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Photon Beam Commissioning and Rapid Arc Prerequisite QA of Varian Unique Performance Low Energy Linear Accelerator (LINAC)

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Abstract

The aim of this study is to present the review of commissioning and Rapid Arc prerequisite QA results of Varian unique performance low energy linear accelerator (linac), was introduced by Varian Medical system (Palo Alto, CA, USA). The acceptance test and commissioning were performed for 6 MV photon beam and for the multileaf collimator (MLC). Percentage Depth Dose, Surface dose, Dose Profiles (In-plane, Cross-plane and Diagonal), Flatness, Symmetry, field size, Penumbra, Couch Sag, Couch transmission factor, MU Linearity, Beam Quality, Collimator Transmission, Photon leakage, MLC transmission factors were measured. Rapid Arc Commissioning and QA procedures specific to RapidArc delivery systems have been proposed using integrated images from an Electronic Portal Imaging Device (EPID). It has been observed that the outcome of a commissioning beam data generation fully complies with vendor specification and published literature.

Keywords: UNIQUE linear accelerator; Rapid ArcQA; Beam commissioning; Electronic Portal Imaging Device (EPID)

Introduction

Medical electron linear accelerator is important equipment, now used in radiotherapy departments clinically worldwide. Varian Unique Performance linear accelerator was introduced by Varian Medical system (Palo Alto, CA, USA) which deliver only single energy Photon beam (6 MV) with maximum dose rate ranges from 100 MU/min to 600 MU/min and it is equipped with Millennium 120 leaf MLC (Multi-Leaf Collimator) with 0.5 cm resolution at isocentre in the inner 20 cm and 1 cm resolution in the outer 20 cm. The couch top is Exact-IGRT couch top, Mechanical and Enhanced Dynamic Wedges were implemented in this machine. Image-guided patient repositioning is facilitated through 2D-2D MV image matching portal vision advanced imaging application and by automatic remote treatment couch movement managed by the image review application.

Before the first clinical use, the acceptance and beam data commissioning tests have to be performed according to international recommendations. The purpose of this study is to summarize commissioning beam data in terms of main mechanical features as well as beam characteristics. Secondly, commissioning and RapidArc prerequisites QA procedure specific to RapidArc delivery systems have been proposed using integrated images from an electronic portal imaging device (EPID) 5. The most commonly applied procedures for the Varian RapidArc platform (Varian Medical Systems, Palo Alto, CA) were developed by Lingetal. The results of the RapidArc commission on UNIQUE were presented as well as an overview of the technical aspects of the first clinical treatments.

Materials and Methods

IAEA, AAPM, AERB recommendations were used for the Commissioning of Varian unique performance medical linear accelerator for Beam data acquisition, appropriate detector selection, measurement techniques, etc. Measurements were performed with the help of IBA Dosimetric system with a scanning volume of 48 cm × 48 cm × 41 cm (water Phantom: Blue Phantom-2 with myQA software) and FC65, CC013 chambers. All the data collection and testing were performed in accordance with International Practice and Guideline such as AAPM Task Group TG-142 [1] and TG-106 [2], Atomic Energy Regulatory Board (AERB), INDIA [3] and IAEA TRS 398 [4]. We used the EPID for performing Rapid Arc QA tests in dosimetry (integrated imaging) mode. All the tests were carried out in the machine QA mode. RapidArc QA files in DICOM RT file format provided by Varian were used in this study [5]. Before image acquisitions for QA, the EPID needed calibration for dosimetry imaging for 6 MV photon beam energy in the Rapid Arc QA plans. For all the tests the MV imager was positioned at 100 cm source to image plane distance (SID) with lateral and longitudinal positions equal to zero. A total of four QA tests were performed during this study.

Mechanical test for couch, gantry and collimator

Isocenter verification: A conventional procedure was performed with Varian calibrated Graph Paper. The specification for the isocenter sphere dia. is within 2 mm. The test was performed in the different collimator, Gantry, Couch angles [1].

Table top sag: Set the gantry angle at zero, table lateral and vertical position also set to zero. End of the table top was positioned at the center of the light field. Place total 30 Kg weight uniformly over the 1 m length from this end of the tabletop. Measure the height of the tabletop at the center of the light field. Increase the longitudinal extension of this end of the tabletop to 1 m beyond the center of the light field. Place weights totaling 135 Kg uniformly over the 2 m length from this end of the table top. Measure the height of the table top at the center of the light field. Calculate the difference between the two heights. IEC-60976: 2007 protocol were followed for performing this test [6] as shown in **Figure 1**.

Figure 1: Couch sag test.

Couch transmission: Couch transmission factor was compare manufacture provide value and actual measured value.

Dosimetry test (Photon beam)

Accuracy of radiation isocenter: A conventional star film shot procedure and Varian spoke shot were performed with gap chromic films. The specification for the isocenter sphere diameter and the length of longest line of trapezoid measured for 2 mm, 1 mm radius respectively. The tests were performed in different collimator, Gantry, Couch angles.

Percentage depth dose (PDD): PDD was measured for 10 × 10 cm^2 field size at 10 cm depth for available 6 MV photon beam with 100 cm SSD. Measurement is performed with a constant Dose rate of 600 MU/min. PDD along the central axis depths also measured from 30 cm to -0.5 cm. Chamber corrections for Effective point of measurement (0.6*rcav) was taken [2]. After that PDD was normalized at the depth of maximum to 100%.

Percentage surface dose: Percentage surface dose was measured for 30 × 30 cm^2 filed size [(Ds=D 0.5 mm/Ddmax*100] for 6 MV Photon beam are ≤ 60% as per AERB Protocol, INDIA.

Depth dose profile: In-line, cross-line and diagonal beam--/+ +, diagonal beam++/-- profiles were measured for available 6 MV flatting filtered photon beam for field sizes 10 × 10 cm^2 at 10 cm depth with 100 cm SSD and then corrected for the central axis correction. After that beam profiles were normalize to 100% at the central axis to their corresponding field sizes. Analysis of beam profile of the flattening filter (FF) beam carried out through the AAPM TG-45 (IEC 60976) protocol.

Flatness: According to AAPM TG-45 protocol, Flatness can be specified as a maximum permissible percentage variation from the average dose across the central 80% of the full width at half maximum (FWHM) of the profile in a plane transverse to the beam axis. That is, the flatness F is given by [7].

$$F=100^{*}(Dmax–Dmin)/(Dmax+Dmin)$$

Where, Dmax and Dmin are the maximum and minimum dose values in the central 80% of the dose profile, usually specified at a depth of Dmax cm or 10 cm.

Symmetry: Symmetry evaluation flattening filter (FF) beam was done as per the recommendation of the International Electrotechnical Commission (IEC 60976, 2008) [1].

Fieldsize: The field size of flat beam defined as the distance between 50% of the isodoselevelin profile, normalized to 100 at the beam central axis at reference depth [8].

Penumbra: Radiation beam Penumbra was measured for flat beam 10 × 10 cm^2 field size at Dmax within ≤ 10 mm. Penumbra defined as the lateral separation of (20%-80%) isodose on either side of beam profile normalized to 100% at the central axis [9,10].

Measurement of dosimetric parameter

Parameter measured for daily QA verification and TPS required data, such as beam quality, Jaw transmission measured with FC65-G ion chamber. All measurements were carried out with an IBA Dose-1 electrometer.

Output constancy at different times in a day: Measure the output of the machine for 10 × 10 cm^2 field size by placing an ion chamber on the central axis in a phantom at the depth of dm with 100 cm SSD. Compare the measured output with the baseline value. Output constancy should be checked for available photon beams at different times in a day.

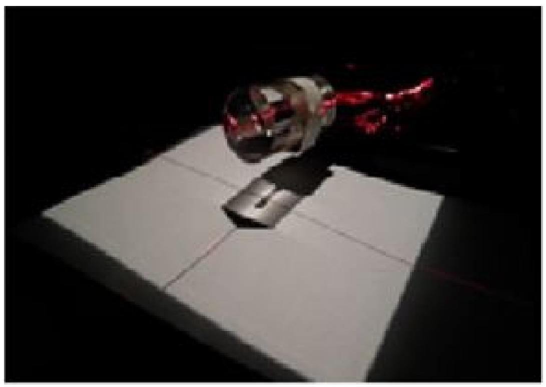

Figure 2: Ion chamber with build-up cap.

Output consistency at cardinal positions of the Gantry: The output consistency at different cardinal positions of gantry were verified by placing an ion chamber with build-up cap on the central axis in the air with isocentric setup and measure the dose for 10 × 10 cm^2 field size for different gantry angles as shown in **Figure 2**.

Beam quality index (TPR 20/10): According to TRS-398, TPR20/10 value is determined from empirical formula TPR20/10=1.2661 × PDD20, 10−0.0595. Where, PDD20, 10 is ratio of PDD at 10 cm and 20 cm [9] depth. TPR20/10 is also measured directly in D20, 10 phantoms in isocentric setup for 10 × 10 field in depth of 10 cm and 20 cm. Value is measured for all available photon beam energy and compared with values obtained from an empirical formula and result shown in **Tables 1 and 2.**

Table 1: Photon beam parameters: Dmax, PDD at 10 cm depths and Quality Index, Surface Dose.

Photon beam	Depth of maximum adsorbed dose to water (Dmax) for 10 × 10 cm2 field size	PDD value at 10 cm depth for 10 × 10 cm2 field size	Quality index for photon beam	Surface dose for 30 × 30 cm2 filed size
6 MV	15.7 mm	67.00%	0.67967	60%

Table 2: Shows flatness (%), symmetry (%) obtained from measurements of in-plane and cross-plane and diagonal profiles for different field size at depth 10 cm, penumbra at Dmax.

Field size (cm^2)	Beam flatness (%)				Symmetry (%)				Penumbra
	Inline	Cross line	Diagonal --/++	Diagonal -+/+-	Inline	Cross line	Diagonal --/++	Diagonal ++/--	Radiation Beam
5 × 5	102	102	100.8	100.8	100.1	100.3	102	100.1	Penumbra
10 × 10	103.5	103.7	102.3	101.7	100.1	100.4	101.2	100.2	10 × 10 cm^2
30 × 30	104.9	104.2	105.1	105.7	101	100.6	100.9	101.4	at Dmax=5.9 mm-6.5 mm

Energy stability at different times in a day: TPR20/10 is also measured directly in D20, 10 phantoms in isocentric setup for 10 × 10 field at the depth of 10 cm and 20 cm. compare the measured beam quality index with baseline values at different times in a day.

Output factors: Output factors are determined as the ratio of corrected dosimeter readings to that measured under reference conditions. It is measured at 100 cm SSD for different field sizes (3 × 3 to 40 × 40 cm^2). Measurements were done at reference depth of 10 cm and then corrected to the depth of maximum dose as shown in **Figure 20.**

Wedge factors: These are

Physical wedge factors: The Physical wedge filters on the Varian Unique accelerator have nominal wedge angles are 15°, 30°, 45°, and 60° with four orientation (LEFT, RIGHT, IN, OUT). As shown in **Table 3**.

Enhanced Dynamic wedge factors: EDW were measured for field size 40 cm × 20 cm at depth 1.5 cm, SSD is 100 cm with the help of 0.6 cc farmer type ion chamber. EDW factor is defined the ratio between the ion chamber integrated reading on the central axis of a wedged field and the integrated reading at the same depth for the open field having the same size and for the same number of monitor units [10]. Two wedge orientations Y1-IN andY2-OUT are possible. As shown in **Table 4.**

Dose monitoring system

Reproducibility of photon beam: Reproducibility is defined in terms of coefficient of variation, C calculated from

C=100*R/Rav

R is Standard deviation

Rav is mean of observations R

Coefficient of variation measured for 20 × 20 cm Field size at normal treatment distance, Dose rate is 600 MU/min and Dose is 100 MU. Coefficient of variation tolerance limit is ≤ 0.5%.

Linearity of photon beam: If L is the meter reading on a calibrated dosimeter at calibration depth for calibrated field size and U is the corresponding monitor chamber reading then the quotient, S of L and U determines the monitor linearity response. This measurement is done with Gantry angle and collimator angle at 0°, Dose Rate is 600 MU/min, increasing number of monitor chamber units from 25 to 500 MU.

MU linearity response (S) was expressed as S=L/U and Coefficient of Linearity (CoL) Tolerance limit is ≤ 2%.

Radiation safety

Maximum and average photon leakage radiation through secondary collimator (X-Jaw and Y-jaw leakage): Percentage of jaw transmission measured in air with help of IBA Dosimetry, FC65 chamber build-up cap of 3 cm diameter, DOSE-1 electrometer for SCD=100 cm for 6 MV photon beam energy by

MLC was fully opened, setting X Jaw was closed and Y jaw open for maximum field sizes that the transmission is occurred only through the pair of X Jaw. Similarly, a detector was placed by setting Y Jaw was closed and X Jaw open for maximum field size that transmission occurred only through the pair of Y Jaw. The readings were taken at different positions inside the 40 × 40 cm^2 fields (20 positions). The maximum and average leakage radiations through the X and Y Jaw were determined and normalization was performed with respect to 10 × 10 cm^2 open fields. A dose rate of 600 MU/min, MU delivered of 500 MU was used for this measurement.

Tolerance: Maximum: 2% and Average: 0.75%.

Photon leakage radiation through MLC is used as a tertiary jaw: The transmission was measured for all X-jaw and Y-jaw opened, MLCs were closed. The meter reading was taken for each of fully closed MLC. Normalization was performed with respect to 10 × 10 cm^2 open fields. A dose rate of 600 MU/min, MU delivered of 500 MU was used for this measurement [11].

Tolerance: Maximum: 5%.

Maximum and average photon leakage radiation in the patient plane: Percentage of Radiation leakage measured in air with help of IBA Dosimetry, FC 65 chamber with Acrylic build-up cap, DOSE-1 electrometer for SCD=100 cm at depth of Dmax for 6 MV photon beam energy [2]. The transmission was measured for all X-jaw and Y-jaw, MLCs were closed.

Radiation leakage measurements in the patient plane-A circular plane of radius 2 m centre on and normal to the central radiation beam axis at the normal treatment distance (NTD) and outside the area of the maximum radiation beam is called patient plane [12]. Meter reading was taken for each at the 16 test points as defined in Figure 3 for radiation leakage measurement in the patient plane. Normalization was performed with respect to 10 × 10 cm^2 open fields. A dose rate of 600 MU/min, MU delivered of 500 MU was used for this measurement.

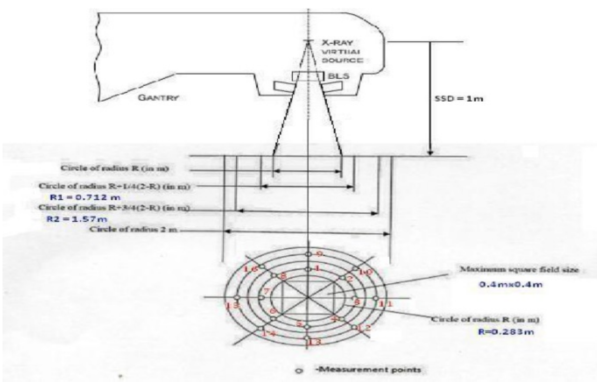

Figure 3: Photon leakage radiation in the patient plane.

Maximum photon leakage radiation at 1 m from the target path of electrons between electron gun and the target and Ref. Axis other than patient plane: Percentage of Radiation leakage measured in air with help of IBA Dosimetry, FC 65 chamber with Acrylic build up cap, DOSE-1 electrometer for SCD=100 cm at depth of Dmax for 6 MV photon beam energy [2]. Transmission was measured from the target path of electrons between electron gun and the target. Meter reading was taken for each of fully closed MLC, X and Y Jaws as defined in **Figure 4**. Normalization was performed with respect to 10 × 10 cm^2 open fields. A dose rate of 600 MU/min, MU delivered of 500 MU were used for this measurement, gantry angular position is 1800.

Tolerance: Maximum: 0.2% and Average: 0.1%.

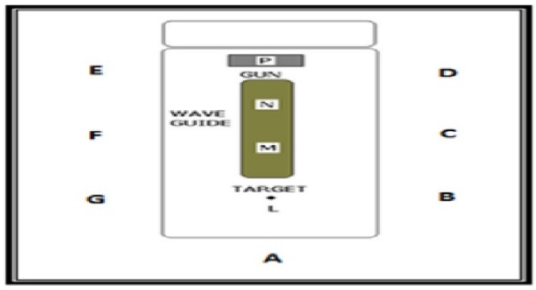

Figure 4: Photon leakage radiation at 1 m from the target path of electrons between electron gun and the target and Ref. Axis other than patient plane.

Performance test result for Filtered Beam IMRT Linear Accelerator

Output consistency for low MU settings (2-4 MU): Measure the output of the machine for low MU settings (2-4 MU) of 10 × 10 cm^2 field size by placing an ion chamber on the central axis in a phantom at the depth of SSD+Dmax. Coefficient of variation should be within 5%.

Output consistency at lowest and highest dose rate settings: Measure the output of the machine for different dose rates of 10 × 10 cm^2 field size by placing an ion chamber on the central axis in a phantom at the depth of SSD+Dmax. Compare the output with baseline values and it should be within 2%.

Rapid arc linear accelerator commissioning: prerequisites QA

In this study, we used the EPID for performing DMLC QA tests in dosimetry (integrated imaging) mode. All the tests were carried out in the machine QA mode of UNIQUE Performance. RapidArc QA files in DICOM RT file format, provided by Varian, were used in this study [13]. Before image acquisitions for QA, the MV imager needed calibration for dosimetry imaging for the each photon energy used in the RapidArc QA plans. For all the tests the MV imager was positioned at 100 cm source to image plane distance (SID) with lateral and longitudinal positions equal to zero.

Test 1: DMLC Dosimetry: In this test, the machine output was measured at gantry angles of 0°, 90°, 180° and 270°. At each gantry angle, the Rapid Arc DMLC QA plan was performed, which delivered a 4 cm × 10 cm DMLC field with a 0.5 cm slit to test the effect of gravity on carriage position. The dose measured by the EPID in a 1 cm^2 area at the center of the field was recorded, and the % deviation calculated relative to the measured value at 0° as shown

Slit opening (cm)-0.5

Target MU-100

Jaw Field Size (cm) W × L-4 × 10

Exposed Field (cm) W × L-4 × 10 Setup/Plan Parameters

Test 2: Picket fence test during rapid arc: Test the effect of gantry rotation on the MLC positional accuracy during Rapid Arc. This mechanical test performed while the gantry is rotating and produced the "picket-fence" pattern of designed MLC positions during Rapid Arc. We record the positions of the picket fences and compare them to the specified picket fence positions as shown in **Figure 18**.

Gap btw Picket Fence (cm)-1.5

Slit opening (cm)-0.1

Of Picket Fences-10

Target MU-480

Dose Rate (MU/min)-600

Jaw Field Size (cm) W x L-20 x20

Exposed Field (cm) W x L-15 x 20

Start Angle (deg)-179

End Angle (deg)-187

Gantry Rotation (deg)-352

Test 3: Accurate control of dose rate and gantry speed during rapid arc delivery: The purpose of the Rapid Arc QA plan is to evaluate the ability of the machine to modulate dose-rate and gantry speed for accurate dose delivery during gantry rotation. It uses 7 combinations of different dose rates and different gantry speeds to deliver the same dose to seven 1.8 cm strips of a Rapid Arc plan. In addition, an Open Field of the same overall field-size is delivered for normalization. We analysed the acquired images in the portal imaging dosimetry application in the Aria system. The dose area histogram tool available in the planner dose image was used for selecting a known Region of Interest (ROI) on the dosimetric image for all the seven strips. The following procedure was then followed:

A Region of Interest (ROI) of 5 mm × 100 mm size was defined at the center of each of the seven strips and the mean pixel value readings in the seven ROIs were recorded as RDR-GS(x).

The mean pixel value named as Ropen (x) has been registered at the corresponding position in the open field.

The corrected readings for all ROIs were calculated using the formula.

Rcorr(x)=(RDR-GS(x)/Ropen(x))100

Where, Rcorr(x) is the normalized mean pixel value at the same ROI in Rapid Arc field.

The average corr was then calculated for the seven corrected

The deviation of the corrected reading was calculated for each ROI from Rcorr using the following formula

Diff(x)={(Rcorr(x)/corr)100}-100.

The average of the absolute values of all Diff(x) was calculated as Diffabs=|()|.

Tolerance of Diffabs is 1.5%.

Test 4: Accurate control of leaf speed during rapid arc delivery: The purpose of the Rapid Arc QA plan is to evaluate the ability of the machine to modulate MLC speed and dose-rate for accurate dose delivery during gantry rotation. It uses 4 combinations of different dose rates and different MLC speeds to deliver the same dose to 4 strips of a Rapid Arc plan. In addition, an open field of the same overall field-size is delivered for normalization and analysis of dosimetric image was done by the same way as for the test 5.

Results and Discussion

Mechanical test for couch, gantry and collimator

Isocenter verification: A conventional procedure was performed with Varian calibrated Graph Paper. The specification for the isocenter sphere diameter is within 2 mm. The test was performed in the different collimator, Gantry, Couch angles.

Accuracy of the angular scale was performed with Spirit level placed on the gantry, the deviation in the digital readout of the gantry, collimator angles were recorded within AERB acceptable limit 0.5°.

Accuracy of couch lateral, longitudinal and vertical motion was recorded to be 1 mm tolerance which is within the 2 mm AERB tolerance.

The sagittal laser and lateral laser were verified within the 1 mm AERB tolerance.

The field sizes deviation in the light field and digital readout from 5 × 5 cm^2, 10 × 10 cm^2, 15 × 15 cm^2, 20 × 20 cm^2, 25 × 25 cm^2, 30 × 30 cm^2, 35 × 35 cm^2, 40 × 40 cm^2 was estimated to be 0 mm against the 1 mm tolerance.

The optical distance indicator was verified with mechanical front pointer for distances from 80 cm to 110 cm are verified within the limit of 2 mm AERB tolerance.

Table top sag: The table top sag at isocentre observed within 2 mm tolerance.

Couch transmission: Couch Transmission factor was comparing manufacture Provide value was 0.9792 and the actual measured value was 0.9750.

Dosimetry test

Accuracy of radiation isocenter: Radiation isocenter test was performed in different collimator; gantry angles (**Figures 5 and 6**).

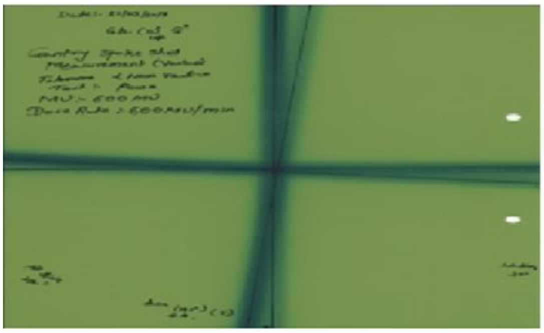

Figure 5: Shows the radiation isocenter test was performed in different collimator, gantry angles.

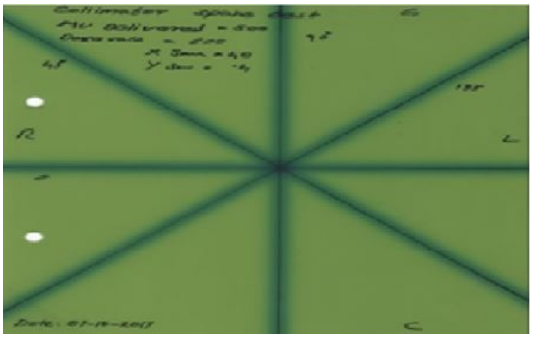

Figure 6: Shows the radiation isocenter test was performed in different collimator, gantry angles.

Percentage depth dose (PDD): The PDD values for 6 MV photon beams energy were determined and are presented in **Table 1**.

The PDD values obtained for our case are matching well with the expected values. Therefore, the evaluated data are in full compliance with the various published literature. The measured depth dose curves of 10 cm × 10 cm field sizes for 6 MV beam energy as shown in **Figure 7.**

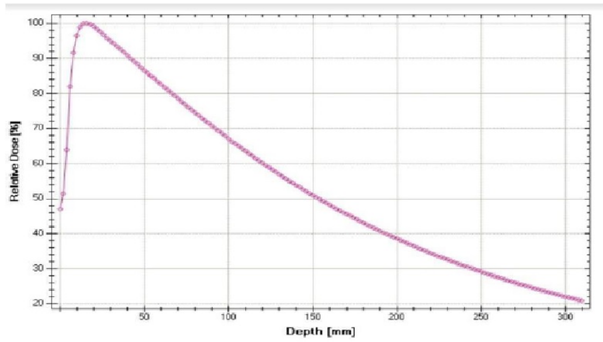

Figure 7: Shows the percentage depth dose.

Depth dose profiles (inline, cross line, diagonal--/++, diagonal-+/+-): The values of beam flatness and symmetry obtained for 6 MV photon beam energy are shown in **Table 2.** From **Table 2**, it can be seen that both beam flatness and symmetry are in comparable with the tolerance limits set by IEC 60976 (169) and AERB.

Measured beam profiles of various field sizes for 6 MV photon beam energy shown in **Figures 8-19**.

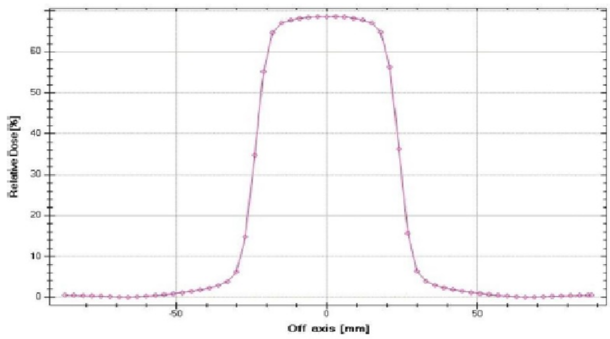

Figure 8: Show inline 5 × 5 cm^2 profiles.

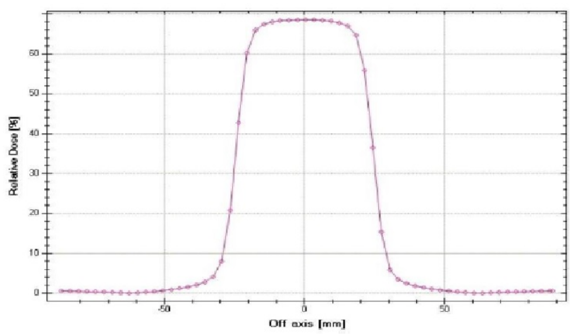

Figure 9: Shows cross line for 5 × 5 cm^2 profile.

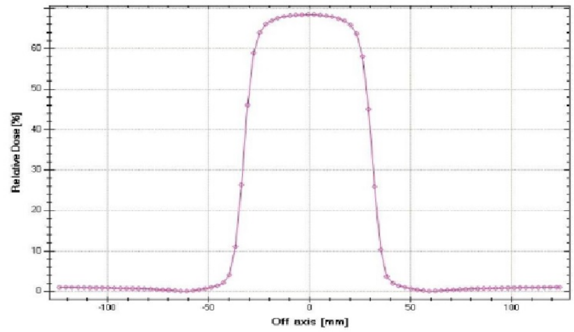

Figure 10: Shows diagonal--/++ for 5 × 5 cm^2 profile.

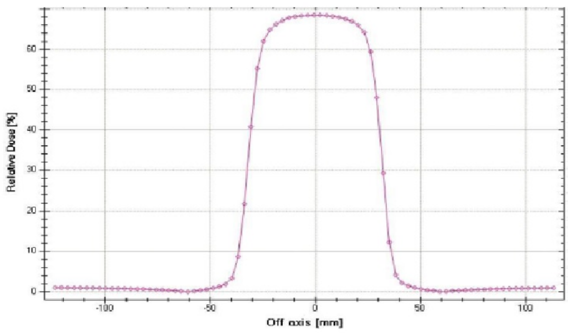

Figure 11: Shows Diagonal-+/+- for 5 × 5 cm^2 profile.

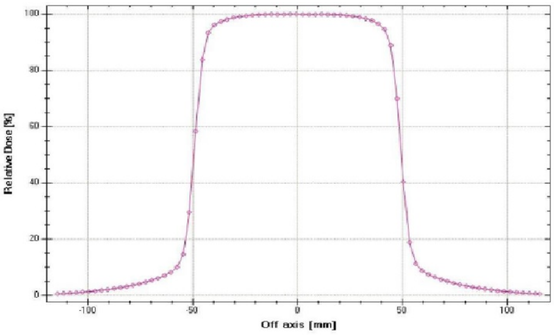

Figure 12: Show inline 10 × 10 cm^2 profile.

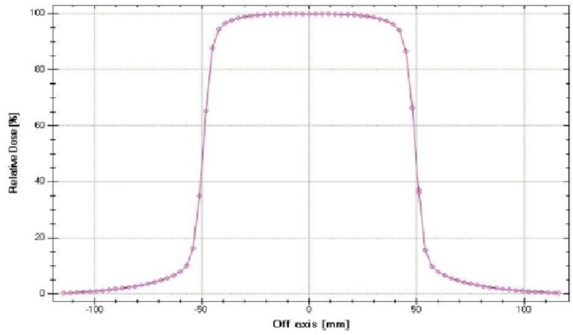

Figure 13: Show cross line 10 × 10 cm^2 profile.

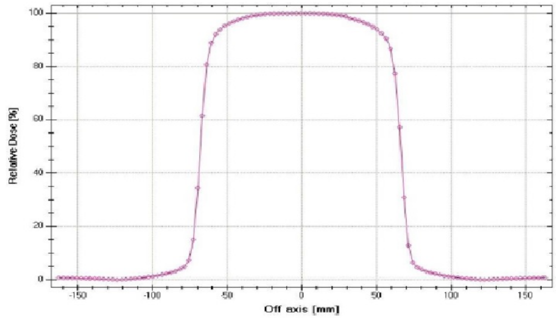

Figure 14: Show diagonal--/++ for 10 × 10 cm^2 profile.

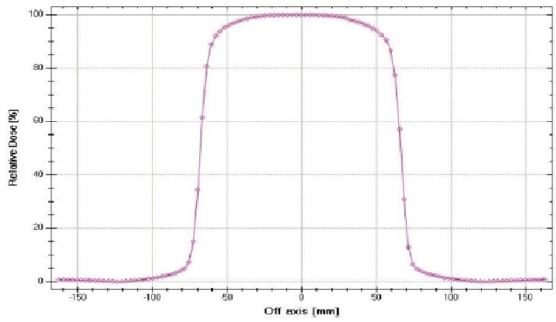

Figure 15: Shows diagonal-+/+- for 10 × 10 cm^2 profile.

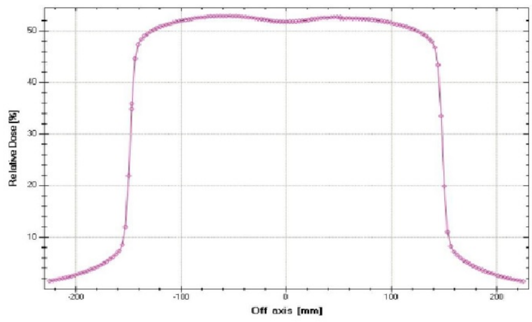

Figure 16: Show inline for 30 × 30 cm^2 profile.

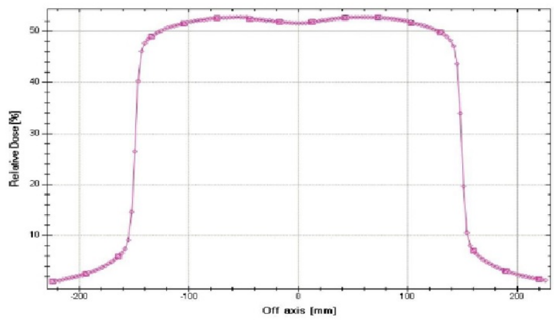

Figure 17: Show cross line 30 × 30 cm^2 profile.

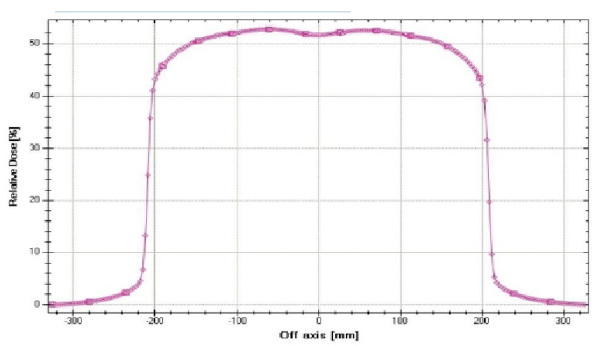

Figure 18: Show diagonal--/++ for 30 × 30 cm^2 profile.

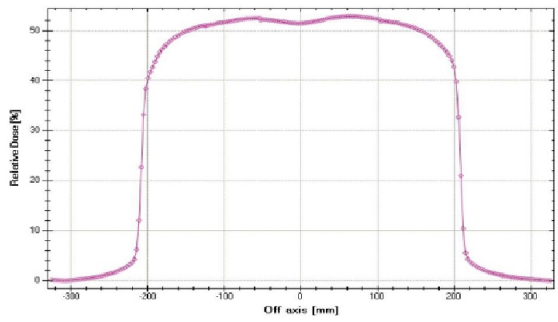

Figure 19: Show diagonal-+/+- for 10 × 10 cm^2 profile.

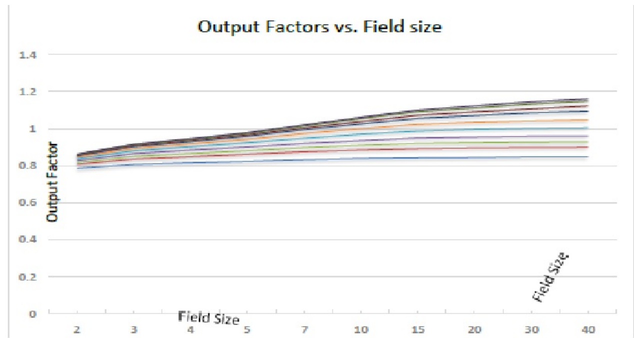

Figure 20: Shows the output factors for 6 MV photon beam.

Measurement of dosimetry parameter

Output constancy at different times in a day and Output consistency at cardinal positions of the Gantry: Output constancy at different times in a day and output consistency at cardinal positions of the Gantry for 6 MV Photon beam were calculated 0.40% and 1.65%.

Energy stability at different times in a day: Energy stability (quality index) for 6 MV photon energies at different times in a day was calculated 0.20%.

Output factors: Output factors **(Figure 20)**.

Wedge Factors: Shown in **Tables 3 and 4.**

Table 3: Shows the Physical Wedge factors for field size X=40 cm, Y=30 cm (IN, OUT) and X=30 cm Y=40 cm (LEFT, RIGHT).

	Wedge factors				
Wedge angle	**Wedge orientation: IN**	**Wedge orientation: OUT**	**Wedge orientation: LEFT**	**Wedge orientation: RIGHT**	**Mean wedge factors**
15°	0.7841	0.7993	0.8093	0.7913	0.796
30°	0.6464	0.6573	0.6709	0.6421	0.6542

45°	0.5144	0.5282	0.5409	0.5079	0.5229
60°	0.4118	0.4325	0.4526	0.4008	0.4244

Table 4: Shows the EDW factors for field size X=40 cm Y=20 cm.

Wedge angle	Wedge factors		
	Wedge orientation: IN	Wedge orientation: OUT	Mean wedge factors
10°	0.876	0.8728	0.8744
15°	0.8231	0.8194	0.8212
20°	0.7736	0.77	0.7718
25°	0.7277	0.7231	0.7254
30°	0.684	0.6781	0.6811
45°	0.5566	0.5494	0.553
60°	0.4233	0.4138	0.4186

Dose monitoring system

Reproducibility of Photon Beam and Linearity of Photon Beam for 6 MV Photon beam was calculated 0.09% and 1.000002252%.

Radiation safety

Maximum and average 6 MV photon beam leakage radiation through Secondary collimator(X-Jaw Leakage) were calculated 0.8207%, 0.3710% and Y-jaw Leakage were calculated 0.4483%, 0.3567%.

Maximum 6 MV Photon beam leakage radiation through MLC is used as tertiary jaws was calculated 2.27%.

Maximum and average 6 MV photon beam leakage radiation in the patient plane for 6 MV Photon beam was calculated 0.0072%, 0.0040%.

Performance test result for filtered beam IMRT linear accelerator

Output consistency for low MU settings (2-4 MU) and Output consistency at lowest and highest dose rate Settings for 6 MV Photon beam was calculated 1.13% and 0.23%.

Performance test result of the Rapid Arc linear accelerator

Rapid Arc QA test have been designed that evaluate Rapid Arc Performance.

Test 1: DMLC DOSIMETRY: The dose measured by the EPID in a 1 cm^2 area at the center of the field was recorded, and the % deviation calculated relative to the measured value at 0° as shown in **Table 5** and the tolerance value % deviation of the test is to be<3%.

Table 5: DMLC Dosimetry results.

DMLC dosimetry results			Tolerance
Gantry angle	Output reading	% of deviation	
0° (Ref)	0.14602	0	± 3%
90°	0.14684	0.56362	± 3%
180°	0.1466	-0.3972	± 3%
270°	0.14493	0.7451	± 3%

Test 2: Picket fence test during Rapid Arc

Test showed that the effect of gantry rotation on leaf accuracy was minimal. **Figure 21** show and **Table 6** below summarizes the results of such comparison and demonstrates the accuracy of the MLC during Rapid Arc to be within the Tolerance of 1 mm.

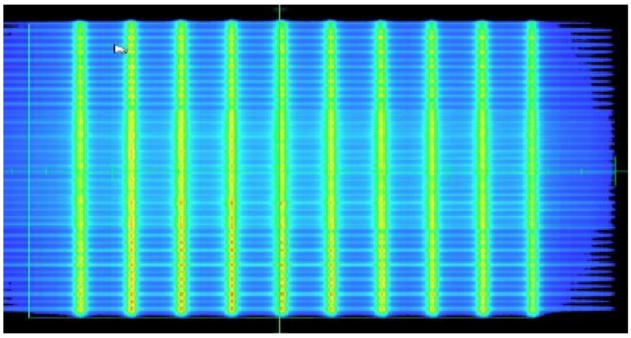

Figure 21: Picket fence test during Rapid Arc.

The result of DMLC picket fence test for RapidArc is shown in **Figure 21**, and a graph plotted between dose value and MLC position detail in Microsoft excel by the same way as in test 2 as shown in **Figure 22**.

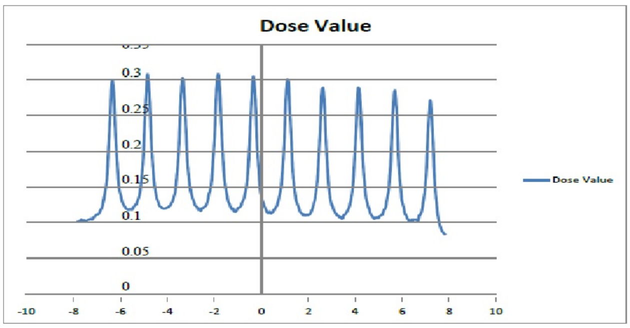

Figure 22: Dose vs. MLC position for picket fence test at Rapid Arc.

The peak positions and spacing between the peaks for DMLC picket fence test for Rapid Arc are shown in **Table 6**. The Accuracy of the MLC during Rapid Arc is shown in **Table 7.**

Table 6: Peak positions, adjacent peak spacing and spacing deviations from planned spacing of picket fence test for Rapid Arc Peak Positions.

Peak	Positions (cm)	Spacing (cm) in two peak	Spacing deviation (mm)
Peak 1	-6.32	1.49	0.13
Peak 2	-4.83	1.49	0.13
Peak 3	-3.35	1.53	0.26
Peak 4	-1.82	1.49	0.13
Peak 5	-0.33	1.45	0.52
Peak 6	1.12	1.53	0.26
Peak 7	2.64	1.49	0.13
Peak 8	4.13	1.57	0.65
Peak 9	5.69	1.49	0.13
Peak 10	7.18	Maximum Deviation=0.65 mm	

Table 7: Accuracy of the MLC during Rapid Arc.

Gantry arc angle	MLC position accuracy (mm)	Tolerance(mm)
179-181	0.65	1

From the graph and the analysis, it was found that for this test the maximum positional spacing deviation was 0.65 mm for Rapid Arc picket fence test, where the tolerance value is 1.0 mm.

Test 3: Accurate control of dose rate and gantry speed during RapidArc delivery

The mean pixel value reading (RDR-GS) created with a combination of different dose-rates, gantry speeds and gantry range to give the same dose to seven strips analysis using 10 cm × 0.5 cm region of interest (**Figure 23**).

When normalized mean pixel value reading (Ropen) to a corresponding open field. From this, the Rcorr (normalized mean pixel value) was calculated to remove the influence of non-flatness/asymmetry of the radiation field in the comparison of the exposures of the seven strips with EPID shows good agreement with a mean deviation of 0.87% (**Tables 8 and 9**).

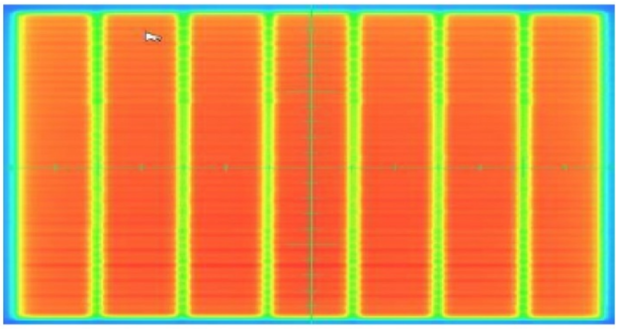

Figure 23: Screenshot of a dosimetric image for combine different dose rates and gantry speeds to deliver the same dose to 7 strips of a RapidArc plan.

Table 8: Shows image analysis using 10 cm × 0.5 cm ROI of mean pixel value reading for variable dose rates and gantry speeds during RapidArc for all seven strips. Average of absolute deviations (DiffAbs) was estimated to be 0.41. These results pass the tolerance of Average of an absolute deviation<1.5%.

Band number	RDR-GS	ROpen	Rcorr	Diff(x)
- 6 cm	0.6422	4.191	15.32	0.87
-4 cm	0.6485	4.292	15.11	-0.54
-2 cm	0.6481	4.285	15.12	-0.44
0 cm	0.6474	4.271	15.16	-0.22
2 cm	0.6516	4.283	15.22	0.16
4 cm	0.6504	4.291	15.16	-0.23
6 cm	0.639	4.19	15.25	0.4

Table 9: Shows ROI analysis.

Position	%	Tolerance (%)	Avg absolute deviation	Tolerance
-6	0.87	± 3%	0.41%	± 1.5 %
-4	-0.54	± 3%		
-2	-0.44	± 3%		
0	-0.22	± 3%		
2	0.16	± 3%		
4	-0.23	± 3%		
6	0.4	± 3%		

These results pass the tolerance of average of an absolute deviation<1.5%.

Test 4: Accurate control of leaf speed during Rapid Arc delivery

The mean pixel value reading (RLS) created with a different combination of MLC speed and dose rate to give the same dose to four strips analysis using 10 cm × 0.5 cm region of interest (**Figure 24**). Mean pixel value reading (Ropen) for the open field was also estimated. From these values, normalized mean pixel value (Rcorr) for all four strips was calculated. The values are shown in **Table 10.** The ROI analysis is shown in **Table 11**.

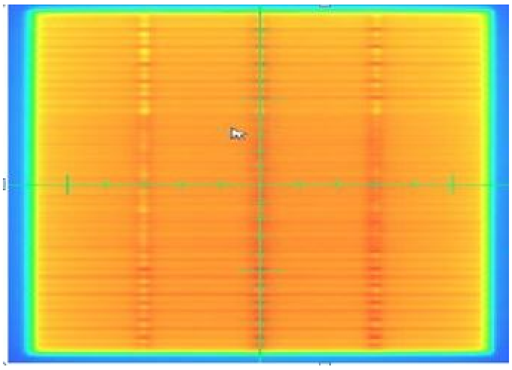

Figure 24: Screen-shot of dosimetric image using four combinations of dose rates and MLC speeds to deliver the same dose to 4 strips of a Rapid Arc plan.

Table 10: Shows MLC leaf speed test image analysis using 10 cm × 0.5 cm ROI.

Band number	RLS	ROpen	Rcorr	Diff(x)
-4.5 cm	0.1821	1.263	14.42	-0.89
-1.5 cm	0.1863	1.272	14.65	0.68
1.5 cm	0.1855	1.272	14.59	0.27
4.5 cm	0.1834	1.261	14.54	-0.06

Average of absolute deviations (DiffAbs)

These results pass the tolerance of average of an absolute deviation<1.5%.

Table 11: Shows ROI analysis.

Position	%	Tolerance (%)	Average absolute deviation	Tolerance
-6	0.87	± 3%	0.41%	± 1.5%
-4	-0.54	± 3%		
-2	-0.44	± 3%		
0	-0.22	± 3%		
2	0.16	± 3%		
4	-0.23	± 3%		
6	0.4	± 3%		

These results pass the tolerance of Average of an absolute deviation<1.5%.

Conclusion

Low-energy linear accelerator commissioning tests and first period of clinical operation of this new delivery system we represented in this paper for beam characterization, periodic quality assurance tests, and Rapid Arc operations. It was observed that the results obtained thereof were well within the tolerance limits prescribed by the Atomic Energy Regulatory Board (the regulatory authority in India) and other international organizations like IEC, AAPM etc.

EPID based QA is less time consuming not only for setting up and dose delivery part of the QA protocols but also for analysing the results as compared to the traditional methods. We recommend the EPID based MLC QA as a standard for clinical commissioning of Rapid Arc and also for routine QA of the Linac radiotherapy systems.

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