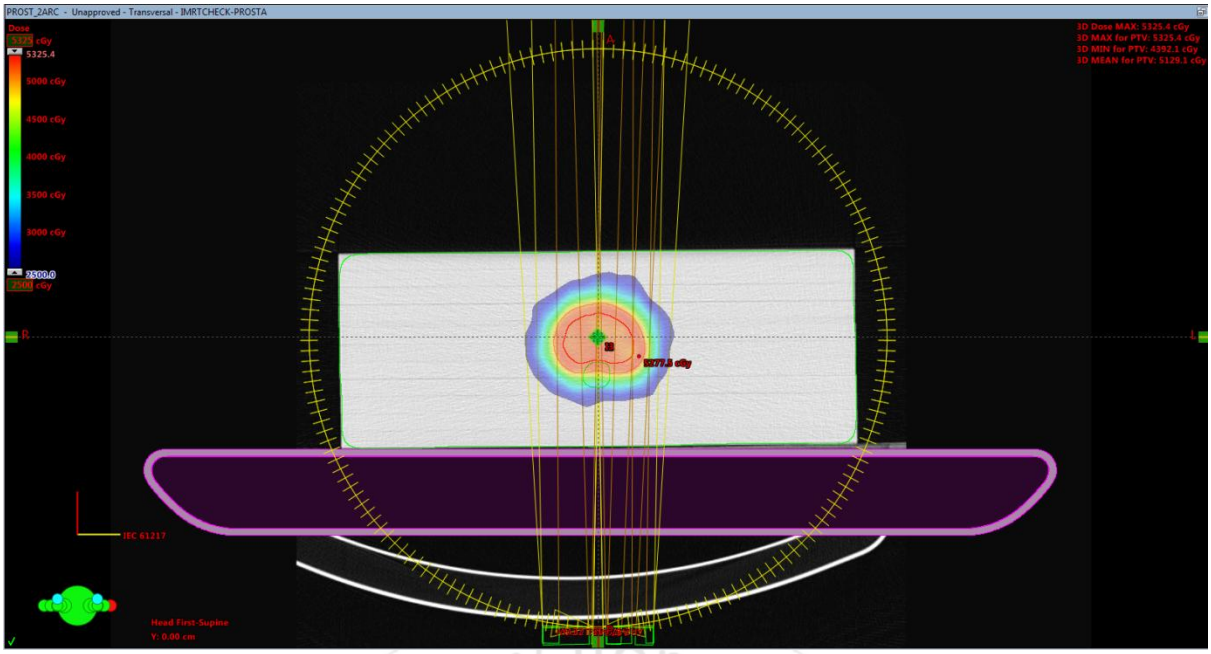


Figure 1: VMAT (2 Arc) – Prostate Beam arrangement and dose distribution

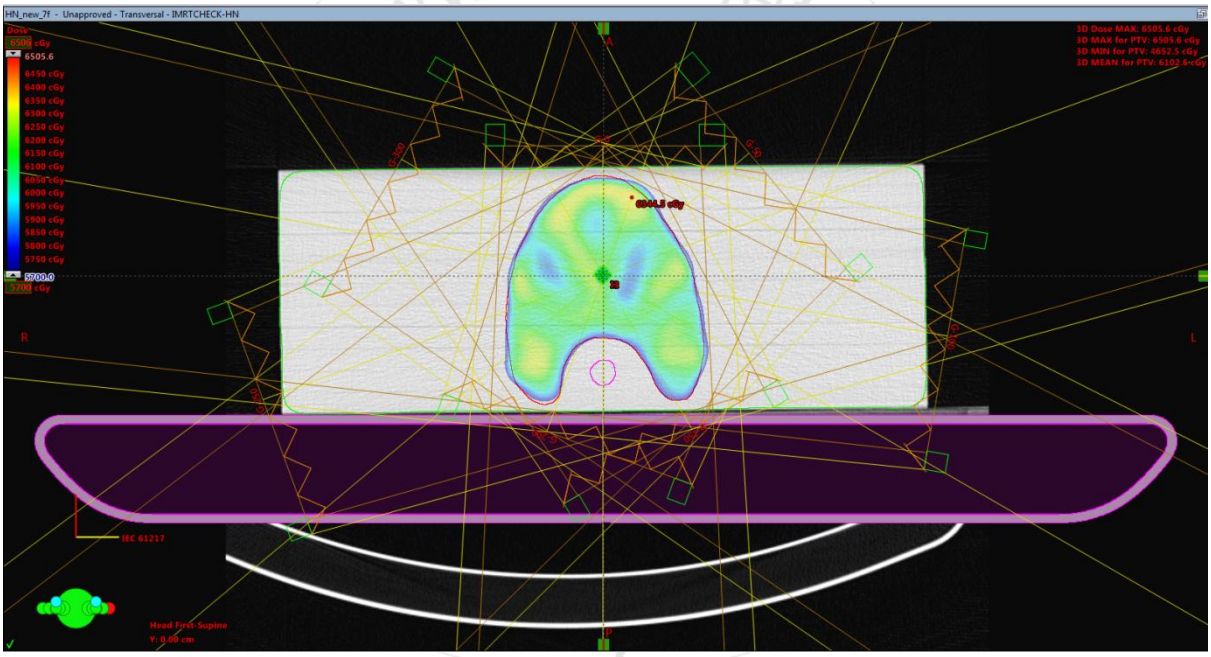


Figure 2: IMRT–Head & Neck beam arrangement and dose distribution

Table 2: Semiflex Chamber (0.125 cc) Point dose measurements results (IMRT test case)

Test	Field	Location	Prescribed Dose/fraction (cGy)	Measured dose (cGy)	Planned dose (cGy)	Dose variation % (Measured – Planned dose)/ Prescribed dose
Multitarget	7	Isocenter	200	205.24	205.33	-0.049
Prostate	7			212.75	211.97	0.393
Head &Neck	7			203.06	203.60	-0.271
C shape	5			201.58	202.57	-0.382
Mean = -0.08 Standard deviation = 0.34 CL= 0.59						

Confidence Limit= $|mean| + 1.96\ \sigma$

Table 3: Semiflex Chamber (0.125 cc) Point dose measurements results (VMAT test case)

Test	No of Arc	Location	Prescribed Dose/fraction (cGy)	Measured dose (cGy)	Planned dose (cGy)	Dose variation % (Measured – Planned dose)/Prescribed dose
Multitarget	1	Isocenter	200	200.45	199.93	0.258
Multitarget	2			202.03	202.40	-0.187
Prostate	1			201.40	202.97	-0.783
Prostate	2			201.85	200.43	0.707
Head and Neck	1			195.51	198.50	-1.496
Head and Neck	2			198.90	201.03	-1.066
C shape	1			208.04	208.13	-0.048
C shape	2			204.23	203.80	0.214
Mean = -0.30 Standard deviation = 0.75 CL= 1.17						

Confidence Limit= $|mean| + 1.96\ \sigma$

Table 4: Octavious 4D: composite gamma evaluation for IMRT and VMAT

Field	Percentage of gamma analysis (3%, 3mm (%))						
	Multi-target	Prostate	Head & Neck	C shape	Mean	SD (σ)	CL
IMRT	96.6	98.7	97.8	96.5	97.4	1.05	4.66
VMAT (1 ARC)	97.9	98.7	97.0	98.4	98	0.74	3.46
VMAT (2 ARC)	98.1	98.7	97.1	98.8	98.18	0.78	3.35

Confidence Limit= $|100 - mean| + 1.96\ \sigma$

Table 4. contains test name, dose planes which corresponds to composite gamma analysis and % pass rate of gamma analysis for IMRT and VMAT. The mean percentage of gamma passing with 3%/3 mm analysing criteria for IMRT is 97.4% and VMAT 1 ARC is 98% & 2 ARC is 98.18%. The minimum value of gamma passing corresponds to 96.5 % in C Shape IMRT plan. The maximum percentage of gamma passing is 98.8% and corresponds to a dose plane at isocentre for C shape VMAT (2 ARC) easy test. The standard deviation of the composite gamma analysis for IMRT planning is 1.05 and corresponding CL is 4.66. The standard deviation of the VMAT 1 ARC and 2 ARC are 0.74 and 0.78 with CL as 3.46 & 3.35 respectively.

Table 5: Portal Dosimetry: composite gamma evaluation for IMRT and VMAT

Field	Percentage of gamma analysis (3 %, 3 mm (%))						
	Multi-target	Prostate	Head & Neck	C shape	Mean	SD (σ)	CL
IMRT	100	100	99.9	100	99.97	0.05	0.12
VMAT (1 ARC)	100	99.9	99.3	99.9	99.77	0.32	0.85
VMAT (2 ARC)	98.9	99.7	99.2	99.5	99.32	0.35	1.36

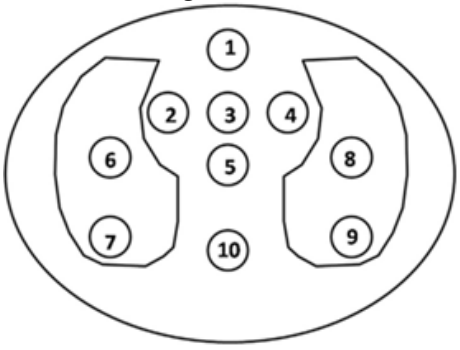
Confidence Limit= $|100 - mean| + 1.96\ \sigma$

The results of composite gamma analysis for different structure sets for both IMRT and VMAT planning are tabulated in table 5.The table contains test name corresponds to composite gamma analysis and % pass rate of gamma analysis for IMRT and VMAT. The minimum percentage of gamma passing is 98.9% and corresponds to a dose plane at multi-target of VMAT (2 ARC). The mean percentage of gamma passing with 3%/3 mm analysing criteria for IMRT is 99.9% and VMAT 1 ARC is 99.77% & 2 ARC is 99.32%.The standard deviation of the composite gamma analysis for IMRT planning is 0.05 and corresponding CL is 0.12. The standard deviation of the VMAT 1 ARC and 2 ARC are 0.32 and 0.35 with CL as 0.85 & 1.36 respectively. Results are closely agreeing with several published data[16-19].

4. TPS Validation using IAEA CIRS phantom contours sets

4.1 IAEA end-to-end on-site IMRT and VMAT audit methodology

The CIRS thorax phantom is elliptical in shape and represents an average human torso in proportion, density and two-dimensional structure. It has tissue equivalent interchangeable rod inserts accommodate ionization chambers allowing point dose measurements in multiple planes within the phantom[8]. The placement of holes allows verification in the most critical areas of the chest. Before irradiation, the output (TRS-398 Protocol) of the machine was performed by a Farmer type chamber (0.6cc PTW-Friedburg) and UNIDOS electrometer. Two scans of the CIRS phantom were done, one with chamber inserted and another without chamber. The structures such as spinal cord, heart, both lung, and PTV were delineated instead of importing the structures set from the guidelines. Plan was produced using 6 MV the treatment planning system. The prescription given in guideline for all treatment techniques is 50.4 Gy in 28 fractions. Phantom alignment was done with the help of cross mark located on top of the phantom and two additional lateral markers. After positioning the phantom, the clinical measurements were performed with calibrated Ionization chambers placed in the corresponding holes 1, 5, 6, 9, 10 in the phantom. Using the MU calculated by the TPS, the phantom was irradiated and readings were recorded and tabulated as given in Table 6 & 7.



(i)

(ii)

Figure 3:(i) Single slice representation of CIRS phantom with rod position defined for planning and irradiation (ii) IMRT thorax phantom.

4.1.1Treatment planning, contouring and measurements for 3DCRT

This is a case of a mass (tumour) located posterior to the mediastinum, axially centred 10 cm posteriorly from the anterior surface (position 5 on the figure 3). It extends longitudinally from 3 cm superior to the centre marker to 5 cm inferior to the centre marker of the CIRS Thorax IMRT Phantom. The tumour is cylindrical with a diameter of 6 cm. 3DCRT case was generated and dose constraints were achieved using 3 fields with gantry angles 0° (Collimator 0°, open beam), 235° (Collimator 90°, EDW 30°) and 125° (Collimator 90°, EDW 30°).3DCRT plans have total monitor units (MU) of 243. MLC leaves positions were checked for all the gantry angles and an independent MU check was manually calculated using the beam data.From the isodose distribution, determine the dose to the centre of the measurement points in the normal tissue, target, lungs and spine (points 1, 5, 6, 9 and 10) on the figure 4 above. In table 6 shows maximum point dose measurement variation in position number 6 and Rutonjski et al[20] showed dose variation upto 5 %.

Table 6: The point dose measurements for 3DCRT

Location	Prescribed dose/fraction (cGy)	Measured Dose (cGy)	Planned Dose (cGy)	Dose Variation % (Measured-Planned)/ Prescribed dose
Position 1	180	96.62	96.00	0.345
Position 5		180.45	182.00	-0.858
Position 6		19.39	22.00	-1.451
Position 9		84.87	86.00	-0.625
Position 10		52.45	53.00	-0.304

4.1.2Treatment planning, contouring and measurements for IMRT and VMAT

The PTV contoured was 3.5 cm diameter circle centred and drawn on plug 1 & plug 2 (9) with both circles connected in a straight manner (9). It is a total of approximately 4.5 cm in length centred (sup- inf) at effective point of measurement. Contoured central plug (plug 5) in phantom and name Oesophagus and Length = 10 cm centred at the effective point of measurement. Plug 4 in phantom is named “heart” and the length = 15 cm extending 5 cm superior and 10 cm inferior of the effective point measurement. Contour “skin” as rind of tissue from surface of phantom to depth of 0.2 cm and entire surface of phantom generated as skin. For IMRT planning there are five fields (230°, 280°, 330°, 350°, 45°) beam

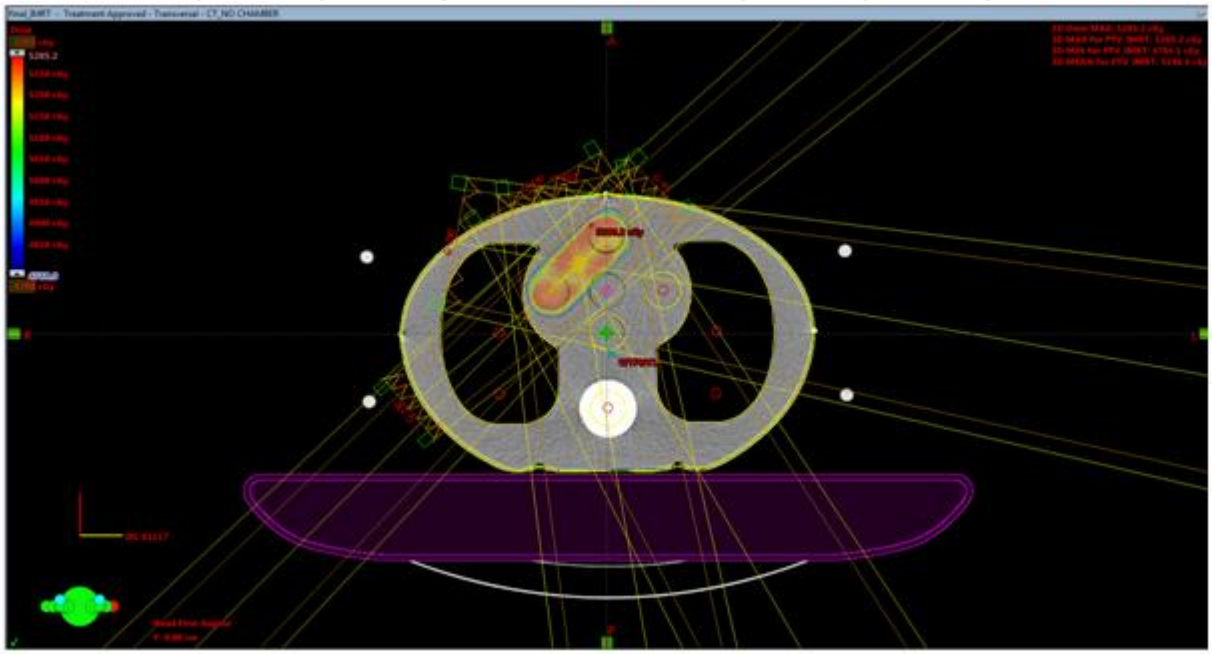


Figure 4: CIRS Phantom - IMRT beam arrangement and dose distribution

arrangement were used and total monitor units (MU) of 354. The VMAT plan were generated using partial arc (45.0°-200.0° counter clock wise arc with collimator angle 0°) and monitor unit (MU) of 317.

Table 7 & 8 shows in both IMRT and VMAT plans the maximum dose variation was -1.498% & 2.419% in position 6. The minimum dose variation in IMRT was 0.203% (position 10) and VMAT was 0.121% (position 5).

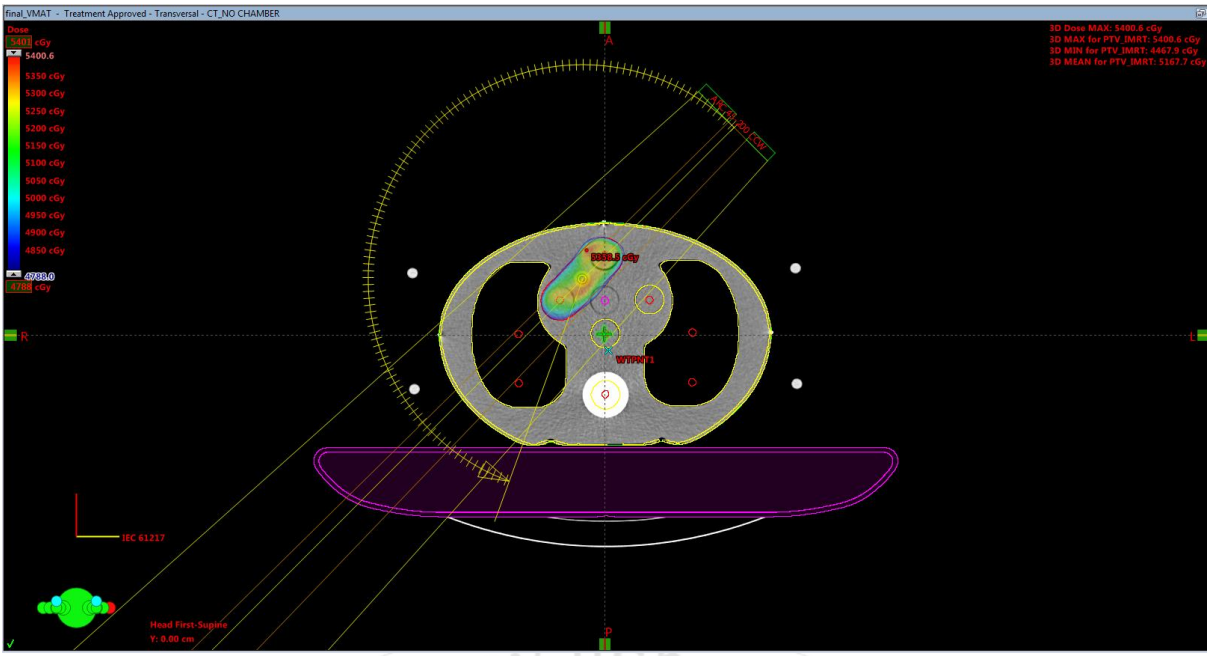


Figure 5: CIRS Phantom - VMAT beam arrangement and dose distribution

Table 7: The point dose measurements for IMRT

Location	Prescribed dose/fraction (cGy)	Measured Dose (cGy)	Planned Dose (cGy)	Dose Variation % (Measured-Planned)/ Prescribed dose
Position 1	180	185.68	184.80	0.488
Position 2		183.70	186.40	-1.498
Position 5		94.40	92.70	0.947
Position 6		65.85	63.20	1.470
Position 10		50.77	50.40	0.203

Table 8: The point dose measurements for VMAT

Location	Prescribed dose/ fraction (cGy)	Measured Dose (cGy)	Planned Dose (cGy)	Dose Variation % (Measured-Planned)/ Prescribed dose
Position 1	180	188.32	187.40	0.508
Position 2		183.87	186.40	-1.407
Position 5		37.62	37.40	0.121
Position 6		93.86	89.50	2.419
Position 10		18.89	18.00	0.494

The value of percentage of points passing gamma criteria of 3 % & 3 mm is 95.1% for both techniques. The portal dosimetry (PDIP) composite evaluation shows 99.9% for IMRT and 99.5% for VMAT.

5. Conclusions

The Varian UNIQUE performance single energy (6 MV) Medical Linear Accelerator (LINAC) was recently installed and commissioned in our institution. This work is a compilation of the commissioning tests and subsequent TPS commissioning and validation to verify that all parameters are within acceptable tolerance limits. This also proves that our Linear Accelerator is capable to deliver IMRT and VMAT accurately. We also participated in IAEA end to end on-site audit with the help of experts to establish comparable performance with international standards.

6. Conflicts of Interest

No conflict of interest was reported by the authors.

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