Journal of Graphic Era University
Vol. 6, Issue 1, 109-122, 2018
ISSN: 0975-1416 (Print), 2456-4281 (Online)

Implementation of Quality Assurance Protocols for an Advanced Linear Accelerator with Volumetric Modulated Arc Therapy Features Using Electronic Portal Imaging Device (EPID)

C. P. Bhatt[1*], Kiran Sharma[2], Manoj K. Semwal[3]

[1,2]Department of Allied Sciences
Graphic Era (Deemed to be University), Dehradun, India
[3]Army Hospital (Research and Referral), New Delhi, India
[*]Corresponding author: cpbhatt.phy@gmail.com

(Received May 12, 2017; Accepted September 12, 2017)

Abstract
To use Electronic Portal Imaging Device (EPID), an integral feature of a TrueBeam linear accelerator (linac) system, for implementing dosimetry based comprehensive Quality Assurance (QA) protocol needed for Volumetric Modulated Arc Therapy (VMAT) modality. Varian makes TrueBeam Version 2.0 linac system with Intensity Modulated Radiotherapy (IMRT), and VMAT treatment modalities were used in the study. The linac is equipped with a Multileaf Collimator (MLC) having 120 leaves (millenium MLC) and an EPID (aS1000) having megavoltage photon (MV) detector system. The EPID has an active imaging area of 40 cm x 30 cm with 1024 x 768-pixel matrix with a pixel resolution of 0.39 mm. It is capable of capturing 14-bit images at 30frames per second. We carried out the following QA tests using the EPID: i) Dynamic MLC (DMLC) dosimetry test ii) DMLC positional accuracy test (Picket Fence test) for fixed and rotating gantry modes iii) DMLC positional accuracy test during rotation with intentional errors iv) dose rate and gantry speed tests during RapidArc delivery and v) DMLC leaf speed test during RapidArc delivery. All the tests were analysed with Microsoft Excel application. Deviations of the EPID pixel values from known regions of interest during the various tests with respect to open fields were estimated for accuracy assessment. DMLC dosimetry test showed a maximum deviation of 0.16 % with respect to reference condition at 0º gantry. The maximum positional accuracy of DMLC was found to be 0.28 mm for fixed gantry and 0.26 mm for rotating gantry. For varying dose rate and gantry speed, the average of the absolute value of all deviations Diff(x) was 0.43. The MLC leaf speed variation during RapidArc resulted in the average of the absolute value of all Diff(x) of 0.20. Similar results have been obtained with a film based QA tests. The time taken in performing the above tests with EPID is far less as compared to the conventional methods. EPID based QA tests are reliable and quick. We believe that protocols developed for performing QA tests with EPID can replace the conventional methods of QA. EPID based QA will result in considerable time saving and thus helpful in increasing the patient throughput in a clinic. Also, the quicker and automated QA procedure based on EPID lends itself to better compliance and hence better treatment quality.

Keywords- Radiotherapy, Quality Assurance (QA), Volumetric Modulated Arc Therapy (VMAT), Dynamic Multileaf Collimator (DMLC), Electronic Portal Imaging Device (EPID).

1. Introduction

Volumetric Modulated Arc Therapy (VMAT) is the rotational version of fixed gantry angle Intensity Modulated Radio Therapy (IMRT) with high energy photons (x-rays). In VMAT the radiation delivery is performed using a continuously rotating linac gantry around the patient.

Journal of Graphic Era University
Vol. 6, Issue 1, 109-122, 2018
ISSN: 0975-1416 (Print), 2456-4281 (Online)

Compared to IMRT, the technique improves the treatment delivery time while maintaining a similar dosimetry quality of a treatment plan (Oliver et al., 2009; Hardcastle et al., 2011; Unkelbach et al., 2015). The VMAT can be delivered either using a single or multiple gantry rotations/arcs around the patient. Compared to a typical nine-field IMRT treatment that may take about 10 min of the beam-on time, a single arc treatment may be completed in 1.5 to 3 min (Oliver et al., 2009; Rangaraj et al., 2010). RapidArc is trade name of VMAT in Varian linac systems.

The planning algorithms for VMAT improve the efficiency of the treatment delivery by optimising three variables during radiation delivery namely speed of the gantry, MLC aperture, and dose rate. The gantry rotates around the patient in 360 degrees with a fixed MLC shape for each defined point called control point on the gantry rotation circle. The control points are distributed uniformly around the rotation circle at fixed gantry intervals. The MLC shape, therefore, changes when the gantry moves from one control point to another.

Leaf position accuracy, leaf speed, leaf transmission (inter- and intra-leaf transmissions, and transmission beneath leaves with jaws combined) are crucial parameters impacting the dose delivery accuracy in VMAT. The tolerance of MLC leaf positions for fixed field IMRT is ±1 mm at four cardinal gantry angles (Ling et al., 2008; Klein et al., 2009; Sharma et al., 2011). The VMAT delivery warrants MLC position accuracy for additional gantry angles as well. Further, the accuracy of dose delivery with different dose rates, gantry, and MLC leaf speeds also need to be consistently assessed.

There are many published studies on protocols for Quality Assurance (QA) tests of MLC used for conventional fixed gantry IMRT (Losasso, 2008; Bedford and Warrington, 2009; Kumar et al., 2014). Also, tolerance values for various MLC parameters namely MLC transmission, leaf position repeatability, MLC spoke shot, light and x-ray field congruence for segmental IMRT (step and shoot) and sliding window IMRT (dynamic IMRT) at four cardinal gantry angles have been defined (Klein et al., 2009). Essers et al. (2001) performed a detailed study on commissioning QA tests for Varian makes MLC for IMRT treatment technique with the film. They suggested pretreatment dosimetry verification for each patient. Ling et al. (2008) carried out the study of commissioning and QA of VMAT delivery system using radiographic films. The tests performed were the accuracy of DMLC position and dose delivery during VMAT with varying dose rate, gantry speed, and MLC leaf speed.Diodes and ion chamber arrays have also been used for VMAT QA (Bedford et al., 2009; Schreibmann et al., 2009; Petoukhova et al., 2011; Boggula et al., 2011). EPIDs were initially developed for geometric treatment verifications on the lines of film based portal imaging. However, over the years with technological advancements, EPIDs have become robust and capable of portal dosimetry. EPID has been explored by many groups (Greer and Popescu, 2003; Van Elmpt et

Journal of Graphic Era University
Vol. 6, Issue 1, 109-122, 2018
ISSN: 0975-1416 (Print), 2456-4281 (Online)

al., 2008; Winkler et al., 2005). Their work suggested that amorphous silicon EPID showed promise as an efficient verification tool for IMRT delivery and dosimetric verification.

However, there is very little published literature on using the EPID integrated with an advanced linac such as a TrueBeam system for carrying out comprehensive QA for VMAT. We believe that a detailed systematic study on using the EPID for QA and commissioning would provide necessary data to assess the performance of EPID with the other established QA methods such as films. We carried out a study and evaluated the reproducibility of the dose delivered by a dynamic MLC at four gantry angles using Electronic Portal Imaging Device (EPID). Also, we validated the VMAT delivery system for varying dose rate and gantry speed for the TrueBeam linac system. For both the studies we used the aS1000 EPID integrated with the linac system. The data collected were analysed using the readily available Microsoft Excel application to make the process faster and cost effective.

2. Material and Methods

The TrueBeam Version 2.0 linac system with the IMRT and VMAT (RapidArc) treatment modalities (Varian, Palo Alto, USA) was used in this study. The linac has three photon energies 6, 10 and 15 MV with Flattening Filter (FF) mode and two energies 6 and 10 MV with Flattening Filter Free (FFF) mode. The linac is equipped with a Varian Millennium MLC system having 120 leaves. The MLC has central 40 leaf pairs with leaf width of 0.5 cm and outer 20 pairs with leaf width of 1.0 cm at isocenter covering a field size from 0.4 cm x0.4 cm to 40 cm x40 cm.

2.1 Electronic Portal Imaging Device (EPID)

For on-board image guidance, the linac system is equipped with kV and MV imaging systems with amorphous silicon based flat-panel EPID (model aS1000).The EPID imager panel is mounted on a robotic support arm called E-arm which helps in deploying the EPID imager panel at 100 cm SID (source to imager distance) with high accuracy.The EPID has a scintillator detector which converts the incoming x-rays to visible light which in turn is sensed by an array of photodiodes in the amorphous silicon panel. The photodiodes integrate and convert the incoming light into an electric charge. The active area of the panel has an imaging area of 40 cm x 30 cm with 1024x768-pixel matrix. The flat panel has a pixel resolution of 0.39 mm, and it is capable of capturing 14-bit images at 30 fps (frames per second).

The aS1000MV imager is mainly used for clinical patient position matching. 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 TrueBeam. RapidArc QA files in DICOM RT file format, provided by Varian, were used in this study [5]. Before image acquisitions for QA, the MV imager needed calibration for dosimetry imaging for each photon energy used in the RapidArc QA plans. For all the tests the MV imager was

Journal of Graphic Era University
Vol. 6, Issue 1, 109-122, 2018
ISSN: 0975-1416 (Print), 2456-4281 (Online)

positioned at 100 cm source to image plane distance (SID) with lateral and longitudinal positions equal to zero. A total of six QA tests were performed during this study.

2.2 Test 1: DMLC Dosimetry Test

In this test, the machine output in Calibrated Unit (CU) was measured at gantry angles of 0, 90, 180 and 270º to verify the effect of gravity on leaf position and clinical dosimetry system. At each gantry angle, the dosimetric image was built from the RapidArc DMLC QA plan named "Millennium MLC: Dosimetry M120.dcm", which delivered a 4cm x 10 cm DMLC field with a 0.5 cm slit. 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 0º.

2.3 Test 2: DMLC Positional Accuracy Test (Picket Fence Test) for Fixed Gantry Angles

This test was performed using RapidArc DMLC QA plan named "Millennium MLC: Picket Fence Static M120.dcm" at gantry angles 0, 90, 180 and 270º. This mechanical test produced the "picket-fence" pattern of designed MLC positions at different static gantry angles. The data was also used as a reference for the "picket-fence" pattern at the same MLC positions but acquired for rotating gantry.

We created ten "picket fence" patterns at specified MLC positions with an MLC opening of 0.1 cm and a gap of 1.5 cm between two picket fences for gantry angle 0ºas shown in Figure 1A. A total of 100 MU was delivered at a dose rate of 600 MU/min for jaw opening of 16cmx8 cm. The same process was repeated for gantry angles 90, 180 and 270º.The line profile of the dosimetric image acquired was exported to Microsoft Excel and analysed for the positional accuracy of the DMLC for all four angles.

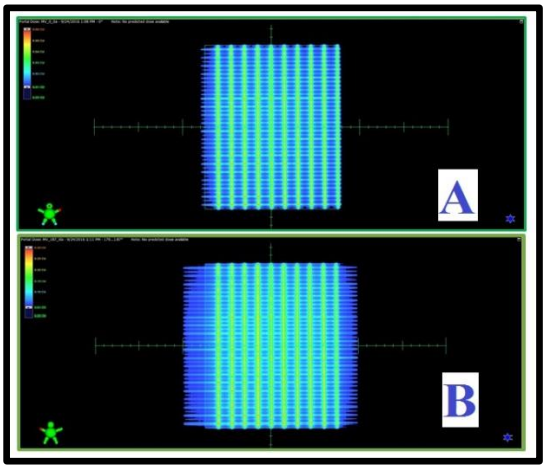

Figure 1. Screen- shots of the dosimetric images acquired (A) for DMLC picket fence test at 0º gantry, (B) for DMLC picket fence test for RapidArc

Journal of Graphic Era University
Vol. 6, Issue 1, 109-122, 2018
ISSN: 0975-1416 (Print), 2456-4281 (Online)

2.4 Test 3: Picket Fence Test During Rapidarc

We evaluated the effect of gantry rotation on MLC positional accuracy using the RapidArc DMLC QA plan "Millennium MLC: Picket Fence RAM120.dcm". Ten "picket fences" were created at specified positions similar to test 2, shown in Figure 1B. A total of 480 MU was delivered at a dose rate of 600 MU/min for jaw opening of 20cm x20 cm for the exposed field of 15 cm x20 cm starting at gantry angle 179ºand ending at 187º (total 352º). Similar to test 2 the measured and the specified positions were compared.

2.5 Test 4: Picket Fence Test During Rapidarc with Intentional Errors

RapidArc DMLC QA plan "Millennium MLC: Picket Fence Error M120.dcm" was used for this test. It is similar to the test 3 except that an intentional positional error of 0.5 mm was introduced in one pair of leaves, and a wider gap of 1.5 mm (instead of 1.0 mm) was used for another leaf-pair. The purpose of this test was to assure that these deliberate errors could be detected by a visual inspection of the "picket-fence" pattern. A total of 180 MU was delivered at a dose rate of 600 MU/min for a jaw opening of 20 cm x20 cm for the exposed field of 12cmx20 cm starting at 170ºand ending at 62º (98º gantry rotation).

2.6 Test 5: Dose Rate and Gantry Speed Accuracy During Rapidarc Delivery

RapidArc DMLC QA plan "Millennium MLC: Dose Rate Gantry Speed M120.dcm" was used for evaluation of the ability of the TrueBeam machine to modulate dose rate and gantry speed for accurate dose delivery. Different combinations of dose rates and gantry speeds were used to deliver the same dose to 7 strips of a RapidArc plan (Figure 4). Table 1 shows the details such as gantry speed and dose rate for the test.

Table 1. Gantry speed and dose rate for 16 control points with its master weight and MU/Deg

CONTROL POINT	GANTRY (DEGREE)	GANTRY ROTATION (DEGREE)	DOSE RATE (MU/MIN)	GANTRY SPEED (DEG/SEC)	MU/DEG
1	179.0	NA	NA	NA	NA
2	169.0	10.0	230.40	4.80	0.800
3	155.8	13.2	600.00	2.75	3.636
4	145.8	10.0	230.40	4.80	0.800
5	131.1	14.7	600.00	3.05	3.272
6	121.1	10.0	230.40	4.80	0.800
7	104.6	16.5	600.00	3.44	2.909
8	94.6	10.0	230.40	4.80	0.800
9	74.0	20.6	600.00	4.29	2.328
10	64.0	10.0	230.40	4.80	0.800
11	36.5	27.5	502.69	4.80	1.745
12	26.5	10.0	230.40	4.80	0.800
13	345.3	41.8	335.13	4.80	1.164
14	335.3	10.0	230.40	4.80	0.800
15	252.8	82.5	167.56	4.80	0.582
16	242.8	10.0	230.40	4.80	0.800

Journal of Graphic Era University
Vol. 6, Issue 1, 109-122, 2018
ISSN: 0975-1416 (Print), 2456-4281 (Online)

The maximum gantry speed and dose rate used for clinical purposes in the True Beam linac is 5.5º /sec and 600 MU/min respectively for a 6 MV photon beam. In this test, we moved the gantry for five preset gantry speeds of 4.80, 2.75, 3.05, 3.44 and 4.29º /sec, with a combination of four dose rates 167.56, 230.40, 335.13 and 600 MU/min for 16 control points. Table 1 shows the details of all 16 control points. A total of 400 MU was delivered with the jaw opening of 13.8cm x 20.0 cm to create seven strips of the same dose value. The distance between the centers of the seven strips from the center of the graticule was -6cm, -4cm, -2 cm, 0 cm +2cm, +4 cm and +6 cm. (Figure 4A).

Also, an open field of the same overall field size was delivered for normalisation. For the open field, a total of 400 MU was delivered at a dose rate of 600 MU/min for jaw opening of 13.8cm x20 cm at 242.76º as shown in Figure 5B.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 x 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 $R_{DR\text{-}GS(x)}$.
- The mean pixel value named as $R_{open}(x)$ has been registered at the corresponding position in the open field.
- The corrected readings for all ROIs were calculated using the formula.
  $Rcorr(x) = [R_{DR\text{-}GS(x)} / R_{open}(x)]$ 100 where $Rcorr(x)$ is the normalized mean pixel value at the same ROI in RapidArc field.
- The average $\overline{R}corr$ was then calculated for the seven corrected readings.
- The deviation of the corrected reading was calculated for each ROI from $\overline{R}corr$ using the following formula $Diff\ (x) = \{[Rcorr\ (x) / \overline{R}corr] 100\} - 100$.
- The average of the absolute values of all $Diff(x)$was calculated as $D_{iffabs} = \overline{|Diff(x)|}$.

2.7 Test 6: MLC Leaf Speed During Rapidarc Delivery

The RapidArc DMLC QA plan “MLCSpeed M120.dcm” was delivered and the dosimetric image evaluated to check the ability of the linac to modulate MLC speed for accurate dose delivery during gantry rotation. It used four combinations of dose rates, and MLC speeds to deliver the same dose to four strips of a RapidArc plan. Also, an open field of the same overall field size was delivered for normalisation.

Journal of Graphic Era University
Vol. 6, Issue 1, 109-122, 2018
ISSN: 0975-1416 (Print), 2456-4281 (Online)

Table 2. Dose rates and MU/Deg for MLC speed test for 25 control points for a gantry speed of 4.8°/sec

CONTROL POINT	GANTRY RTN (DEGREE)	GANTRY MOVEMENT (DEGREE)	DOSE RATE (MU/MIN)	MU/DEG
1	170.0	NA	NA	NA
2	166.5	3.5	411.43	1.429
3	163.0	3.5	411.43	1.429
4	159.5	3.5	411.43	1.429
5	156.0	3.5	411.43	1.429
6	152.5	3.5	411.43	1.429
7	149.0	3.5	411.43	1.429
8	147.0	2.0	600.00	2.500
9	145.0	2.0	600.00	2.500
10	143.0	2.0	600.00	2.500
11	141.0	2.0	600.00	2.500
12	139.0	2.0	600.00	2.500
13	137.0	2.0	600.00	2.500
14	131.0	6.0	240.00	0.833
15	125.0	6.0	240.00	0.833
16	119.0	6.0	240.00	0.833
17	113.0	6.0	240.00	0.833
18	107.0	6.0	240.00	0.833
19	101.0	6.0	240.00	0.833
20	89.0	12.0	120.00	0.417
21	77.0	12.0	120.00	0.417
22	65.0	12.0	120.00	0.417
23	53.0	12.0	120.00	0.417
24	41.0	12.0	120.00	0.417
25	29.0	12.0	120.00	0.417

The gantry moved with a fixed speed of 4.8 deg/sec with a combination of four dose rates411.43, 600.00, 240.00, and 120.00 MU/min at 25 control points as shown in Table 2. With 25 control points of four combinations of different dose rate and MU/deg, we created four strips of the same dose (Figure 5A). A total of 120 MU was delivered at a dose rate from 120 to 600 MU/min for jaw opening of 12 cm x 20 cm, started at 170 degrees and ended at 32 degrees (138-degree rotation). The distances of the center of four bands from the center of the graticule were -4.5 cm, -1.5 cm, +1.5 cm, and +4.5 cm. For the open field, a total of 120 MU was delivered at a dose rate of 600 MU/min for jaw opening of 12cm x 20 cm at 32º gantry angle was also delivered for normalisation (Figure 5B). Analysis of dosimetric image was also done by the same way as for the test 5, in section 2.6.

Journal of Graphic Era University
Vol. 6, Issue 1, 109-122, 2018
ISSN: 0975-1416 (Print), 2456-4281 (Online)

3. Results and Discussion

3.1. Test 1: DMLC Dosimetry

The dose measured by EPID in a 1 cm^2 area at the center of the field was recorded in Calibrated Unit (CU). The CU value at gantry angle 0º taken as baseline and deviations at other gantry angles were calculated accordingly (Table 3). LaSasso (2008) recommended the tolerance value of deviation for the above test be to be <3%.

Table 3. Output measured at four gantry angle 0, 90, 180 and 270º. CU: Count unit

Gantry angle (degrees)	Output reading (CU)	% of deviation	Tolerance
0 (Ref)	0.128097	0	±3 %
90	0.128013	-0.06557	±3 %
180	0.126887	-0.94459	±3 %
270	0.128302	0.16003	±3 %

3.2 Test 2: Picket Fence for Positional Accuracy of DMLC for Fixed Gantry Angle

A line profile of position and dose values in the acquired dosimetric image was plotted in portal dosimetry application and exported into Microsoft excel. Figure 2 shows the graph plotted between dose and MLC position in the imager. The peak positions and spacing between two adjacent peaks for all the ten strips were recorded from the graph, and the deviations from the known spacing (1.5 cm) were estimated.

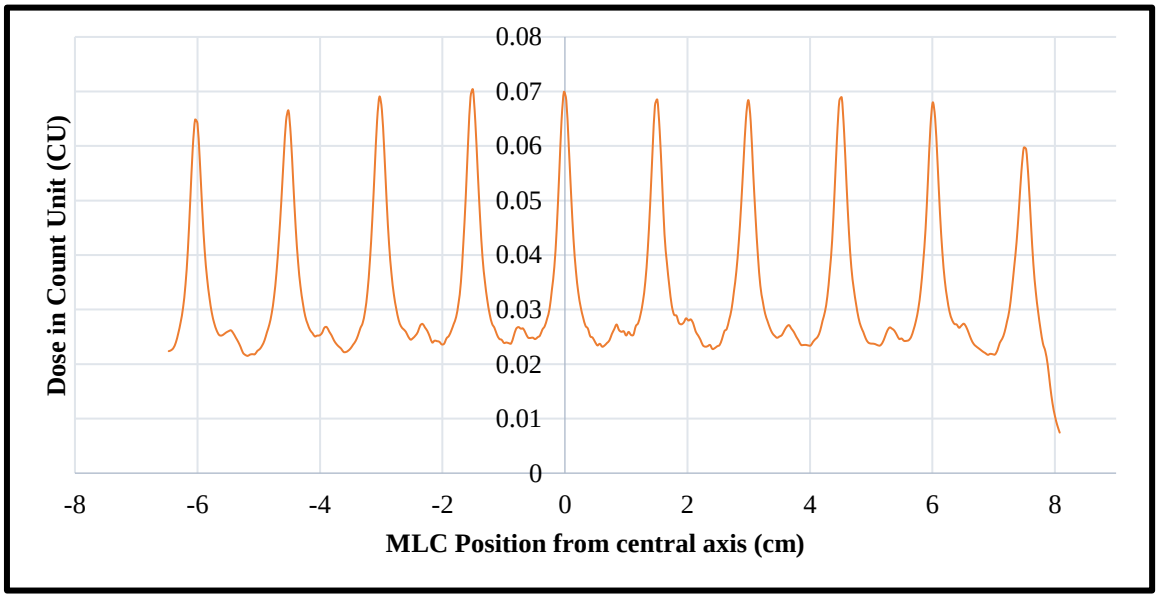

Figure 2. Dose Vs MLC position for picket fence test at 0º gantry

Journal of Graphic Era University
Vol. 6, Issue 1, 109-122, 2018
ISSN: 0975-1416 (Print), 2456-4281 (Online)

Table 4A. Positions of peaks, adjacent peak spacings, and deviations from planned spacing (1.5 cm) of picket fence test at0º gantry

Dose Peak	Positions [cm]	Dose Peak	Spacing [cm]	(Spacing Deviation) [mm]
Peak 1	-6.04	Peak 1 to 2	1.53	0.25
Peak 2	-4.51	Peak 2 to 3	1.49	0.14
Peak 3	-3.03	Peak 3 to 4	1.53	0.25
Peak 4	-1.50	Peak 4 to 5	1.49	0.14
Peak 5	-0.02	Peak 5 to 6	1.53	0.25
Peak 6	1.51	Peak 6 to 7	1.49	0.14
Peak 7	2.99	Peak 7 to 8	1.53	0.25
Peak 8	4.52	Peak 8 to 9	1.49	0.14
Peak 9	6.01	Peak 9 to 10	1.49	0.14
Peak 10	7.49		Maximum deviation= 0.25 mm	

Table 4B. Peak position accuracy for all cardinal gantry angles for picket fence test

Gantry Angle(deg)	MLC Position Accuracy(mm)	Tolerance(mm)
0	0.25	1.0
270	0.28	1.0
90	0.26	1.0
180	0.28	1.0

Table 4A shows the maximum deviation of positional accuracy of DMLC for 0º gantry angle is 0.25 mm. Table 4B shows similar deviations for the four cardinal gantry angles 0, 90, 180, and 270 degrees. TG 142 suggested the tolerance value of 1.0 mm of MLC position accuracy for IMRT.

3.3 Test 3: Positional Accuracy of DMLC Picket Fence Test during RapidArc

The result of DMLC picket fence test for RapidArc is shown in Figure 1B, and a graph plotted between dose value and MLC position detail in Microsoft excel by the same way as in test 2. The peak positions and spacing between the peaks for DMLC picket fence test for RapidArc are shown in Table 5.

Table 5. Peak positions, adjacent peak spacing and spacing deviations from planned spacing of picket fence test for RapidArc

Does Peak	Positions [cm]	Spacing [cm] in two Peak	(Spacing Deviation) [mm]
Peak 1	-5.95	Peak 1 to 2 = 1.49	0.14
Peak 2	-4.46	Peak 2 to 3 = 1.49	0.14
Peak 3	-2.98	Peak 3 to 4 = 1.53	0.26
Peak 4	-1.45	Peak 4 to 5 = 1.49	0.14
Peak 5	0.04	Peak 5 to 6 = 1.49	0.14
Peak 6	1.52	Peak 6 to 7 = 1.53	0.26
Peak 7	3.05	Peak 7 to 8 = 1.49	0.14
Peak 8	4.53	Peak 8 to 9 = 1.53	0.26
Peak 9	6.06	Peak 9 to 10 = 1.49	0.14
Peak 10	7.55	Maximum Deviation = 0.26 mm	

Journal of Graphic Era University
Vol. 6, Issue 1, 109-122, 2018
ISSN: 0975-1416 (Print), 2456-4281 (Online)

From the graph and the analysis, it was found that for this test the maximum positional spacing deviation was 0.26 mm for RapidArc picket fence test, where the tolerance value is 1.0 mm.

3.4. Test 4: Picket Fence Test of DMLC During Rapidarc with Deliberate Errors

Visual inspection of Figure 3 shows the wider leaf pair (marked by the thick red arrow) and the shifted leaf pair (characterised by the yellow arrow).

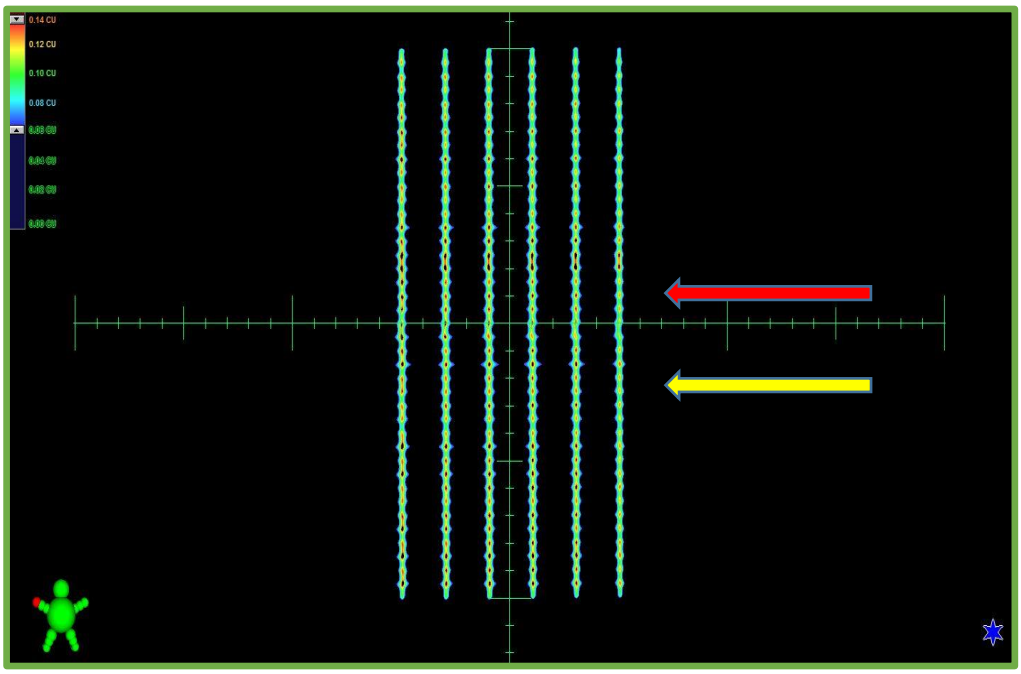

Figure 3. Screen-shot of the dosimetric image for intentional errors in the DMLC positions during RapidArc. The red and yellow arrows show the intentional errors

3.5 Test 5: Accuracy of Dose Rate and Gantry Speed During Rapidarc Delivery

Analysis of dosimetric image shown in Figure 4 was done as per the defined method at section 2.7 above. The mean pixel value reading ($R_{DR\text{-}GS)}$ created with a combination of gantry speed and dose rate for all seven bands and that for the open field (R_{open}) was found out. From this, the R_{corr} (normalised 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.

Journal of Graphic Era University
Vol. 6, Issue 1, 109-122, 2018
ISSN: 0975-1416 (Print), 2456-4281 (Online)

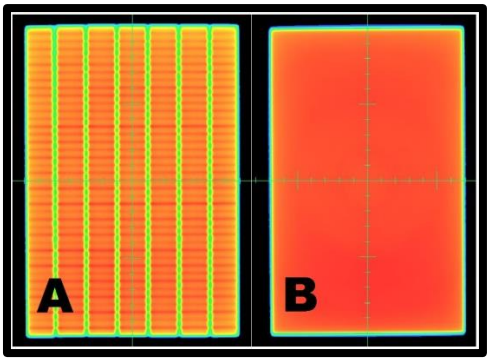

Figure 4. Screenshot of (A) acquired a dosimetric image for seven combinations of different dose rates and gantry speeds to deliver the same dose to 7 strips of a RapidArc plan, and (B) open field image for 400 MU

Table 6 shows the detailed analysis of mean pixel value reading for variable dose rates and gantry speeds during RapidArc for all seven strips.

Table 6. Mean pixel values for dose rate and gantry speed analysis using 10 cm x 0.5 cm region of interest. R_{DR-GS} (mean pixel value for the seven strips); R_{open} (mean pixel value corresponding ROI for an open field); R_{corr} (normalised mean pixel value for the same ROI and $D_{iff(x)}$ (deviation of the corrected reading)

Band number	- 6 cm	-4 cm	-2 cm	0 cm	2 cm	4 cm	6 cm
R_{DR-GS}	0.6207	0.6285	0.6271	0.6257	0.6270	0.6285	0.6161
R_{open}	4.114	4.213	4.203	4.191	4.200	4.206	4.086
R_{corr}	15.09	14.92	14.92	14.93	14.93	14.94	15.08
$D_{iff(x)}$ (%)	0.78	-0.37	-0.35	-0.29	-0.29	-0.19	0.71

Maximum value of Diff (x) is 0.78 %. From Diff (x), we calculated the average of the absolute value of all Diff(x): $D_{iffabs}=\overline{|Diff(x)|}$. The average of the absolute value of all Diff(x) was estimated to be 0.43.

3.6 Test 6: Accuracy of MLC Leaf Speed During Rapidarc Delivery

From the dosimetric image (Figure 5), the R_{LS} (the mean pixel value reading created with a different combination of MLC speed and dose rate) was estimated for all four bands. As per the plan, all four strips have the same dose value. R_{open} (the mean pixel value reading for the open field) was also estimated. From these values, R_{corr} (normalised Mean pixel value) for all four strips was calculated. The values are shown in Table 7.

Journal of Graphic Era University
Vol. 6, Issue 1, 109-122, 2018
ISSN: 0975-1416 (Print), 2456-4281 (Online)

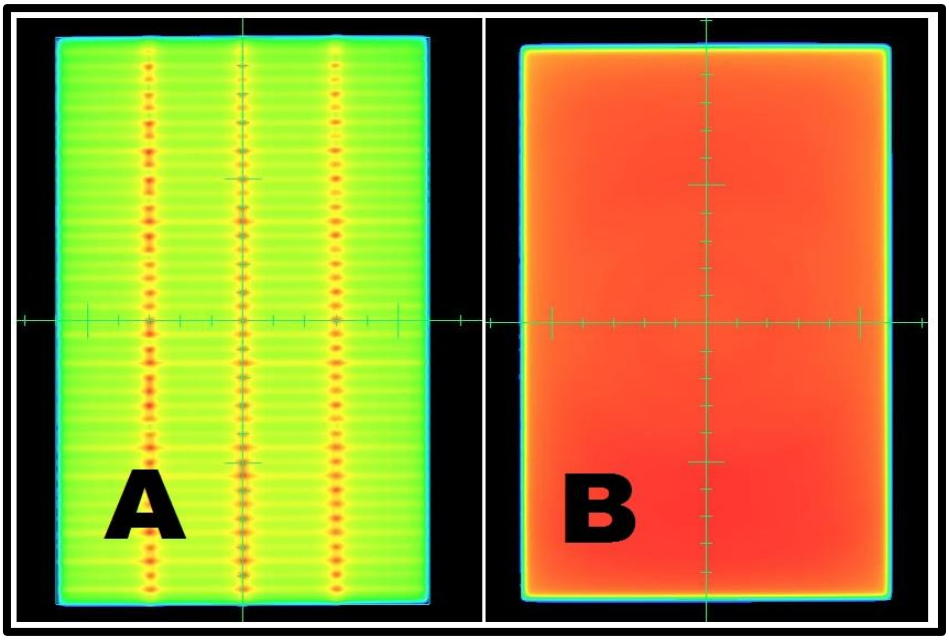

Figure 5. Screen-shot of (A) dosimetric image using four combinations of dose rates and MLC speeds to deliver the same dose to 4 strips of a RapidArc plan, (B) open field dosimetric image for 400 MU

Table 7 shows MLC leaf speed test image analysis using 10 cm x 0.5 cm ROI. It indicates that the mean deviation of the four strips from the average *Diff(x)* was 0.2% with a range from -0.26% to 0.21%.

Table 7. MLC leaf speed test image analysis using 10 cm x 0.5 cm ROI. R_{LS} (the mean pixel value reading); R_{open} (the mean pixel value for the corresponding open field), Rcorr (normalised mean pixel value), $D_{iff(x)}$ (deviation of the corrected reading)

Band number	-4.5 cm	-1.5 cm	1.5 cm	4.5 cm
R_{LS}	0.1743	0.1766	0.1764	0.1737
R_{open}	1.240	1.251	1.249	1.235
R_{corr}	14.06	14.12	14.12	14.07
$D_{iff(x)}$	-0.26	0.19	0.21	-0.14

Test 1 analysed the machine output at different gantry angles to check the effect of gravity on leaf position and clinical dosimetry system. The comparison of EPID and ion-chamber results for static fields showed that EPID was equally effective for the purpose. For positional accuracy picket fence test is a well-tested method (Essers et al., 2001; Wang et al., 2008; Rowshanfarzad et al., 2014). In test 2, we analysed the positional accuracy of MLC leaf position at fixed gantry angles. A similar type of picket fence test is used for the moving gantry in test 3. As per the recommendation of TG 142 for both test 2 and 3, the accuracy of the MLC position should be less than 1 mm. Ling et al. (2008) performed the picket fence tests with radiographic films. It is quite evident that film based QA procedure is expensive

and time consuming compared to the EPID. Our results of the MLC positional accuracy for fixed gantry and moving gantry are similar to radiographic film based tests. For the latter, the MLC shift from the known position is 0.28 mm and 0.30 mm respectively, which is well within the tolerance limits (1.0 mm). With Test 4 we could visually analyse the reproducibility of error. With Test 5 and 6 we analysed the accuracy of the dose delivery with varying dose, gantry speed, and varying MLC speed.

EPID has a pixel resolution of 0.39 mm, which is good enough for sub-mm accuracy similar to the radiographic film but better than the diode and ion chamber arrays. Further, the precision and consistency of the measurements discussed above show the robustness and stability of EPID. The commercially available software applications used for analyses with the other QA systems are costly while with EPID we could transfer the measured data to Microsoft excel for analyses of the dose images. Further, we believe that for routine QA the film processing conditions are additional uncertainty in the film based tests as compared to EPID measurements.

4. Conclusion

At the time of commissioning of VMAT, a comprehensive dosimetric QA is mandatory. We used EPID to perform QA. 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. Also, it is cost effective and equally accurate. We recommend the EPID based MLC QA as a standard for clinical commissioning of VMAT and also for routine QA of the linac radiotherapy systems.

Reference

Bedford, J. L., & Warrington, A. P. (2009). Commissioning of volumetric modulated arc therapy (VMAT). International Journal of Radiation Oncology Biology Physics, 73(2), 537-545.

Bedford, J. L., Lee, Y. K., Wai, P., South, C. P., & Warrington, A. P. (2009). Evaluation of the Delta4 phantom for IMRT and VMAT verification. Physics in Medicine and Biology, 54(9), N167-176.

Boggula, R., Birkner, M., Lohr, F., Steil, V., Wenz, F., & Wertz, H. (2011). Evaluation of a 2D detector array for patient-specific VMAT QA with different setups. Physics in Medicine and Biology, 56(22), 7163-7177.

Essers, M., de Langen, M., Dirkx, M. L., & Heijmen, B. J. (2001). Commissioning of a commercially available system for intensity-modulated radiotherapy dose delivery with dynamic multileaf collimation. Radiotherapy and Oncology, 60(2), 215-224.

Greer, P. B., & Popescu, C. C. (2003). Dosimetric properties of an amorphous silicon electronic portal imaging device for verification of dynamic intensity modulated radiation therapy. Medical Physics, 30(7), 1618-1627.

Hardcastle, N., Tomé, W. A., Foo, K., Miller, A., Carolan, M., & Metcalfe, P. (2011). Comparison of prostate IMRT and VMAT biologically optimised treatment plans. Medical Dosimetry, 36(3), 292-298.

Klein, E. E., Hanley, J., Bayouth, J., Yin, F. F., Simon, W., Dresser, S., Serago, C., Aguirre, F., Ma, L., Arjomandy, B., Liu, C., Sandin, C., & Holmes, T. (2009). Task Group 142 report: quality assurance of medical accelerators. Medical Physics, 36(9), 4197-4212.

Kumar, R., Sharma, S. D., Deshpande, S., Sresty, N. M., Bhatt, C. P., Amols, H. I., Chourasiya, G., & Mayya, Y. S. (2014). Analysis of patient specific dosimetry quality assurance measurements in intensity modulated radiotherapy: A multi centre study. Journal of Cancer Research and Therapeutics, 10(3), 611-617.

Ling, C. C., Zhang, P., Archambault, Y., Bocanek, J., Tang, G., & LoSasso, T. (2008). Commissioning and quality assurance of RapidArc radiotherapy delivery system. International Journal of Radiation Oncology Biology Physics, 72(2), 575-581.

LoSasso, T. (2008). IMRT delivery performance with a varian multileaf collimator. International Journal of Radiation Oncology Biology Physics, 71(1), S85-S88.

Oliver, M., Ansbacher, W., & Beckham, W. A. (2009). Comparing planning time, delivery time and plan quality for IMRT, RapidArc and Tomotherapy. Journal of Applied Clinical Medical Physics, 10(4), 117-131.

Petoukhova, A. L., Van Egmond, J., Eenink, M. G. C., Wiggenraad, R. G. J., & Van Santvoort, J. P. C. (2011). The ArcCHECK diode array for dosimetric verification of HybridArc. Physics in Medicine and Biology, 56(16), 5411-5428.

Rangaraj, D., Oddiraju, S., Sun, B., Santanam, L., Yang, D., Goddu, S., & Papiez, L. (2010). Fundamental properties of the delivery of volumetric modulated arc therapy (VMAT) to static patient anatomy. Medical Physics, 37(8), 4056-4067.

Rowshanfarzad, P., McGarry, C. K., Barnes, M. P., Sabet, M., & Ebert, M. A. (2014). An EPID-based method for comprehensive verification of gantry, EPID and the MLC carriage positional accuracy in Varian linacs during arc treatments. Radiation Oncology, 9(1), 249-259.

Schreibmann, E., Dhabaan, A., Elder, E., & Fox, T. (2009). Patient-specific quality assurance method for VMAT treatment delivery. Medical Physics, 36(10), 4530-4535.

Sharma, D. S., Dongre, P. M., Mhatre, V., & Heigrujam, M. (2011). Physical and dosimetric characteristic of high-definition multileaf collimator (HDMLC) for SRS and IMRT. Journal of Applied Clinical Medical Physics, 12(3), 142-160.

Unkelbach, J., Bortfeld, T., Craft, D., Alber, M., Bangert, M., Bokrantz, R., Chen, D., Li, R., Xing, L., Men, C., Nill, S., Papp, D., Romeijn, E., & Salari, E. (2015). Optimization approaches to volumetric modulated arc therapy planning. Medical Physics, 42(3), 1367-1377.

Van Elmpt, W., McDermott, L., Nijsten, S., Wendling, M., Lambin, P., & Mijnheer, B. (2008). A literature review of electronic portal imaging for radiotherapy dosimetry. Radiotherapy and Oncology, 88(3), 289-309.

Wang, H. C., Chui, C. S., Tsai, H. Y., Chen, C. H., & Tsai, L. F. (2008). Dose deviations caused by positional inaccuracy of multileaf collimator in intensity modulated radiotherapy. Radiation Measurements, 43(2), 925-928.

Winkler, P., Hefner, A., & Georg, D. (2005). Dose-response characteristics of an amorphous silicon EPID. Medical Physics, 32(10), 3095-3105.