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Beam Data Validation for Treatment Planning System Considering AAPM TG 119 Protocol as A Verification Tools for Low, Medium and High Energy Beam While Shifting from Flatten Beam to Unflatten Beam.

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Abstract:
Purpose: Our research aimed to find out how the commissioning parameter of TG119 will change when we shift from a low-energy (6MV) to medium energy (10MV) to high energy (15MV) for RapidArc (RA) and Intensity-modulated Radiotherapy (IMRT) plans.
Methods: We evaluate effect of dose rate, gantry speed, leaf speed, and intentional error by Picket Fence(PF) tests using Electronic Portal Imaging Device(EPID) and EBT 3 films. For comparison, RA and IMRT plans are made for all tests as per American Association of Physicists in Medicine Task Group-119 (AAPM TG-119). Confidence Limit (CL) was set to have 95 percent of the measured data within tolerance limit.
Results: Average absolute deviation ($Diff_{Abs}$) for variable Dose Rate & Gantry Speed (DR_GS) has been within 1.5 %. For 6MV, 10MV, and 15MV energies. Their ($Diff_{Abs}$) for variable leaf speed and dose rate (LS_DR) was also within 1.5%. TG 119 recommendations and methodology were evaluated effectively to check commissioning precision of flatten and unflatten beams for IMRT and RA modality to set reference values.
Conclusion: Understanding a system's limitations is better before using it in a clinical application. To guarantee accurate delivery of RapidArc and IMRT plans for 6MV, 10MV and 15MV beam modalities, measurements and accepted CL values can be utilized as baseline to evaluate quality of QA procedure.

Keyword: Intensity-modulated Radiotherapy, RapidArc, Confidence limit, Task Group-119, Quality Assurance, High Definition Multi-Leaf Collimator, Flattening Filter-Free.

1 Introduction:

Intensity-modulated Radiotherapy (IMRT) is a sophisticated but highly conformal approach for treating cancer patients worldwide [1]. The IMRT technique provides a very sharp dose gradient. Utilizing this IMRT feature allows us to provide very high conformal dose to target area while minimizing impact on function of surrounding Organs at Risk (OAR). Yu et al. introduced Intensity Modulated Arc Therapy (IMAT) or Volumetric-Modulated Arc Therapy (VMAT) with better conformity than other types of conventional treatment in 1995 [2-5]. Currently, utilization of VMAT/RapidArc has grown globally. RapidArc has shown equivalent or better results for the many cancer site cases compared to IMRT and other available treatment techniques [6-9]. Unlike IMRT, RapidArc utilizes continuous gantry rotation at variable dose rates with dynamic MLC for dose delivery motion [10]. It is discussed in detail in the commissioning and QA of VMAT [11-12].

True Beam linear accelerators (Linac)(Varian Medical System, Palo Alto, CA) have both photon modes, such as Flattening Filter (FF) and Flattening Filter Free (FFF) [13-15]. In the True Beam machine, we have 6,10&15MV in FF mode with extra freedom of FFF mode in 6MV & 10MV energies. Maximum dose rate in FF mode of energies 600MU/minute, and in FFF mode it depends on the type of energies, like 1400MU/minute in 6MV and 2400MU/minute in 10MV.

There is a lack of literature review focusing on commissioning, planning and delivery accuracy of RapidArc and IMRT [16-17]. Consequently, it is crucial to assess planning and verification accuracy more thoroughly and establish their baseline value during commissioning. 28% of 250 head and neck phantom irradiations used for IMRT verification did not satisfy set standards, according to 2008 study by Radiological Physics Center. This comprised 4mm Distance To Agreement (DTA) in high dose gradient area and 7 percent dosage variation in low dose gradient area [18]. Improper commissioning and inadequate acceptance and agreement between delivery and planning processes were leading causes of this. Then, in 2009, American Association of Physicists in Medicine (AAPM) published Task Group-119(TG-119), IMRT commissioning guideline, evaluating precision of IMRT delivery and planning systems [19].

The commissioning process for IMRT and RapidArc is very rigorous and tedious. It involves manifold beam data measurement, quality assurance, and acceptance testing of different parts of Linac. Treatment Planning System (TPS), QA is essential to whole system because it involves dose calculation and dose delivery checks before treating any patient. Some tests before delivery of IMRT/RapidArc are point dose, portal dose, fluence check, and MLC accuracy with reproducibility, which needs to be, performed regularly [20-21].

2 Materials and Methods

(A) MLC performance check

Multiple tests are needed to analyse effect of dose rate, MLC speed gantry speed and range on MLC performance [22]. The Varian Medical System provided QA files on its "My Varian" portal, which can be downloaded free of cost. A series of picket fence (PF) tests, both static and dynamic, were performed. A PF test has been conducted to assess system's error detection capability.

(B) Measurement of Dosimetric Leaf Gap(DLG) and Leaf transmission

DLG and leaf transmission significantly impact dosimetric accuracy of IMRT and RapidArc plans. A baseline value was measured according to manufacture's guidelines. An SNC 125 chamber (Sun Nuclear Corporation, Florida, USA) measured leaf transmission for both leaf banks. DLG was also calculated for various sliding MLC gap widths, but for the same setup and according to the guidelines.

(C) Couch modelling for TPS

We first need to model a couch into the TPS(v16.1, Eclipse, Varian, Palo Alto, CA, USA) for treatment planning. According to different parts of the couch, i.e, thin, medium, and thick portions, there is indexing on the couch like F8 to F1, F1 to H2, and H2 to H4, respectively, for different sites, pelvis, thorax, and head-neck. Using a chamber of volume 0.6 cc (SNC600c) placed in middle of solid water phantom, thin and thick couch transmission has been measured. Solid water phantom was exposed to PA fields in various locations to get chamber readings and compute couch transmission factors.

(D) Calibration Curve and Film Dosimetry

We used Varian Medical System's electronic portal imaging device (EPID aS1200) for gamma analysis. The aS1200 detector features large measurement area (40cm x 40cm) with small pixel size (0.0336cm) [23]. GAFCHROMIC film does not depend on beam angle, dose rate, or energy, with excellent spatial resolution. This quality of GAFCHROMIC film makes it most suited for treatment plans with various commissioning QA [24-25]. In film dosimetry, we convert optical density to its respective dose with the help of a calibration curve. Cut an 8" x 10" sheet of EBT3 film in 1.25" x 8" strips. Film orientation should be maintained throughout this procedure to avoid irregularities in the results. Eight to ten equal strips are sufficient to make a good calibration curve. Calibration is valid for doses to the highest dose used during this procedure. So, a different dose point can be selected per your institution's protocol. We have choose dose pattern 25cGy, 50cGy, 100cGy, 200cGy 400cGy, 800cGy 1600cGy and 3200cGy for making our calibration curve [Figure 1]. After exposing the films, we should wait around 24 hours for better results. To scan a film, we utilized Epson software and Epson expression 1200XL flatbed scanner (Nagano, Seiko Epson Corp, Japan). Before scanning any dose film, at least 16 successive blank scans should be taken. Position the film at center of scanner bed for a more uniform response. Films were scanned using transmission mode to enhance scan stability, utilizing a scanner fix setting of 75 dots per inch and 48 bit color resolution. Tagged Image File Format (TIFF) was utilized to export images for analysis. We used EBT3 film in the ArcCHECK phantom (Sun Nuclear Corporation, Florida, USA) for film dosimetry.

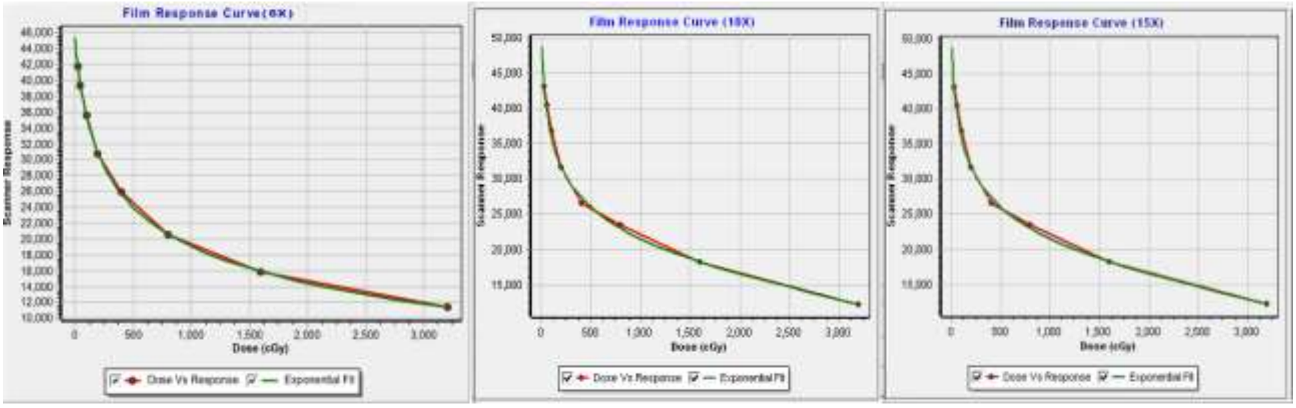

Fig:1 Calibration Curve for 6X, 10X and 15X

(E) IMRT and RapidArc dosimetry as per TG-119
Our institution has recently commissioned a TrueBeam system equipped with HD 120 MLC, featuring all 5 photon and electron energy levels. Commissioning of TrueBeam Linac was done with the help 3D SCANNER™ RFA (Sun Nuclear Corporation, Florida, USA) with its software SNC Dosimetry (version 3.7.1.21). We employed Varian Medical System's electronic portal imaging device (EPID aS1200) for gamma analysis. AS1200 detector features large measurement area (40cm x 40cm) with small pixel size (0.0336cm). We also used ArcCHECK, a helical detector grid with 1386 diode detectors with MultiPlugTM that accepts ion chambers, stereotactic detectors, and film for the measurement. We also used a solid water phantom (density of 1.04 g/cm^3) of dimension LxWxH (30x30x15 cm^3) for point dose measurement. Our dedicated CT-simulator, Discovery RT Gen 3 (GE Healthcare, Chicago, USA) scanned all the required items. TG119 has four test structures set for evaluation, i.e, C-shape target, head-neck, prostate, and multi-target. On AAPM website, CT datasets with their defined structure set are freely accessible. By TG-119 recommendations on TrueBeam system, this study attempts to evaluate overall beam commissioning accuracy and calculate CLs for IMRT and RapidArc utilizing 6MV, 10MV and 15MVphoton energies [26]. Then, it can be incorporated with TPS (v16.1, Palo Alto, Varian, Eclipse, CA, USA) to make further plans, as well as an Analytical An-isotropic Algorithm (AAA) and evaluation. Before making a comparison plan, we have adopted the same criteria as the TG119 guideline. Preliminary tests P1 have Anteroposterior-Posteroanterior (AP-PA) open field of 10x10cm^2 with 200Gy dose prescription at the isocenter. Test P2 involves various AP-PA open fields with differing sizes, establishing stair-step dosing pattern that varies from 40cGy-200cGy. For the tests P1 and P2, we used a Sun Nuclear ionization SNC125c chamber of Volume 0.125cc for measurement.

The energy used for planning is 15MV, 10MV and 6MV. No predefined weighting factor selected for the field; it is set automatically by Eclipse TPS. We used an equispaced field for all test plans, like 7 fields for prostate & multi-target, 9 for head-neck & C-shape target [27-28]. We used two full coplanar arcs, like clockwise (181^0-179^0) and counter clockwise (179^0-181^0), with complementary angles for collimator, i.e, 45^0 & 315^0. Before planning, we set the same isocenter position and optimization parameter for all IMRT and their corresponding RapidArc plan. We used a 2.5mm grid size for dose calculation without normalizing to compare DVH for RapidArc and IMRT plans. This study aims to provide RapidArc and IMRT plans for TG119 structural set. Dose objective that is provided in TG119 used as standard guideline for creating plans with similar complexity and modulation. Table 1 shows number of beams and their arrangement per TG 119 recommendation, while RapidArc with two full arcs is the easiest way to achieve dose goal criteria as per TG 119. Many plan parameters are available for different target coverage comparisons, like D_{99}, D_{95}, D_{90}, D_5, D_{50}, D_{10}, D_{max}, for different OARs comparisons. We also examined several Monitor Units (MUs) to evaluate low doses to normal organs and determine treatment duration. Homogeneity Index (HI) and Conformity Index (CI) act as parameters for evaluating plans' quality against one another [29-30]. They are defined as:

Table 1: Beam parameter for IMRT and RapidArc

	Number of Beam/Arcs	Beam Arrangement	Collimator Angle	Prescribe Dose	Dose per fraction(Gy)
IMRT					
Multitarget	7	50^0 from Anterior	0	50	2
Prostate	7	50^0 from Anterior	0	80	2
Head and Neck	9	40^0 from Anterior	0	50	2
C-Shape(Easy)	9	40^0 from Anterior	0	50	2
C-Shape(Hard)	9	40^0 from Anterior	0	50	2
RapidArc					
Multitarget	2	179^0-181^0 CCW 181^0-179^0 CW	45^0 315^0	50	2
Prostate	2	179^0-181^0 CCW 181^0-179^0 CW	45^0 315	80	2
Head and Neck	2	179^0-181^0 CCW 181^0-179^0 CW	45^0 315	50	2
C-Shape(Easy)	2	179^0-181^0 CCW 181^0-179^0 CW	45^0 315	50	2
C-Shape(Hard)	2	179^0-181^0 CCW 181^0-179^0 CW	45^0 315	50	2

Conformity Index (CI):

$CI = (TV^2_{PIV}) / TV \times PIV$

Where

TV refer as target volume

PIV refer as prescribed isodose volume

TV_{PIV} define as the target volume encompassed by the defined isodose volume.

Homogeneity Index (HI):

$HI = (D_{2\%} - D_{98\%})/D_{50\%}$

Where

$D_{2\%}$ defined as dose revived by 2% of the PTV volume.

$D_{98\%}$ defined as dose revived by 98% of the PTV volume.

$D_{50\%}$ defined as dose received by 50% of the PTV.

(F) Statistical Analysis:

With aid of measured and planned dose, dose difference ratio may be computed. This is defined as prescription dose/(divided dose-plan dose). TG 119 identified agreement between set of measurements and anticipated values using CL approach. Formula for CL for point dosages is $\{|\text{mean}| + 1.96\ \sigma\}$, where σ and mean are the standard deviation and average value, respectively, for many measurements. CL for gamma analysis is $\{(100\text{-mean}) + 1.96\ \sigma\}$, where σ is standard deviation and mean is the average % of points that meet predetermined criteria. 95% of data should be within range of confidence.

3 Results

(A) MLC performance check

Using EPID, effect of gantry angle and rotation on leaf position and precision was evaluated. Picket Fence images were compared among 6MV, 10MV and 15MV energy. Figures 2,3,4,5,6 and 7 show their PF images at static and dynamic modes. Intentional 0.5mm positional errors were easily discerned with the help of EPID. Dose deviation calculations using seven different DR_GS combinations for 6MV, 10MV and 15MV are listed in Table-2. Four LS_DR combinations for 6MV, 10MV and 15MV are displayed in Table 3. Region of interest described in one of the strips, delivered with distinct LS_DR and DR_GS, corresponds to each place in tables. DR_GS and LS_DR test images with EPID for 6MV, 10MV and 15MV are displayed in Figures 8 and 9. Table 4 shows DMLC dosimetry results for 6MV, 10MV and 15MV energies. Output variation is within the tolerance ***<±3%*** at 4 cardinal gantry angles.

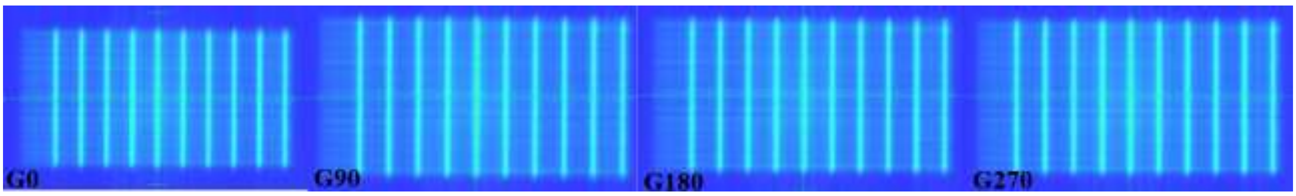

Fig:2 Picket Fence images for 6X at Static mode

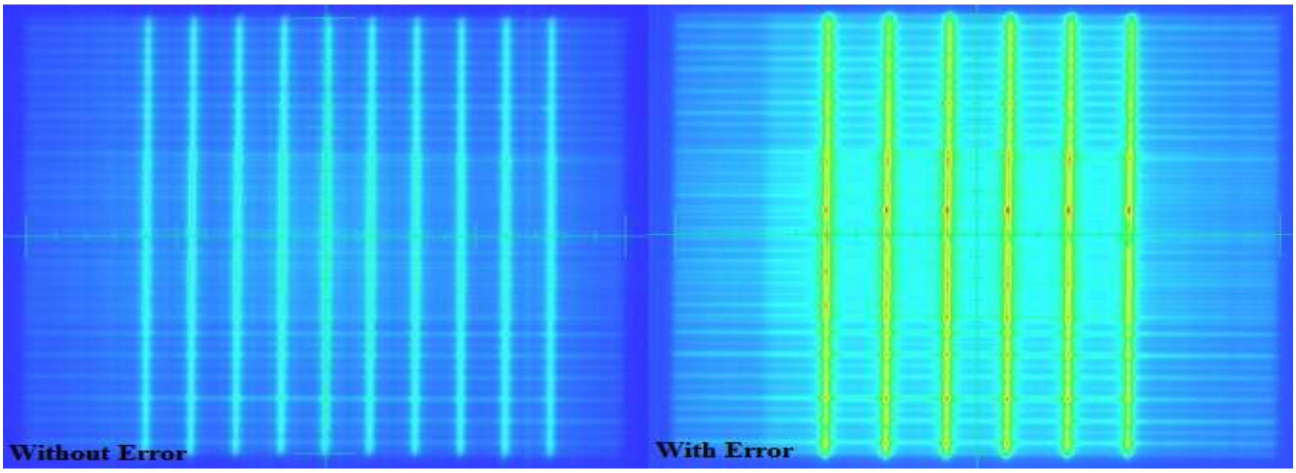

Fig:3 Picket Fence in RapidArc mode without and with error(6X)

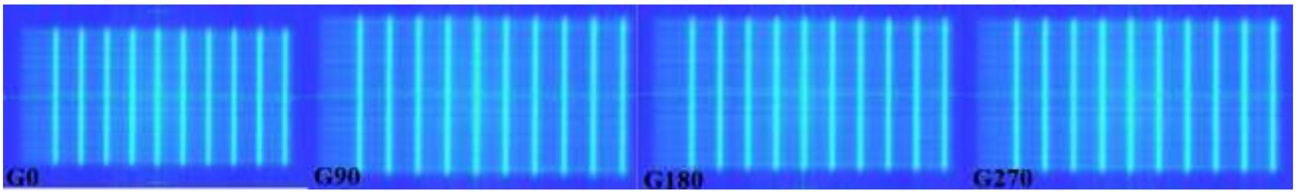

Fig:4 Picket Fence images for 10X at Static mode

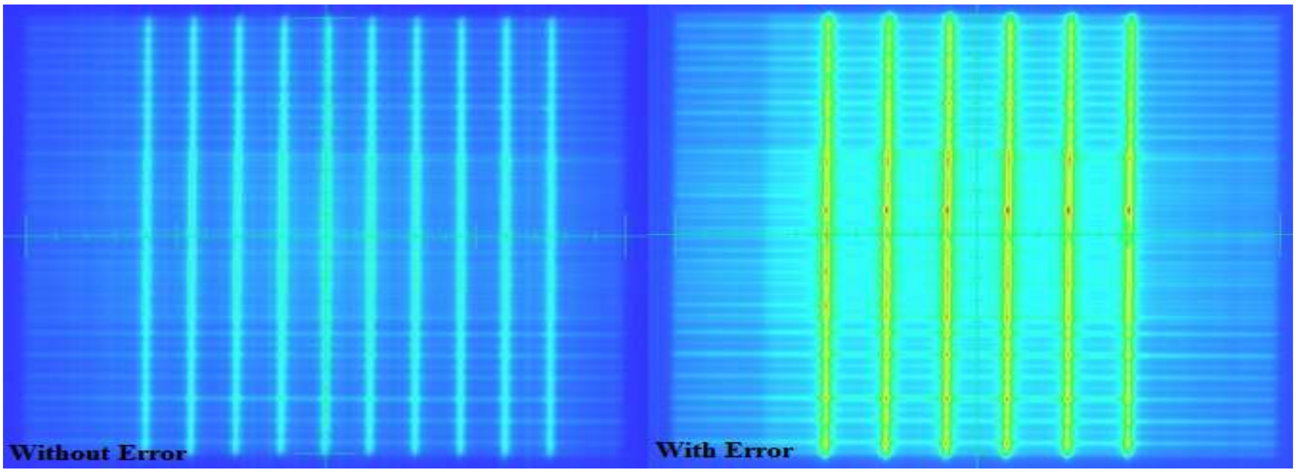

Fig:5 Picket Fence in RapidArc mode without and with error(10X)

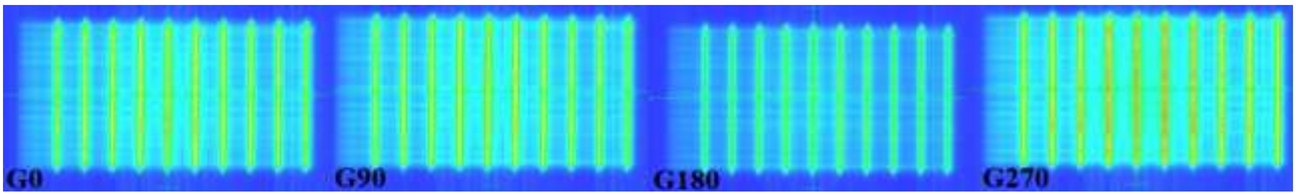

Fig:6 Picket Fence images for 15X at Static node

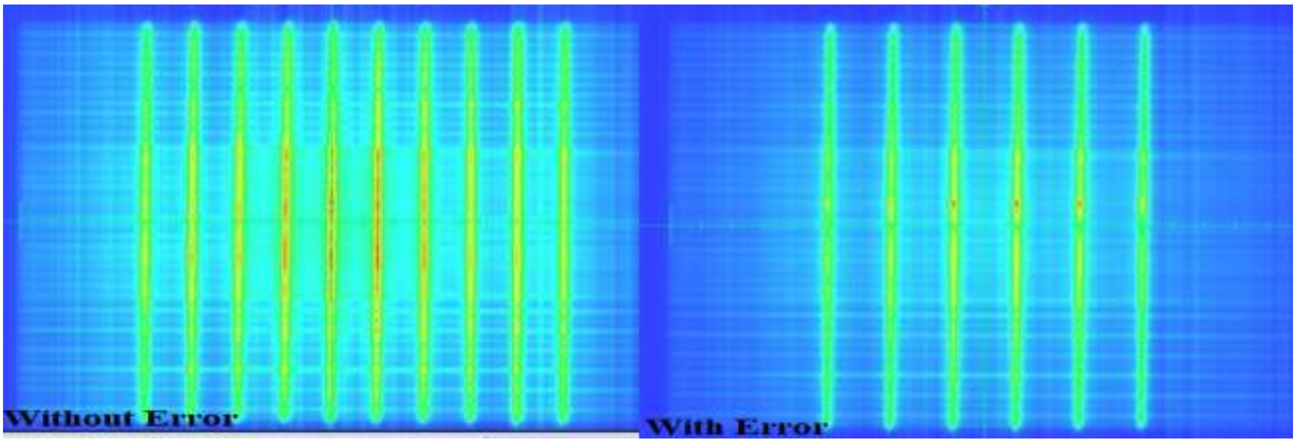

Fig:7 Picket Fence in RapidArc mode with and without error(15X)

Table 2: DR_GS test for RapidArc delivery corresponding to their respective energies

Band No	-6			-4			-2			0			2			4			6			
	6MV	10MV	15MV	6MV	10MV	15MV	6MV	10MV	15MV	6MV	10MV	15MV	6MV	10MV	15MV	6MV	10MV	15MV	6MV	10MV	15MV	
R_{DR-GS}	0.6033	0.6274	0.437	0.6121	0.6389	0.488	0.6170	0.6400	0.531	0.6119	0.6414	0.549	0.6116	0.6412	0.527	0.6107	0.6396	0.483	0.5948	0.6204	0.427	*Threshold*
R_{Open}	4.132	4.203	2.940	4.259	4.332	3.327	4.277	4.335	3.627	4.278	4.331	3.750	4.274	4.338	3.599	4.248	4.332	3.296	4.088	4.162	2.877	
R_{Corr}	14.60	14.93	14.87	14.37	14.75	14.66	14.43	14.76	14.63	14.30	14.81	14.66	14.31	14.78	14.64	14.38	14.76	14.64	14.55	14.91	14.83	
Diff(x)	1.26	0.77	1.10	-0.33	-0.44	-0.29	0.04	-0.36	-0.49	-0.80	-0.03	-0.31	-0.76	-0.22	-0.44	-0.30	-0.34	-0.42	0.89	0.62	0.84	*<±3%*
Average of absolute deviations($Diff_{Abs}$)	6MV																			0.63		*<1. 5%*
	10MV																			0.40		
	15MV																			0.56		

Table 3: LS_DR test for RapidArc delivery corresponding to their respective energies

Band No	-4.5			-1.5			1.5			4.5			
	6MV	10MV	15MV	6MV	10MV	15MV	6MV	10MV	15MV	6MV	10MV	15MV	
R_{LS}	0.1676	0.1757	0.1313	0.1699	0.1786	0.1498	0.1696	0.1795	0.1487	0.1665	0.1745	0.1437	*Threshold*
R_{Open}	1.245	1.270	0.979	1.259	1.289	1.106	1.255	1.288	1.082	1.235	1.263	1.057	
R_{Corr}	13.46	13.83	13.41	13.50	13.86	13.54	13.51	13.94	13.74	13.48	13.82	13.60	
Diff(x)	-0.22	-0.21	-1.18	0.09	-0.05	-0.24	0.17	0.55	1.24	-0.04	-0.30	0.18	*<±3 %*
Average of absolute deviations($Diff_{Abs}$)	6MV											0.13	*<1.5%*
	10MV											0.28	
	15MV											0.71	

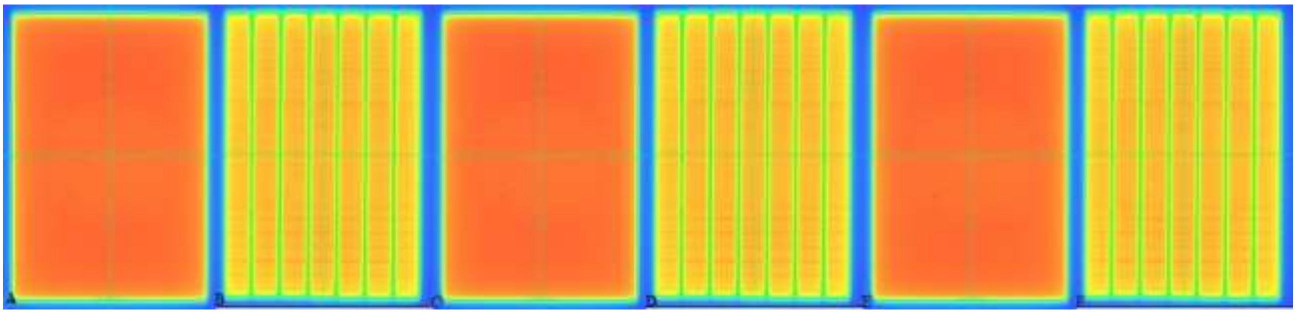

Figure 8: (A) for DR_GS_6X(Open), (B) for DR_GS_6X, (C) for DR_GS_10X(Open), (D) for Dr_GS_10X, (E) for DR_GS_15X(Open) and (F) for DR_GS_15X,

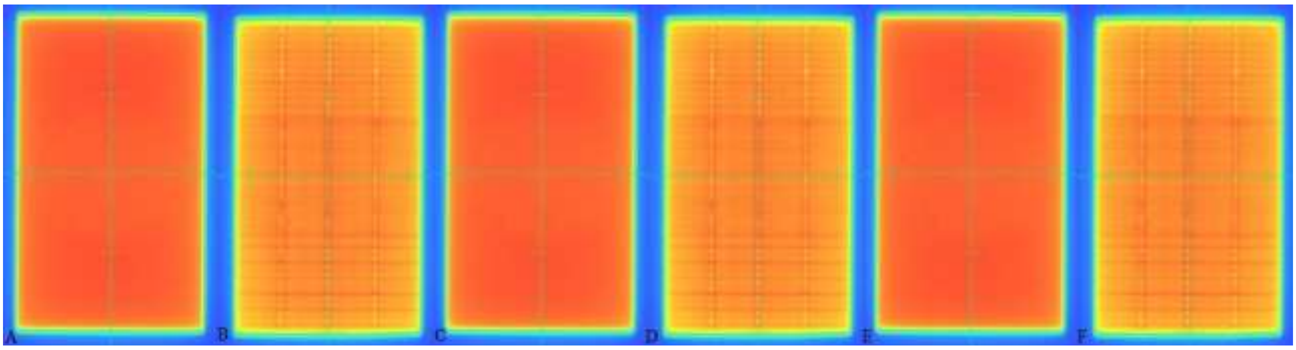

Figure 9: (A) for LS_DR_6X(Open), (B) for LS_DR_6X, (C) for LS_DR_10X(Open), (D) for LS_DR_10X (E) for LS_DR_15X(Open) and (F) for LS_DR_15X

Table 4: DMLC Dosimetry results corresponding to their respective energies

Gantry Angle	Output result			Variation(%)			Tolerance
	6MV	10MV	15MV	6MV	10MV	15MV	
0^{0}(Ref)	0.0533	0.0562	0.055	0%	0%	0%	<±3%
90^{0}	0.0530	0.0558	0.054	-0.46301331	-0.618566613	-0.570	<±3%
180^{0}	0.0535	0.0562	0.055	-0.283987997	-0.12659783	-0.370	<±3%
270^{0}	0.0532	0.0559	0.054	0.288075504	0.301804954	0.171	<±3%

(B) Measurement of Dosimetric Leaf Gap(DLG) and Leaf transmission

MLC and DLG transmission values were acquired as recommended by the vendor. Table 5 shows DLG and MLC transmission results for 6MV, 10MV and 15MV energies.

Table 5: DLG and transmission values corresponding to their respective energies

Energy	6MV	10MV	15MV
DLG(mm)	0.96	0.4923	0.4438
Transmission (%)	1.55%	1.380%	1.164%

(C) Couch modelling for TPS

Table 6 lists the calculated and measured transmission values for the couch's thin and thick indexing parts for the 6MV, 10MV and 15MV energies.

Table 6: Couch transmission corresponding to their respective energies

Energy	Thicker area			Thinner Aera		
	Calculated	Measured	% Diff	Calculated	Measured	% Diff
6MV	0.9769	0.9685	-0.84	0.9830	0.9747	-0.83
10MV	0.9740	0.9633	-1.07	0.9789	0.9727	-0.62
15MV	0.9837	0.9763	-0.74	0.9885	0.9845	-0.40

(D) Gamma Analysis

(D-1) Film Dosimetry

Film measurement is done with the help of the Sun Nuclear ArcCHECK phantom by placing the film in the assigned slot. Percentage of locations in high-dose and low-dose zones that meet suggested 3 percent/3mm gamma requirements for both RapidArc plans and IMRT for 6MV, 10MV and 15MVenergies is displayed in Tables 7 and 8, respectively. Percentage of points passing gamma criteria, averaged over all tests was 96.32 (IMRT) and 98.92 (RapidArc) for the high-dose plans for 6MV, 98.3 (IMRT) and 97.6 (RapidArc) for the high-dose plans for 10MV, 97.9 (IMRT) and 97.1 (RapidArc) for the high-dose plans for 15MV. The CLs using 3%/3 mm gamma criteria were 7.7 for IMRT and 2.5for RapidArc in the high-dose planes for 6MV, 6.2for IMRT and 5.9 for RapidArc in the high-dose planes for 10MV, 5.9for IMRT and 7.3 for RapidArc in the high-dose planes for 15MV. Percentage of points passing gamma criteria, averaged over all tests was 98.9 (IMRT) and 98.1 (RapidArc) for the low dose avoidance structure plane for 6MV, 97.9 (IMRT) and 98.9 (RapidArc) for the low dose avoidance structure plane for 10MV, 97.0 (IMRT) and 99.2 (RapidArc) for the low dose avoidance structure plane for 15MV. The CLs using 3%/3 mm gamma criteria were 1.6 for IMRT and 4.5 for RapidArc in the low dose avoidance structure plane for 6MV, 7.5 for IMRT and 2.1 for RapidArc in the low dose avoidance structure plane for 10MV,7.8 for IMRT and 1.7 for RapidArc in the low dose avoidance structure plane for 15MV.

Table7: Gamma Evaluation (3%, 3mm) in high dose PTV plane for IMRT and RapidArc with ArcCHECK Phantom corresponding to their respective energies

Test	IMRT			RapidArc		
	6MV	10MV	15MV	6MV	10MV	15MV
Prostate	95.8	99.7	97.5	99.2	97.2	98.3
H&N	96.4	98.9	98.9	97.7	97.9	99.1
C-Shape Hard	97.5	94.2	94.7	99.3	94.8	93.5
C-Shape Easy	98.7	99.3	99.1	98.9	98.3	96.3
Multitarget	93.2	99.5	99.2	99.5	99.7	98.1
Overall Mean	96.32	98.3	97.9	98.92	97.6	97.1
Overall SD	2.1	2.3	1.9	0.7	1.8	2.2
Confidence Limit	7.7	6.2	5.9	2.5	5.9	7.3

Table 8: Gamma Evaluation (3%, 3mm) in the low dose avoidance structure plane for IMRT and RapidArc with ArcCHECK Phantom corresponding to their respective energies

Test	IMRT			RapidArc		
	6MV	10MV	15MV	6MV	10MV	15MV
Prostate	98.6	99.3	98.8	98.9	99.2	99.5
H&N	98.8	99.5	99.4	98.7	99.6	99.7
C-Shape Hard	99.1	93.8	94.5	98.5	98.3	98.7
C-Shape Easy	98.9	98.9	95.3	96.1	98.8	98.9
Overall Mean	98.9	97.9	97.0	98.1	98.9	99.2
Overall SD	0.2	2.7	2.5	1.3	0.56	0.48
Confidence Limit	1.6	7.5	7.8	4.5	2.1	1.7

(D-2) Field by field gamma measurement

Portal dosimetry is the easiest and convenient way to do any field-by-field measurement and gamma analysis for any modality like IMRT and RapidArc. Table 9 shows field-by-field measurements for IMRT for 6MV, 10MV and 15MV, and Table 10 shows same result for RapidArc for 6MV, 10MV and 15MV energies. Result shows that overall mean for 6MV energy is 99.83 and 99.88, respectively, for IMRT and RapidArc cases, with CL values of 0.50 and 0.32. The 10MV energy result is 99.83 and 99.88 for IMRT and RapidArc cases, with CL values of 0.51 and 0.32. The 15MV energy result is 99.81 and 99.87 for IMRT and RapidArc cases, with CL values of 0.54 and 0.37.

Table 9: Field by field measurement for IMRT corresponding to their respective energies

Field	Multitarget			Prostate			Head-Neck			C shape (easy)			C Shape (hard)		
	6MV	10MV	15MV	6MV	10MV	15MV	6MV	10MV	15MV	6MV	10MV	15MV	6MV	10MV	15MV
1	99.8	99.9	100	100	99.8	99.5	100	99.8	100	99.9	99.9	99.7	99.8	100	99.9
2	99.5	100	99.9	99.8	99.5	100	99.6	100	99.9	100	100	99.9	100	99.6	100
3	99.9	99.8	99.5	99.5	99.9	99.7	99.8	99.9	99.9	100	100	100	99.9	99.8	99.9
4	100	100	99.8	99.9	100	99.9	99.9	99.5	99.7	99.7	99.7	99.5	99.5	99.9	99.7
5	99.6	99.9	100	100	99.6	99.5	99.8	99.7	99.4	99.5	99.5	100	99.7	99.8	99.5
6	100	99.6	99.7	99.8	100	99.8	99.7	99.8	100	100	100	99.8	99.8	99.7	99.8
7	99.7	99.4	99.6	99.6	99.7	100	100	100	99.8	99.9	99.9	99.8	100	100	99.9
8							99.8	99.7	100	100	100	99.7	99.7	99.8	100
9							100	100	99.7	99.8	99.8	100	100	100	99.8
Mean	99.79	99.80	99.79	99.80	99.78	99.77	99.84	99.82	99.82	99.87	99.87	99.82	99.82	99.84	99.83

Overall Mean	6MV	99.83
	10MV	99.83
	15MV	99.81
Overall Sigma	6MV	0.167
	10MV	0.17
	15MV	0.18
CL	6MV	0.50
	10MV	0.51
	15MV	0.54

Table10: Field by field measurement for RapidArc corresponding to their respective energies

Field	Multitarget			Prostate			Head-Neck			C shape (easy)			C Shape (hard)		
	6MV	10MV	15MV	6MV	10MV	15MV	6MV	10MV	15MV	6MV	10MV	15MV	6MV	10MV	15MV
1	100	99.7	100	99.9	100	99.8	99.8	99.9	100	100	99.8	99.9	99.7	100	99.7
2	99.8	99.9	99.7	100	99.8	100	99.9	100	99.8	99.8	99.9	100	99.9	99.8	99.8
Mean	99.9	99.8	99.85	99.95	99.9	99.9	99.85	99.95	99.9	99.9	99.85	99.95	99.8	99.9	99.75

Overall Mean	6MV	99.88
	10MV	99.88
	15MV	99.87
Overall Sigma	6MV	0.103
	10MV	0.10
	15MV	0.13
CL	6MV	0.32
	10MV	0.32
	15MV	0.37

(E) IMRT and RapidArc Dosimetry as per TG-119

(E-1) Preliminary tests

These preliminary tests were designed to check accuracy of treatment planning system and its dosimetry before implementing IMRT and RapidArc in any system. First, output dose calibration for 6MV, 10MV and 15MV energy was done according to TRS 398 before any experiments were performed. The variation between the measured and reference doses were 0.025%, meaning the plan and estimated values were very close. Their calibration result was utilized in IMRT and RapidArc plans. Preliminary test for 6MV, 10MV and 15MV was performed and measured as recommended in TG 119. Dose point measurement for P1 & P2 preliminary tests utilizing ion chamber SNC125 is displayed in Tables 11 and 12, together with difference between measured and planned doses. Dose variation result for tests P1 & P2 was less than 2%, which shows that non-IMRT and RapidArc system was commissioned with decent accuracy.

Table 11: The Point dose measurements for preliminary test P1 corresponding to their respective energies

		Plan Dose(cGy)	Measure Dose(cGY)	Dose Variation	% of Variation
P1	6MV	200	200.8	0.0040	0.40
	10MV	200	201.1	0.0055	0.55
	15MV	200	201.7	0.0085	0.85

Table 12: The Point dose measurements for preliminary test P2 corresponding to their respective energies

	Location	Plan Dose(cGy)	Measured Dose(cGy)	Dose Variation	% of Variation
P2(6MV)	1st band left	40	40.45	0.0113	1.13
	2nd band left	80	80.57	0.0071	0.71
	Isocenter	120	121.25	0.0104	1.04
	1st band right	160	161.35	0.0084	0.84
	2nd band right	200	201.77	0.0089	0.89
	Mean dose variation			0.00922	0.90
P2(10MV)	**Location**	**Plan Dose(cGy)**	**Measured Dose(cGy)**	**Dose Variation**	
	1st band left	40	40.25	0.0063	0.63
	2nd band left	80	80.53	0.0066	0.66
	Isocenter	120	121.5	0.0125	1.25
	1st band right	160	161.4	0.0087	0.87
	2nd band right	200	201.89	0.0095	0.95
	Mean dose variation			0.0087	0.87
P2(15MV)	**Location**	**Plan Dose(cGy)**	**Measured Dose(cGy)**	**Dose Variation**	
	1st band left	40	40.15	0.0038	0.37
	2nd band left	80	80.62	0.0077	0.77
	Isocenter	120	120.8	0.0067	0.67
	1st band right	160	161.7	0.0106	1.06
	2nd band right	200	201.5	0.0075	0.75
	Mean dose variation			0.0073	0.73

For both RapidArc plans and IMRT, ion chamber measurement findings in high & low-dose locations are displayed in Tables 13 and 14, respectively. CLs and dose difference ratios are computed according to TG 119. 0.014 in 6MV_IMRT, 0.019 in 6MV_RapidArc, -0.007 in 10MV_IMRT, and 0.005 in 10MV_RapidArc, -0.012 in 15MV_IMRT, and 0.004 in 15MV_RapidArc are average dose difference ratios for high-dose, low-gradient targets. These values translate into average 95% CLs of 0.028 for 6MV_IMRT, 0.044 for 6MV_RapidArc, 0.018 for 10MV_IMRT, 0.021 for 10MV_RapidArc, 0.034 for 15MV_IMRT and 0.044 for 15MV_RapidArc respectively. Average CL for all test cases was within 0.045, and institution took part in TG 119. Average dose difference ratios for low dose points in avoidance structures are 0.015 in 6MV_IMRT, 0.013 in 6MV_RapidArc, -0.005 in 10MV_IMRT, 0.011 in 10MV_RapidArc, -0.011 in 15MV_IMRT, and 0.005 in 15MV_RapidArc. These ratios translate into average 95% CLs of 0.030 for 6MV_IMRT, 0.045 for 6MV_RapidArc, 0.027 for 10MV_IMRT, 0.026 for 10MV_RapidArc, 0.044 for 15MV_IMRT and 0.020 for 15MV_RapidArc, respectively. For CLs, average of all tests and institutions in low-dose area from TG 119 was 0.047.

Table 13: High Dose Point in PTV for both IMRT & RapidArc corresponding to their respective energies

Test	Location	IMRT			RapidArc		
		6MV	10MV	15MV	6MV	10MV	15MV
Prostate	Isocenter	0.014	-0.001	-0.013	0.010	-0.001	-0.007
H&N	Isocenter	0.003	-0.015	-0.028	0.005	-0.005	0.003
C-Shape Hard	2.5cm Anterior to Isocenter	0.020	-0.005	-0.005	0.034	0.012	-0.02
C-Shape Easy	2.5cm Anterior to Isocenter	0.012	-0.011	0.003	0.031	0.014	0.035
Multitarget	Isocenter	0.020	-0.002	-0.015	0.013	0.005	0.007
Overall Mean		0.014	-0.007	-0.012	0.019	0.005	0.004
Overall SD		0.0070	0.006	0.012	0.0130	0.008	0.020
Confidence Limit		0.028	0.018	0.034	0.044	0.021	0.044

Table 14: Low Dose Point in the avoidance structure for both IMRT & RapidArc corresponding to their respective energies

Test	Location	IMRT			RapidArc		
		6MV	10MV	15MV	6MV	10MV	15MV
Prostate	2.5cm posterior to isocenter	0.023	-0.003	-0.018	0.045	0.023	0.004
H&N	4cm posterior of isocenter	0.002	-0.015	-0.015	0.010	0.017	0.013
C-Shape Hard	Isocenter	0.021	0.015	0.011	0.005	0.007	-0.003
C-Shape Easy	Isocenter	0.009	-0.007	0.009	0.002	0.005	0.015
Multitarget	4cm superior to isocenter	0.015	-0.005	-0.031	0.013	0.011	-0.005
Multitarget	4cm inferior to isocenter	0.018	-0.015	-0.021	0.005	0.005	0.003
Overall Mean		0.015	-0.005	-0.011	0.013	0.011	0.005
Overall SD		0.008	0.011	0.017	0.016	0.007	0.008
Confidence Limit		0.030	0.027	0.044	0.045	0.026	0.020

(E-2) RapidArc and IMRT plan comparison

RapidArc and IMRT dose distributions for varied structure sets (Prostate, Multi-target, C-shape, and Head-Neck) are shown in Fig.7. From this figure, it is clear that dose distribution for IMRT and RapidArc for 6MV, 10MV and 15MV is comparable with each other. RapidArc and IMRT dose results for 5 clinical tests are tabulated in Table15. With exception of C-shaped hard clinical test, Table 15 demonstrates that clinical tests can meet dose target criteria established by TG 119. Established a target for core D10< 10 Gy, established by TG 119 for C-shape hard, which is nearly impossible to achieve at required PTV coverage. It tests any planning system and how much we can push it to achieve the desired value of D_{10} by maintaining an optimal coverage of PTV. Table 16 compares RapidArc and IMRT plan parameters; their respective values are tabulated. Both modalities and energies include CI, HI, dosage per fraction, total MU, number of beams, and MU ratio of RapidArc and IMRT. All the plans have good CI values with better comparative results as defined in Table 16, 10X and 10X_FFF. As CI, all the plans for 10X and 10X_FFF also have well-defined values of HI, and their results are well tabulated in Table 16 for comparison. Table 16 also describes the MUs of all the plans for 6MV, 10MV and 15MV. It defines a ratio of IMRT and RapidArc for their respective energies. From their MU values, it is well described that as plan complexity increases, the number of MUs also increases. In comparison to RapidArc, IMRT plans have more MUs. This is due to a greater degree of freedom in RapidArc plan, so fewer MUs are required to achieve the same result as IMRT. In some cases, the ratios between IMRT and RapidArc are almost double. RapidArc plans require less time to deliver the same or better results than IMRT plans.

Table15: RapidArc and IMRT planning results in the respect of TG 119 reference data corresponding to their respective energies

	Plan Parameter	Planning Goal (cGy)	IMRT Plans(cGy)			RapidArc Plans(cGy)			IMRT/TG_119			RA/TG_119		
			6MV	10MV	15MV	6MV	10MV	15MV	6MV	10MV	15MV	6MV	10MV	15MV
Multitarget	Central D_{99}	>5000	5039	5038	5000	5044	5029	5000	1.008	1.008	1.01	1.009	1.006	1.010
	Central D_{10}	<5300	5280	5275	5300	5286	5288	5300	0.996	0.995	0.991	0.997	0.998	0.997
	Superior D_{99}	>2500	2568	2564	2500	2549	2560	2500	1.027	1.026	1.034	1.020	1.024	1.025
	Superior D_{10}	<3500	3248	3279	3500	2942	2932	3500	0.928	0.937	0.928	0.841	0.838	0.866
	Interior D_{99}	>1250	1258	1257	1250	1299	1293	1250	1.006	1.006	1.019	1.039	1.034	1.028
	Interior D_{10}	<2500	1981	1986	2500	1718	1748	2500	0.792	0.794	0.808	0.687	0.699	0.740
Prostate	PTV Prostate D_{95}	>7560	7673	7595	7643	7763	7726	7726	1.01	1.005	1.011	1.03	1.022	1.022
	PTV Prostate D_5	<8300	8539	8100	8643	8156	8156	8146	1.03	0.976	1.041	0.98	0.983	0.981
	Rectum D_{30}	<7000	5012	4520	5008	4713	4919	4977	0.72	0.646	0.715	0.67	0.703	0.711
	Rectum D_{10}	<7500	6985	6747	6971	7331	7314	7692	0.93	0.899	0.929	0.98	0.975	1.025
	Bladder D_{30}	<7000	3108	3161	3088	3252	3234	3308	0.44	0.452	0.441	0.46	0.462	0.473
	Bladder D_{10}	<7500	5089	5081	5071	5182	5210	5241	0.68	0.677	0.676	0.69	0.695	0.699
Head and Neck	PTV D_{90}	5000	5133	5046	5183	5084	5132	5105	1.03	1.009	1.037	1.02	1.026	1.021
	PTV D_{99}	>4650	4759	4684	4835	4674	4744	4729	1.02	1.007	1.039	1.01	1.020	1.016
	PTV D_{20}	<5500	5322	5238	5373	5352	5344	5295	0.97	0.952	0.977	0.97	0.972	0.962
	Cord max	<4000	3652	3600	3719	3907	3825	3927	0.91	0.900	0.929	0.98	0.956	0.982
	Rt_Prt D_{50}	<2000	1478	1539	1592	1567	1517	1479	0.74	0.769	0.796	0.78	0.758	0.739
	Lt_Prt D_{50}	<2000	1503	1523	1571	1613	1639	1584	0.75	0.761	0.785	0.81	0.819	0.792
C shape easy	PTV D_{95}	5000	5041	5074	5043	5026	5028	5028	1.01	1.015	1.009	1.01	1.006	1.006
	PTV D_{10}	<5500	5367	5421	5386	5235	5275	5261	0.98	0.986	0.979	0.95	0.959	0.956
	Core D_{10}	<2500	2380	2447	2423	2141	2261	2215	0.95	0.979	0.969	0.86	0.904	0.886
C shape hard	PTV D_{95}	5000	5037	5042	5107	5053	5025	5020	1.01	1.008	1.021	1.01	1.005	1.004
	PTV D_{10}	<5500	5389	5398	5470	5250	5252	5259	0.98	0.981	0.995	0.95	0.955	0.956
	Core D_{10}	<1000	2232	2283	2435	2012	2136	2150	2.23	2.283	2.435	2.01	2.136	2.150

Table16: Plan Evaluation Parameter corresponding to their respective energies

Parameter	Multitarget						Prostate						Head and Neck						C Shape Easy						C Shape Hard					
	IMRT			RA			IMRT			RA			IMRT			RA			IMRT			RA			IMRT			RA		
	6MV	10MV	15MV	6MV	10MV	15MV	6MV	10MV	15MV	6MV	10MV	15MV	6MV	10MV	15MV	6MV	10MV	15MV	6MV	10MV	15MV	6MV	10MV	15MV	6MV	10MV	15MV	6MV	10MV	15MV
CI	0.95	0.96	0.95	0.96	0.97	0.96	0.96	0.95	0.94	0.97	0.96	0.95	0.95	0.94	0.95	0.97	0.96	0.97	0.91	0.92	0.91	0.93	0.94	0.93	0.86	0.87	0.86	0.88	0.89	0.87
HI	0.11	0.10	0.11	0.09	0.08	0.09	0.13	0.11	0.12	0.10	0.11	0.13	0.20	0.21	0.23	0.15	0.16	0.17	0.25	0.23	0.25	0.23	0.24	0.26	0.28	0.28	0.27	0.26	0.27	0.25
No of Beams	7	7	7	2	2	2	7	7	7	2	2	2	9	9	9	2	2	2	9	9	9	2	2	2	9	9	9	2	2	2
Dose per fraction(cGy)	200	200	200	200	200	200	200	200	200	200	200	200	200	200	200	200	200	200	200	200	200	200	200	200	200	200	200	200	200	200
MU	639.1	593	983.1	546.1	484.6	520.9	823.4	795.7	1266.2	712.4	603.1	623.6	1843.5	1709.9	3007.6	962.6	1176.1	1395.8	1493.4	1427.2	2351.2	779.2	695.8	756.3	1554.5	1479.8	2412.3	789.6	683.1	747.0
MU Ratio	1.17	1.22	1.88	1	1	1	1.16	1.32	2.0	1	1	1	1.91	1.45	2.15	1	1	1	1.91	2.05	3.11	1	1	1	1.97	1.97	2.17	1	1	1

(F) Statistical calculation

Confidence limit and dose difference ratio measurement and calculation done as per TG 119 methodology only. CL is given as {(100-mean) + 1.96σ} for gamma analysis and {│mean│+1.96σ} for point doses. 95 percent of data should fall inside CL, and CL was computed using gamma passing conditions of 3 percent and 3 percent mm.

4 DISCUSSION

We utilized TG 119 test cases for TPS commissioning to compare 6MV, 10MV and 15MV energies for RapidArc and IMRT plans. It included information on optimizing MLC settings and displayed a straightforward commissioning quality evaluation. 6MV, 10MV and 15MV beams provide the same CLs value without showing much difference. Due to DLG optimization and transmission employing RapidArc measurement data, RapidArc CLs show somewhat better values than their respective IMRT plans. Each energy and technique's CLs are lower than baseline values listed in TG 119. This practice involves checking accuracy of new technology, which gives us confidence to use any new technology in clinical settings. The HDMLC performance evaluation was performed per the recommendations and standard guidelines, including Picket Fence test performed in rotational and stationary modes. For several combinations of DR_GS and LS_DR, radiation pattern about associated open field has been investigated. For 6MV, 10MV and 15MV energies, we conducted a comprehensive analysis of changes in DLG and leaf transmission. It is crucial to assess DLG and leaf transmission settings appropriately because dose delivery is sensitive to both. Many uncertainties from various sources related to film dosimetry, like film uniformity, background, and type of scanner, can affect the accuracy of film dosimetry. All the films were scanned after 24 Hr only to minimize the effect of time on our measurement results. For RapidArc and IMRT commissioning, all measurements were divided based on respective energies. A separate calibration curve was drawn with different film sets and energy types. After that, only the respective plans were exposed under the series for IMRT and RapidArc. RapidArc and IMRT plans have been created and equated regarding quality assurance and planning for 6MV, 10MV and 15MV energies by TG119 recommendations. Our IMRT and RapidArc planning and QA findings showed some parallels, but not all of them.

5 Conclusion

Understanding a system's limitations is better before using it in a clinical application. The capability of a TPS can be easily understood by completing the assignment and comparing it with existing literature review for errors in QA workflow and treatment planning. There is always a balance between minimum OAR dosages and maximum target dose. We use an ion chamber, EPID, and EBT 3 films derived from TG 119 methodology to assess planning and delivery accuracy utilizing RapidArc and IMRT procedures and 6MV, 10MV and 15MV beams. To guarantee accurate delivery of RapidArc and IMRT plans for 6MV, 10MV and 15MV beam modalities, measurements and accepted CL values can be utilized as baseline to evaluate quality of QA procedure.

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CONFLICT OF INTEREST DECLARATION
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