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Evaluation of ArcCHECK SNC Machine QA tool for Modern Linear Accelerator

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Original Article

Abstract

Purpose: ArcCHECK SNC Machine QA tool is used to test geometric and delivery aspects of linear accelerator. **Methods**: In this study we evaluated the performance of this tool. For each item analyzed by the tool, wherever possible, tests across the same time period using portal dosimetry were also evaluated. Machine QA feature allows user to perform quality assurance tests using ArcCHECK phantom. Following tests can be performed 1) Gantry Speed, Rotation and Angle 2) MLC/Collimator 3) Beam Profile Flatness and Symmetry. Data was collected on true BEAM STx for a year. All plans were created for 6 and 10 MV beams as per the SNC patient user manual in Eclipse v.13. **Results:** The Gantry speed was 3.9 deg/sec with speed maximum deviation around 0.3 deg/sec. The Gantry Isocenter for arc delivery was 0.9 mm and static delivery was 0.4 mm which was well consistent with MPC (0.4 mm). The average maximum percent positive and negative diff was found to be 1.9%, -0.25% and average maximum distance positive and negative diff was 0.4 mm, -0.3 mm for MLC/Collimator QA. The average gamma error at 1% 1 mm criteria was 1.4% using portal Dosimetry for 6 MV. The Flatness for Arc delivery was 1.8% and Symmetry for Y was 0.8% and X was 1.8%. **Conclusion:** ArcCHECK SNC Machine QA tool is useful for quality assurance of modern linear accelerators as it tests both geometric and delivery aspects. This test can be incorporated in the regular quality assurance protocol for VMAT delivery.

Keywords: Machine QA, VMAT, ArcCHECK

1. Introduction

Radiotherapy is a highly complex process, involving many steps and many individuals in the planning and delivery of the treatment. Such complexity leads to a multitude of opportunities for errors to occur. Radiotherapy is evolving fast with new technologies and modalities are launched frequently by vendors and by research groups. Today we have commercially available dynamic delivery of rotational intensity modulated treatments e.g. Rapid Arc, VMAT and tomotherapy. Intensity modulated radiotherapy (IMRT) is today the standard modality at many departments. The challenge for medical physicists and other professionals within radiation oncology is to cope with this accelerated process of new modalities and technologies. Especially regarding acceptance and commissioning of the new equipment, but also creating new procedures for the daily work to establish a safe environment for these modalities for patients but also for staff. The aim of quality assurance (QA) in radiotherapy is to make sure that the machine parameters do not deviate significantly from their baseline values acquired at the time of acceptance and commissioning. There are many publications that describe procedures and conditions for testing, as for example the International Electro technical Commission (IEC) publications.[1, 2, 3]

Rapid Arc is the Varian version of volumetric-modulated arc therapy (VMAT) that was first proposed by Otto.[4] VMAT is an extension of IMRT where in addition to dynamic MLC motion and dose rate modulation the treatment is delivered as a gantry arc with gantry speed modulation. Hence VMAT requires an additional QA tests for delivery of beam as compared with IMRT.[4, 7] Linear accelerator quality assurance and commissioning for VMAT has usually been based upon the work of Ling *et al.* or tests later expanded upon by Van Esch *et al.* [5, 6] In the first test a picket fence pattern is delivered in arc mode and it is qualitatively analyzed for positional errors. Other two tests vary dose rate and gantry speed over different arc segments to deliver the same nominal

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dose in each segment. The MLC moves between each segment to irradiate a separate strip of film or similar detector. The method is limited in that it only shows whether a consistent integrated dose can be delivered with different dose rates and provides no information on dose rate stability or control of dose rate modulation. The authors state that the method "is an initial attempt in designing a commissioning and QA protocol. There are areas for refinement and improvement in the future.[6] The results from the above tests does not ensure that the dose delivered is correct and thus additional measurements become necessary. It has been realized that the independent dose calculation alone is not sufficient for a comprehensive QA program because the data transfer from treatment planning system to accelerator and the performance of the deliver unit are not checked. Therefore a periodic testing of machine delivery accuracy is required. The use of log files to verify VMAT delivery accuracy has been under investigation, but is lacking in published data. The tests performed during commissioning acts as a baseline values for an ongoing QA program. The report of Task Group 142 addresses the MLC performance tests for intensity-modulated radiation therapy (IMRT) and not for VMAT, hence there is the need to anticipate a supplemental set of tests targeted at VMAT.[1, 7]

We commissioned the Varian Rapid Arc at our institute in early 2015. At present at our institute we perform weekly quality assurance for rapid arc using tests recommended by Ling *et al.* and also machine performance check on trueBEAM STx unit on weekly basis. The patient specific QA for IMRT,VMAT,SRS,SRT & SBRT are performed on ArcCHECK cylindrical diode array and 3DVH software(Sun Nuclear Inc., Melbourne, FL). The ArcCHECK SNC Patient software also contains an additional tool for Machine QA.SNC Machine QA tool is used to test geometric and delivery aspects of linear accelerator. In this study we describe the tool and present the results of measurements that were taken over an extended period of time to explore the feasibility of its implementation for routine QA. For each item analyzed by the Machine QA tool, wherever possible, tests across the same time period using portal Dosimetry were also evaluated, as external independent checks for results comparison.

2. Methods and Materials

The measurements were carried out on TrueBEAM STx linear accelerator (Console version 2.5; Varian Medical Systems, Palo Alto, CA) for 6 MV and 10 MV beam. Plans were generated on Eclipse treatment planning system (v13.0) as per the instructions given in SNC Machine QA tool user manual. The ArcCHECK phantom was used for the measurements along with SNC patient software. The ArcCHECK is a cylindrical acrylic phantom with a three-dimensional array of 1386 diode detectors with 10 mm spacing with active detector size of 0.8 mm × 0.8 mm placed in a spiral geometry across the length of the 21 cm and 26.6 cm diameter, in a non-overlapping beam's eye view (BEV) geometry. There is a 15 cm diameter cavity in the center of the phantom to accommodate ion chamber placement for absolute dose measurement and various homogenous inserts. The ArcCHECK also features two inclinometers to measure the angle of rotation about the cylinder axis and to measure the tilt of the axis. A temperature sensor measures the ambient temperature of the detector area. ArcCHECK has the capability to measure both absolute and relative measurement in real time and saves all measurements as a function of time for every 50 ms.[9, 10] Apart from its use for Patient Specific QA, it also contains several tools such as Machine QA, MLC QA, and Beam QA.

In this study we evaluated the performance of ArcCHECK SNC Machine QA tool. Data was collected for a period of one year on weekly basis. In order to evaluate the SNC Machine QA tool, an independent check was performed at the same time of the acquisition of the SNC Machine QA tool. For the independent checks, Portal imager model AS1000 EPID which have a resolution of 1024 × 768 with a pixel size of 0.392 × 0.392 mm was used and Portal Dosimetry software (v13.0) was used to evaluate the images which were acquired at source detector distance of 100 cm. and IsoCal phantom for Machine performance check available in the department and routinely used for quality assurance. The aim was not to check one-by-one tests relative to the Machine QA tool, but to compare and validate two different methodologies for testing the Accelerator performances. The recent Netherlands Commission on Radiation Dosimetry (NCS) Report 24, which provides recommendations for comprehensive VMAT quality assurance was mostly used for tolerance of all the tests.[11] The Machine QA feature allows you to perform quality assurance tests on the delivery system. Following are the tests that can be performed using the ArcCHECK instrument:

- Gantry Speed QA
- Gantry Rotation QA
- Gantry Angle QA
- MLC/Collimator QA
- Beam Profile Flatness and Symmetry

2.1. Gantry QA

The Gantry QA tests allow the user to view errors in gantry angle and rotation and view how accurately the gantry moves around the isocenter. The Gantry QA test can be performed with dynamic or static delivery. For static beam delivery the ArcCHECK was isocentrically set up with specific field size of X = 1 cm and Y = 25 cm and collimator 9 degrees and at least 50 MU at any desired gantry angle was delivered without stopping measurement and the data for all angles was stored in one file. Movie files which took a snapshot exposure every 50 ms were recorded. To measure the gantry angle an inbuilt virtual inclinometer tool of the ArcCHECK was used at each snapshot, it would record multiple angle values for each 5° projection. For Arc delivery a field size of 1 cm wide × 25 cm long "Plus" (+) shaped field in both X and Y directions (using MLC) and rotate collimator by 9 degrees was created in eclipse with full arc as shown in Figure 1(a) and appropriate MUs were delivered.

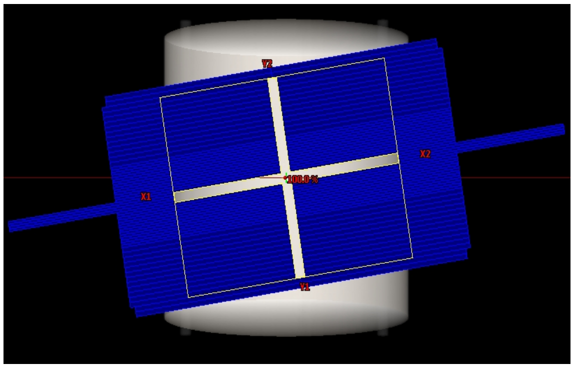


Figure 1(a): Gantry ARC Isocenter test field shape.

The Gantry QA results for both dynamic and static deliveries display gantry angle per update and the location of the calculated isocenter with respect to the Arc CHECK isocenter. Additionally, when arc delivery data is loaded the display shows gantry speed with respect to gantry angle and the shortest distance from the calculated isocenter to each beam. For the Eclipse treatment planning system (Varian Medical Systems, Palo Alto, CA), VMAT plans are composed of up to 178 control points. At each control point the gantry angle, cumulative dose fraction, and position of each MLC leaf is specified. At the accelerator, control is separated into two systems. Firstly, the treatment console controls the dose versus gantry angle by varying the dose rate and gantry speed as required to deliver the plan. The MLC controller provides control of the MLC position versus gantry angle. The gantry angle therefore synchronizes for the two control systems and is critical to VMAT delivery. The nominal dose rate is usually set to the maximum 600 MU/min and the maximum leaf speed to 2.5 cm/s. The maximum gantry speed is limited in the Eclipse TPS (v 13.0) to 6 °/s. We also tested the maximum gantry speed by changing the monitor units.

The static isocenter was evaluated using machine performance check phantom which is a new major mode in true BEAM which is designed to evaluate the machine geometric performance in 5 minutes. It uses IsoCal phantom which is a hollow cylinder 23 cm in diameter and length with 16 tungsten-carbide bearing balls (each 4 mm in diameter) as shown in Figure 1(b) (12). The phantom is mounted on the couch top along with a dedicated holder and a series of MV and kV images are acquired and the results are displayed for a quick evaluation. The treatment isocenter is then determined using acquisitions with the IsoCal phantom on eight gantry angles (0°, 45°, 90°, 135°, 180°, 225°, 270°, 315°), representative for the full gantry rotation. The images are loaded in IsoCal software, and the treatment isocenter is determined with respect to phantom. Then the software calculates the offset between position of imager and treatment isocenter as a function of gantry angle.

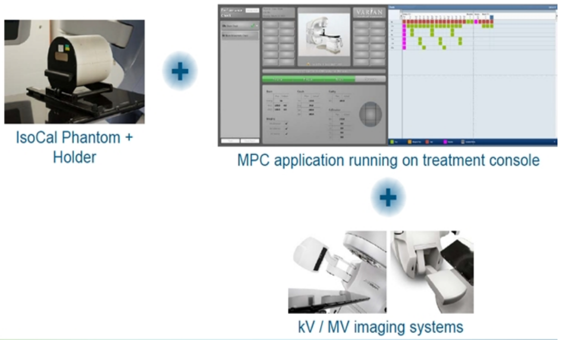


Figure 1(b): IsoCal phantom

2.2. MLC/Collimator QA

The Multileaf Collimator (MLC)/Collimator QA tool is used to analyze and locate differences between the leaf bank positions and jaw positions of the accelerator, using the ArcCHECK instrument. This tool is designed for use with linear accelerators that have an MLC and jaws. Two measurements are required for analysis. The first measurement moves the jaws to the specified location (MLC retracted), and the second measurement retracts the jaw and uses only the MLC leaf banks. If the two measurements are perfectly aligned, the response of detectors at the beam edge should be identical. Any deviation corresponds to MLC leaf bank/jaw positioning error. For MLC/Jaw QA the ArcCHECK was isocentrically set up with specific field size planned in eclipse according to the field size guide on machine qa user interfaces. Two plans were created in eclipse one with jaws only and other with MLC only and at least 50 MU was delivered without stopping measurement and the data for jaw and MLC were stored in separate files. This test can be performed for various gantry angle. (0, 60, 120, 180, 240 and 300). In order to perform the MLC/Jaw QA one needs to measure Penumbra transfer fit function. The penumbra transfer function (PTF) is a fit of the penumbra shape that is used to convert the percent difference between the MLC and Jaw measurements to distance in mm. Each PTF is specific to a linear accelerator. Once the PTF is generated, the parameters are saved on the local computer in ASCII file format. Once the measurements are saved the software reads both measurements (jaw and MLC) and normalizes them to their maximum value (the maximum value of each measurement is 1). It calculates the percent difference between jaw and MLC bank as one result and then with the help of penumbra transfer function it calculates the distance difference between MLC and jaw. In order to check the alignment of jaw and MLC independently same plans were exposed on portal imager and the results were analyzed in portal Dosimetry workspace. To evaluate the results with portal Dosimetry, we used gamma index values which are calculated for both plans and area gamma was evaluated to indicate better agreement.

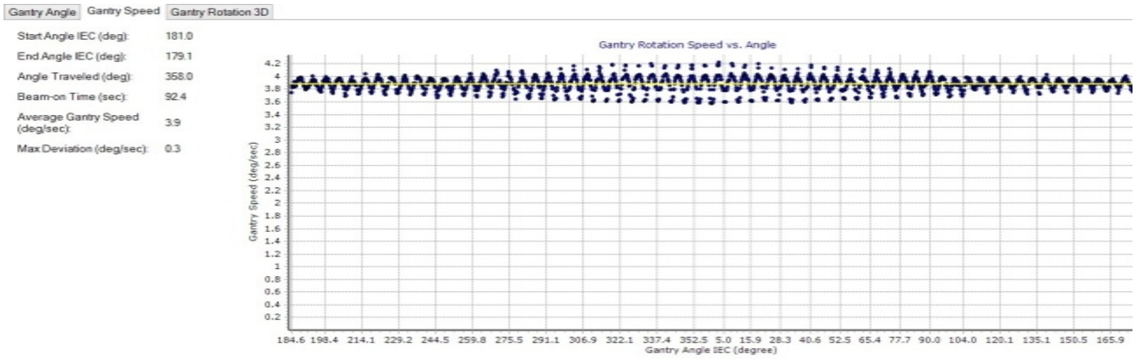
2.3. Flatness & Symmetry

The Flatness & Symmetry test allows the user to quantify beam flatness and symmetry in the IEC-y direction, and symmetry in the IEC-x direction, using the ArcCHECK instrument. The Flatness & Symmetry test can be performed for static or dynamic delivery. For static beam delivery the ArcCHECK was isocentrically set up with field size of X = 25 cm and Y = 25 cm and at least 50 MU at any desired gantry angle was delivered without stopping measurement and the data for all angles was stored in one file. For Arc delivery a field size of 25 cm wide × 25 cm long shaped field in both X and Y directions was created in eclipse with full arc and appropriate MUs were delivered. The same plans were again exposed on portal imager and the results were analyzed in portal Dosimetry workspace for all gantry angles.

3. Results

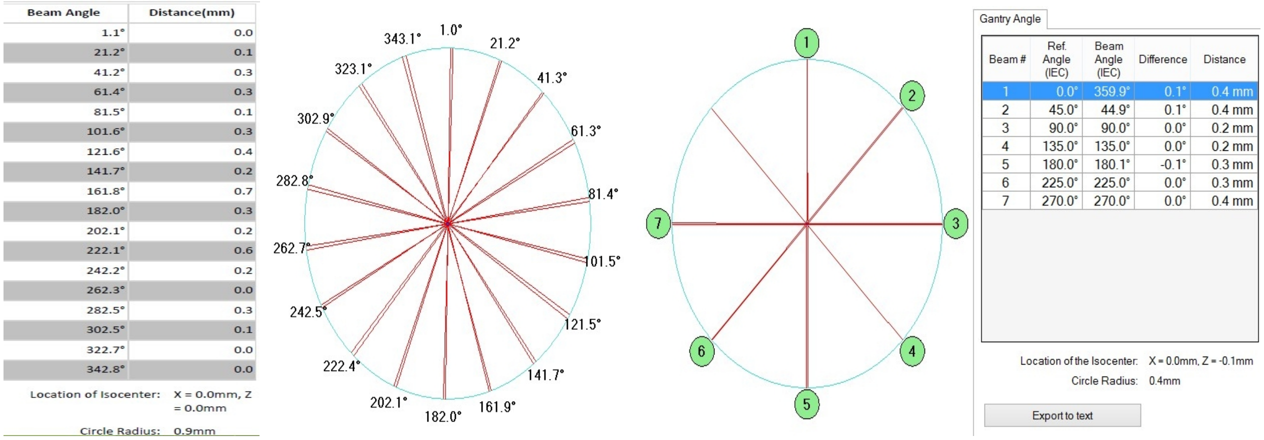
3.1. Gantry Speed, Rotation and Gantry Angle QA

The Gantry speed was 3.9 deg/sec with maximum speed deviation around 0.3 deg/sec and for 6 deg/sec the maximum speed deviation was around 0.4 deg/sec. The left side of the window in Figure 2 displays the gantry start and end angles, the total angle traveled, the beam-on time, the average gantry speed in degrees per second, and the maximum deviation of gantry speed with respect to the average. The right side of the window displays a graph of the gantry rotation speed with respect to gantry angle. Each point in the graph represents one update (50 ms). The table on the left side of the window in Figure 3(a) is populated with the angle at approximately every 20 degrees, and the shortest distance from the center of the beam to the calculated isocenter. The graph on the right side of the window displays red lines that correspond to the center of each beam, as defined by the midline between the 80% values of the beam profile.



Start Angle IEC (deg): 181.0
End Angle IEC (deg): 179.1
Angle Traveled (deg): 358.0
Beam-on Time (sec): 92.4
Average Gantry Speed (deg/sec): 3.9
Max Deviation (deg/sec): 0.3

Figure 2: Gantry Speed indicating average gantry speed and maximum deviation.



Beam Angle	Distance(mm)
1.1°	0.0
21.2°	0.1
41.2°	0.3
61.4°	0.3
81.5°	0.1
101.6°	0.3
121.6°	0.4
141.7°	0.2
161.8°	0.7
182.0°	0.3
202.1°	0.2
222.1°	0.6
242.2°	0.2
262.3°	0.0
282.5°	0.3
302.5°	0.1
322.7°	0.0
342.8°	0.0

Location of Isocenter: X = 0.0mm, Z = 0.0mm
Circle Radius: 0.9mm

Beam #	Ref. Angle (IEC)	Beam Angle (IEC)	Difference	Distance
1	0.0°	359.9°	0.1°	0.4 mm
2	45.0°	44.9°	0.1°	0.4 mm
3	90.0°	90.0°	0.0°	0.2 mm
4	135.0°	135.0°	0.0°	0.2 mm
5	180.0°	180.1°	-0.1°	0.3 mm
6	225.0°	225.0°	0.0°	0.3 mm
7	270.0°	270.0°	0.0°	0.4 mm

Location of the Isocenter: X = 0.0mm, Z = -0.1mm
Circle Radius: 0.4mm

Figure 3(a): Gantry Isocenter reports for Arc and Static delivery.

In Figure 3(b) each point in the graphs represents a beam isocenter. The graph on the left side of the window (red) shows the location of each beam center in relation to the ArcCHECK isocenter (0, 0). The graph on the right side of the window (blue) shows the distance of each beam center from the ArcCHECK isocenter, but with respect to the gantry angle. The distribution of points in the graphs reveals any trends that are occurring during gantry rotation, such as gantry sag.

The accuracy of gantry in static mode was found to be < 0.1◦ for machine QA tool when compared with MPC (0.04◦) The average Gantry Isocenter for arc delivery was 0.9 mm & static delivery was 0.4 mm for 6 MV and 10 MV. The gantry isocenter size for Static gantry was found to be well consistent when compared with MPC (0.4 mm). Figure 4 shows the data collected for 1 year from Machine QA tool and MPC for Static gantry isocenter.

3.2. MLC/Collimator QA

The average maximum percent positive and negative diff for 6 MV and 10 MV was found to be 1.9% , - 0.25% and 2.3%, 0% and average maximum distance positive & negative diff for 6 and 10 MV was 0.4 mm, - 0.3 mm and 0.5 mm, -0.2 mm respectively for MLC/Collimator QA . The vertical lines in Figure 5 show the MLC/Jaw Coincidence Difference panel which represents the beam edge coincidence. If the MLC is perfectly aligned with the corresponding jaw, the difference will be close to zero (green). Any deviation from zero indicates an error in the MLC or Jaw. For independent verification both plans were exposed on Portal and gamma index was evaluated at 1% 1 mm criteria. The average area gamma error was 1.4% as compared to 1.9% with machine QA tool for 6 MV and 2.2 % with machine QA tool and 2.3% with portal Dosimetry for 10 MV. If the MLC is perfectly aligned with the corresponding jaw, we shall expect the area gamma to be 0 % for portal Dosimetry. A congruence of MLC and jaws seen as basically + / - 0.4 mm.

3.3. Flatness and Symmetry

The average Flatness and Symmetry for Arc and static delivery are tabulated in Table 2 for 6 and 10 MV.

Figure 7 displays the dynamic and static gantry delivery results in three different graphs that show the flatness and symmetry as a function of gantry angle. When a static gantry measurement is loaded, the beam data table displays one row for each beam found in the measurement, and displays the following for each beam: measured beam number, calculated gantry angle, % flatness (IEC-y), % Symmetry (IEC-x), and % symmetry (IEC-y).

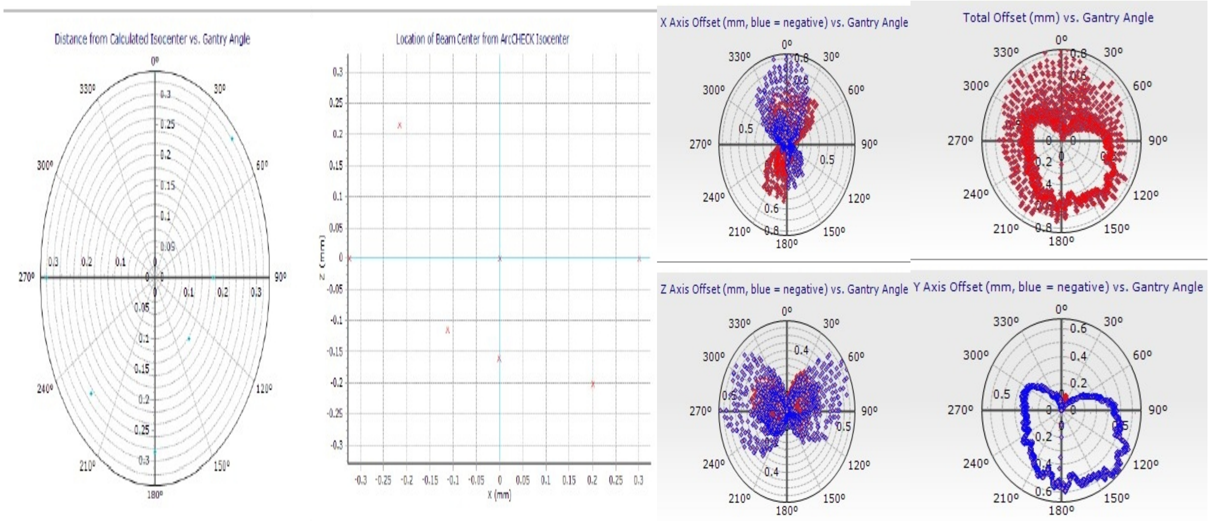


Figure 3(b): Gantry Isocenter reports for Arc and Static delivery.

Table 1: Gantry QA and MLC/Jaw QA for 6 MV and 10 MV

Parameter	Tol	6X		10X	
Gantry QA		Machine QA	Indep(MPC/Portal)	Machine QA	Indep(MPC/Portal)
Isocenter Static	± 1 mm	0.4 mm	0.41 mm	0.41 mm	Na
Isocenter Arc	± 1 mm	0.9 mm	na	0.9 mm	Na
Gantry angle	1 deg	0.1 deg	0.04 deg	0.1 deg	Na
MLC/Jaw QA					
Max percent positive		1.90%	1.40%	2.20%	2.30%
Max percent Negative		-0.25%		0	

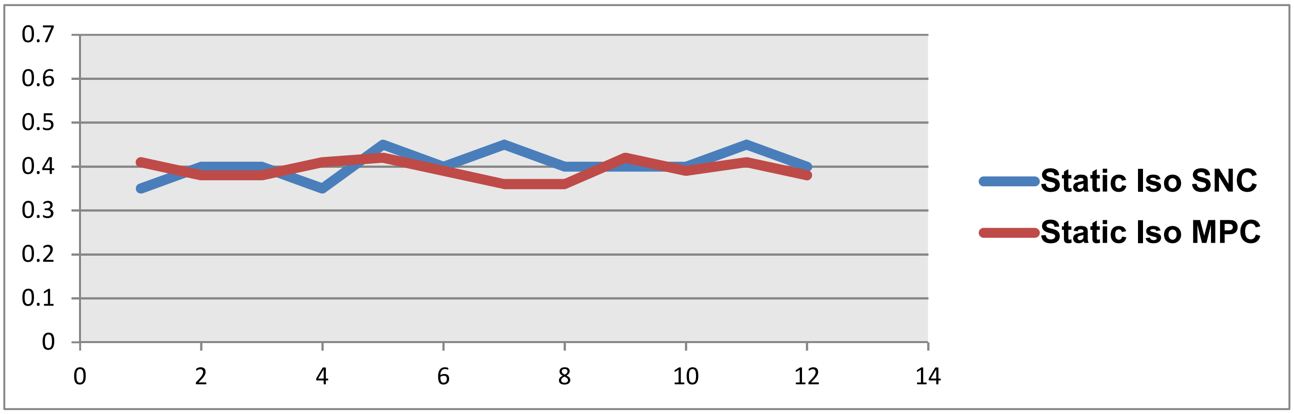
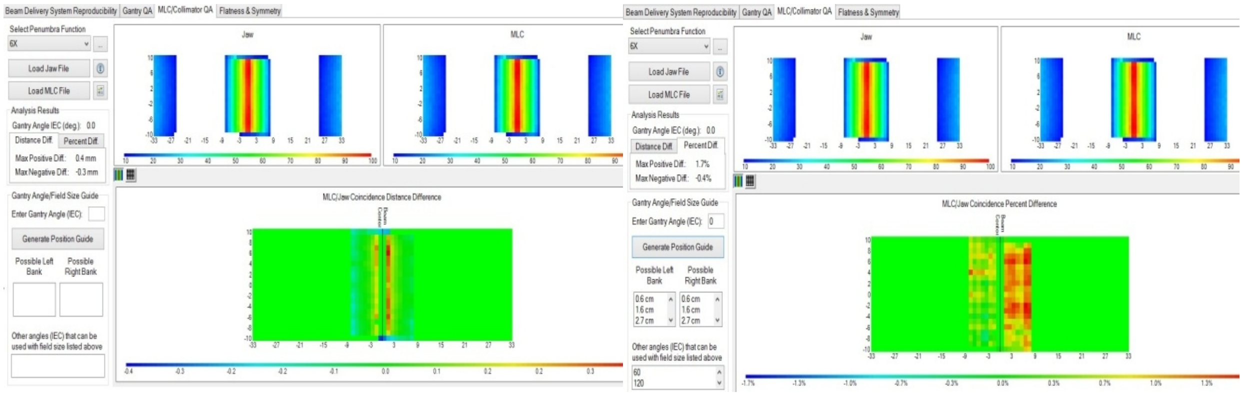


Figure 4: Static Isocenter data of 6 MV for a period of 1 year of Machine QA tool and IsoCal Phantom.



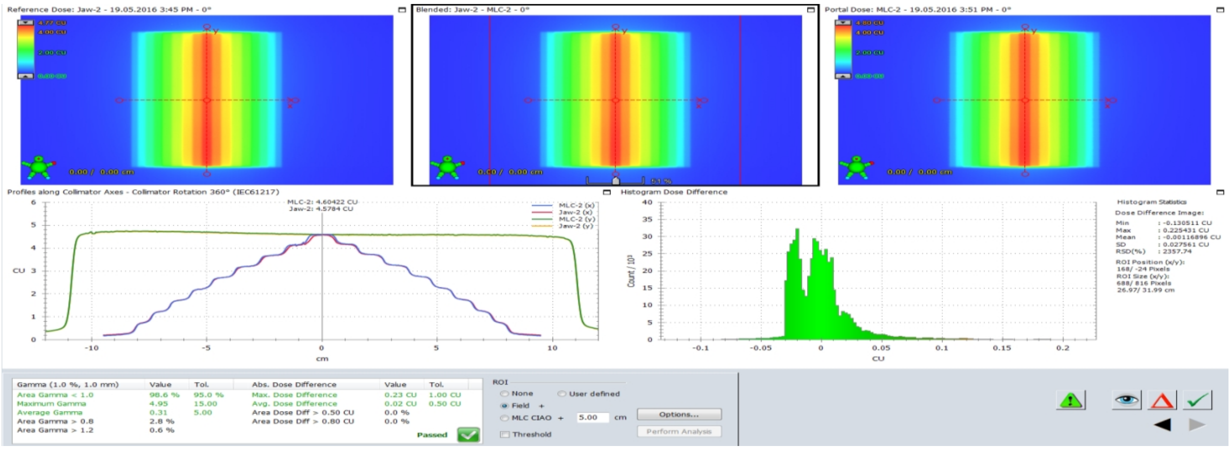
Select Penumbra Function: 6X
Gantry Angle IEC (deg.): 0.0
Max Positive Diff.: 0.4 mm
Max Negative Diff.: -0.3 mm
Enter Gantry Angle (IEC):
Other angles (IEC) that can be used with field size listed above

Select Penumbra Function: 6X
Gantry Angle IEC (deg.): 0.0
Max Positive Diff.: 1.7%
Max Negative Diff.: -0.4%
Enter Gantry Angle (IEC): 0
Possible Left Bank: 0.6 cm, 1.6 cm, 2.7 cm
Possible Right Bank: 0.6 cm, 1.6 cm, 2.7 cm
Other angles (IEC) that can be used with field size listed above: 60, 120

Figure 5: MLC-Jaw QA using Machine QA tool.

Table 2: Flatness and Symmetry for Static and Arc Delivery on Machine QA tool & Portal Dosimetry for 6 MV & 10 MV.

Parameter	Tol	6X		10X	
Flatness/Symmetry for Arc & Static		Machine QA	Indep(portal)	Machine QA	Indep(portal)
Flatness for Arc	± 2 %	1.8	1.5	2	1.2
Symmetry for Arc X	± 2 %	0.8	1.6	2.6	2.6
Symmetry for Arc Y	± 2 %	1.8	2.6	0.8	1.6
Flatness for G 0◦	± 3 %	1.75	1.6	2.1	1.9
Symmetry for G 0◦ X	± 3 %	0.8	14	1.8	1.3
Symmetry for G 0◦ Y	± 3 %	0.6	2.6	1	2.5
Flatness for G 270◦	± 3 %	1.9	1.6	2	2
Symmetry for G 270◦ X	± 3 %	0.6	1.3	1.4	1.3
Symmetry for G 270◦ Y	± 3 %	0.7	2.7	0.5	2.7
Flatness for G 90◦	± 3 %	1.8	1.6	1.8	1.9
Symmetry for G 90◦ X	± 3 %	0.6	1.4	1.9	1.4
Symmetry for G 90◦ Y	± 3 %	1	2.6	0.6	2.5
Flatness for G 180◦	± 3 %	1.6	1.5	2.1	1.9
Symmetry for G 180◦ X	± 3 %	0.6	1.6	1.6	1.5
Symmetry for G 180◦ Y	± 3 %	0.7	2.6	0.8	2.7



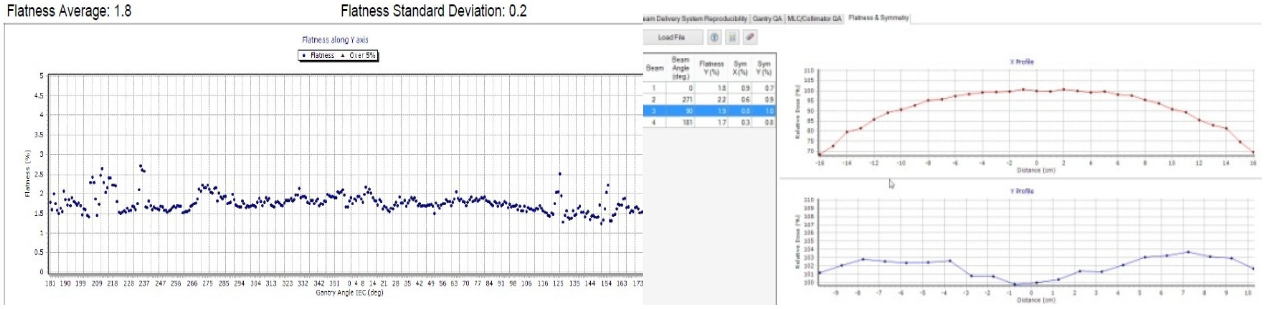
Histogram Statistics
Dose Difference Image:
Min : -0.130511 CU
Max : 0.225431 CU
Mean : -0.00116896 CU
SD : 0.027561 CU
RSD(%) : 2357.74
ROI Position (x/y):
168/ -24 Pixels
ROI Size (x/y):
688/ 816 Pixels
26.97/ 31.99 cm

Gamma (1.0 %, 1.0 mm)	Value	Tol.	Abs. Dose Difference	Value	Tol.
Area Gamma < 1.0	98.6 %	95.0 %	Max. Dose Difference	0.23 CU	1.00 CU
Maximum Gamma	4.95	15.00	Avg. Dose Difference	0.02 CU	0.50 CU
Average Gamma	0.31	5.00	Area Dose Diff > 0.50 CU	0.0 %	
Area Gamma > 0.8	2.8 %		Area Dose Diff > 0.80 CU	0.0 %	
Area Gamma > 1.2	0.6 %				

Passed ✓

ROI
○ None ○ User defined
● Field +
○ MLC CIAO + 5.00 cm
☐ Threshold

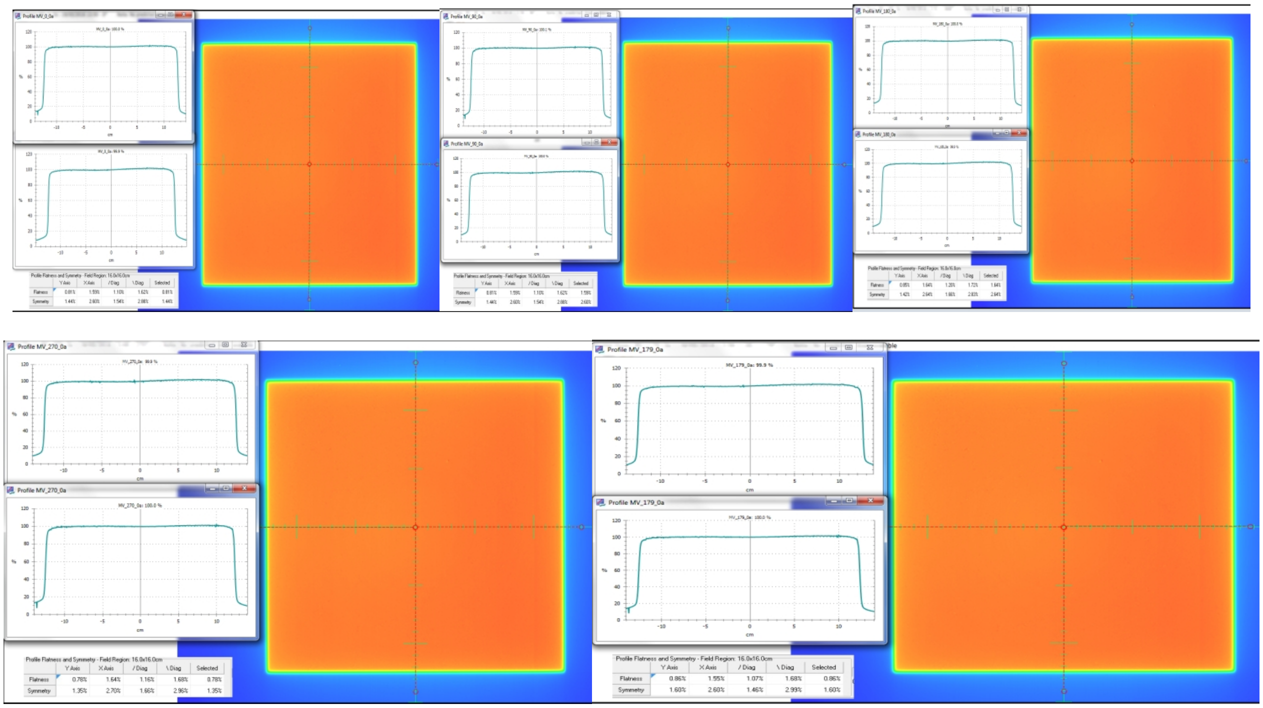
Figure 6: MLC QA Jaw QA using Portal Dosimetry.


Flatness Average: 1.8

Flatness Standard Deviation: 0.2

Beam	Beam Angle (deg.)	Flatness Y (%)	Sym X (%)	Sym Y (%)
1	0	1.8	0.9	0.7
2	271	2.2	0.6	0.9
3	90	1.9	0.8	1.0
4	181	1.7	0.3	0.8

Figure 7: Flatness and Symmetry for Arc and Static delivery.



Profile Flatness and Symmetry - Field Region: 16.0x16.0cm

	Y Axis	X Axis	/ Diag	\ Diag	Selected
Flatness	0.81%	1.59%	1.10%	1.62%	0.81%
Symmetry	1.44%	2.60%	1.54%	2.08%	1.44%

Profile Flatness and Symmetry - Field Region: 16.0x16.0cm

	Y Axis	X Axis	/ Diag	\ Diag	Selected
Flatness	0.81%	1.59%	1.10%	1.62%	1.59%
Symmetry	1.44%	2.60%	1.54%	2.88%	2.60%

Profile Flatness and Symmetry - Field Region: 16.0x16.0cm

	Y Axis	X Axis	/ Diag	\ Diag	Selected
Flatness	0.85%	1.64%	1.20%	1.72%	1.64%
Symmetry	1.42%	2.64%	1.66%	2.83%	2.64%

Profile Flatness and Symmetry - Field Region: 16.0x16.0cm

	Y Axis	X Axis	/ Diag	\ Diag	Selected
Flatness	0.78%	1.64%	1.16%	1.68%	0.78%
Symmetry	1.35%	2.70%	1.66%	2.96%	1.35%

Profile Flatness and Symmetry - Field Region: 16.0x16.0cm

	Y Axis	X Axis	/ Diag	\ Diag	Selected
Flatness	0.86%	1.55%	1.07%	1.68%	0.86%
Symmetry	1.60%	2.60%	1.46%	2.99%	1.60%

Figure 8: Flatness and Symmetry for Arc and Static delivery on Portal Dosimetry for different gantry angles.

4. Discussion

Volumetric modulated arc therapy (VMAT) is a novel form of radiotherapy treatment that allows the radiation dose to be delivered in one or two arcs.[5, 8] It offers precise target coverage with lower OAR doses and shorter delivery times compared with intensity-modulated radiotherapy (IMRT). VMAT is very complex than IMRT since there are many variables like gantry speed, dose rate and MLC .[4, 7] Hence QA programs developed for IMRT are not sufficient for VMAT and there is a need to develop more sophisticated QA programs for accurate delivery of VMAT.. .

In the case of VMAT treatments, this involves gantry angle-resolved dosimetric information.[4, 7] There are studies which indicate that the misalignment of the accelerator angular settings severely affect the dose distribution of an IMAT plan delivery and have serious clinical consequences due to the steep dose gradients and complex MLC shapes.[13] The basic method for gantry QA is holding a spirit level on a flat surface close to gantry head graticule and align it accordingly till the bubble settles down at the centre. The method used is applicable only for cardinal angles and the flatness of the surface remains unchecked. An alternative to this method is to perform a star shot on a film at different gantry angles .[13, 14] This method is not suitable for testing in arc mode, and introduces the difficulties of film measurements and processing.

Many methods have been proposed to verify the gantry angle based on cine EPID images of specially designed phantoms but few of them can be used during QA delivery to provide gantry-resolved plan information. A mechanical inclinometer could be used for this purpose and has the advantage of being independent from the linac vendor provided information. Rowshanfarzad *et al. (*2012) determined the gantry speed during arc delivery with constant gantry speed standard arcs using two different inclinometers for Delta and Matrixx dosimeters.[15] They found that the average difference with reference angle data were less than 0.3 deg for static mode which was 0.1 deg in our measurement and in the arc mode was less than 0.6 deg with independent inclinometers which was 0.3 deg in our study using ArcCHECK.

During IMRT delivery, there is an dosimetric impact of random and systematic changes in gantry angle and has been reported by few studies. Low *et al.*[16] presented a method that estimates dose errors caused by unintended collimator, gantry and couch setting errors due to angular misalignments in IMRT. However Xing *et al.*[17] noted that although angular setting misalignments play a smaller role than patient positioning errors, as they found that a 5° gantry error in only one of nine coplanar beams resulted in a 1.5% decrease in the minimum target dose or 5.1% in the maximum cord dose. In contrast, it has been shown that the impact of slightly displacing the gantry angle of beam apertures is minimal to IMAT deliveries.[18, 19] As discussed earlier, VMAT delivery system provides continuous variation of dose rate, gantry speed, and multileaf collimator (MLC) leaf position, the advantage of this tools is that it gives a comprehensive, all-in package for the Rapid Arc solution, addressing machine QA by providing the information about the gantry speed, gantry angle as well as the gantry isocenter during arc and static delivery. Rowshanfarzad *et al.* studied the stability of gantry, epid and mlc for arc treatments for the accelerator and found that an average gantry sag values was 0.7 mm in in-plane and 0.4 mm cross plane directions was observed which could be one of the reasons in case of our measurements where the arc isocenter was around 0.9 mm when compared with 0.4 mm of static treatments.[20] Due to the continuously changing field shape and gantry angle, VMAT plans generally show more dose segments at low dose rates than in IMRT or 3D-CRT to meet the speed limiting properties of the various accelerator components. The flatness and symmetry checks are already part of the standard machine QA at cardinal gantry angles. However, to ensure an accurate dose delivery in a dynamic mode of the linear accelerator, the field profiles in dynamic mode should be equal to the profiles in static mode. This test provides the information for flatness and symmetry for arc and static delivery. The flatness and symmetry for X correlated well with Machine QA and portal Dosimetry, but the symmetry for Y was found to be on a higher end on portal Dosimetry which could be due to the backscattered radiation of support arm from portal imager.

The multi-leaf collimators (MLCs) translate continuously at variable speeds during the irradiation while the upper and lower jaws stay static in case of dynamic IMRT.. LoSasso *et al.*[21], studied the transmission of MLC and found that the MLC transmission increases with increasing jaw field size and beam energy. Cadman *et al.*[22] found that the transmission through the jaw and the MLC together is smaller than 0.1%. Jaw tracking technique provided by linear accelerators keeps jaws during dose delivery as close as possible to the MLC aperture, and further minimizes leakage and transmission through the MLC leaves. The Dosimetric effects of jaw tracking was first studied by Joy *et al.*[23] for step-and-shoot IMRT, but failed to indicate which patients would benefit most from jaw tracking. The Dosimetric benefits of jaw tracking for prostate and head and neck (H&N) patients using d-IMRT and volumetric-modulated arc therapy (VMAT) were also evaluated by others.[24, 25] It showed that, the organs far from the target showed larger sparing in jaw-tracking static arc than the organs adjacent to the target. Recently

Varian Medical systems have come up with new digital accelerators True-Beam with jaw tracking technique (JTT), where the jaws are travelling with MLC to minimize the leakage and transmission of the MLC leaves, resulting in in reduction of OAR doses adjacent to the target, and dose fall off towards the surrounding critical structures. On this context this MLC Jaw QA tool is ideal to check the alignment for linear accelerators capable of jaw tracking.

5. Conclusion

With the introduction of complex technologies, more accurate methods are required to ensure correct delivery. Arc CHECK Machine QA is a useful tool for Quality assurance of Modern linear accelerators as it tests both geometric and delivery aspects. The static gantry QA showed identical results as WL QA. MLC-QA tool do indicate to be a good tool for QA of jaw tracking. This tool tests the accuracy of gantry rotation, speed, MLC-jaw alignment along with flatness and symmetry for Rapid Arc capable linear accelerators. This test can be incorporated in the regular quality assurance protocol for VMAT delivery.

Conflict of Interest

The authors declare that they have no conflicts of interest. The authors alone are responsible for the content and writing of the paper.

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