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Portal Dosimetry for Pre-treatment Verification of Imrt/Vmat Plan: A Comparison with 2D Array Detector for Quality Assurance

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Abstract

Purpose: The present study is to investigate the measured and calculated doses for different malignant tumours utilizing various gamma criteria and QA for confirmation of IMRT/VMAT with portal dosimetry and 2D array.

Methods: Different malignant tumors are treated by IMRT/VMAT techniques on Varian IX linear accelerator with 6 MV photon beams. Treatment planning system (TPS) is used to plan Patient's charts. Gamma Index (GI) variation is compared to the procedure of pre-treatment verification in IMRT/VMAT plans.

Results: The gamma criteria (DD/ DTA) of IMRT for (3%/3 mm), mean ± SD are $\gamma_{\leq 1\%}$=99.41% ± 0.67%, γ_{max}=2.11 ± 0.56 and γ_{avg}=0.23 ± 0.03 by EPID, and $\gamma_{\% \leq 1}$=98.55% ± 0.79%, γ_{max}=1.65 ± 0.45 and γ_{avg}=0.27 ± 0.04 by using 2D array. For VMAT mean ± SD are $\gamma_{\% \leq 1}$= 99.42% ± 0.67%, γ_{max}=2.11 ± 0.56 and γ_{avg}= 0.19 ± 0.05 using portal dosimetry, and $\gamma_{\% \leq 1}$=99.36% ± 0.53%, γ_{max}=1.65 ± 0.45 and γ_{avg}=0.22 ± 0.05 using 2D array.

Conclusions: Specific QA of IMRT/VMAT patient using (portal dosimetry or 2D array) to verify IMRT/VMAT fields. 3%/3 mm is the most appropriate of gamma criteria (DD/DTA) for IMRT/VMAT plans quality assurance. The control chart is an effective tool to detect uncontrolled variation.

Keywords: IMRT/VMAT; Portal dosimetry; 2D array; Gamma index; Control charts; QA

Introduction

Quality Assurance programs ensure quality of radiotherapy treatment intrinsically for patient safety and avoidance of accidental exposure. Consequently, patient safety is automatically integrated with the QA program [1]. IMRT is a new technology in radiation therapy that delivers radiation more precisely to the tumor while relatively sparing the surrounding normal tissues. It also introduces new concepts of inverse planning and computer-controlled radiation deposition and normal tissue avoidance in contrast to the conventional trial-and-error approach [2,3]. VMAT is a more advanced technique; the beam is delivered in two-ways of MLC movement including the dose rate and gantry speed variation for beam modulation as well. IMRT and VMAT have become standard treatment techniques replacing conventional radiotherapy technique for head and neck cancer in many cancer centers [4]. The most widely used form of pre-treatment QA for IMRT/VMAT generally consists of absolute dose measurements such as ionization chamber, diode, etc. combined with Isodose distribution measurements in a phantom [5-7]. IMRT/VMAT requires patient-specific quality assurance measurements, which can benefit from the convenience of using 2D array ion chamber and Electronic Portal Imaging Device (EPID) for dose verification [8]. The delivery of radiation beam to the tumour requires a quality assurance (QA) for every plan before treatment of patient using 2D array or portal dosimetry [9]. The 2D-array is a very reliable tool for the fast and precise verification of IMRT fields. The dosimetric verification of IMRT/VMAT fields is an important part of the routine quality assurance package for IMRT/VMAT treatments [10,11]. To compare 2D dose distribution, the concept of distance to agreement (DTA), is utilized at rotating gantry by special software. The software is used to evaluate the gamma index (GI), maximum and average deviation between a measured and calculated plan [12]. Due to its short acquisition time, less time consuming, easy to use and quick read out of the results, electronic portal imaging device using amorphous silicon replaces film dosimetry for comparison of 2D dose computation of Treatment Planning System (TPS) and measured doses [13,14]. Portal dosimetry is used to directly verify the measured dose distributions by comparing it was calculated from the TPS and portal dose prediction (PDP) of the algorithm achieved in TPS [15,16]. For assessment of the measured dose distributions in the systems of detector in comparison to the TPS calculated dose distribution, the gamma index (γ) evaluation could be applied [17], using Dose Different (DD) and distance to agreement (DTA). DD is a percentage of near-maximum dose (planned dose), the default value is 3%. DTA (mm), the default value is 3 mm. The tolerance of gamma evaluation: area Gamma <1.0=97%, Maximum Gamma=3.50, Average Gamma=0.50 [18].

The gamma method, as presented by D.A. Low [19], is a comparison of two dose distributions. The deviation between calculated and measured dose distribution for a given treatment plan could be determine by the gamma methods, as shown in Figure 1, the acceptance criteria is denoted by DD (ΔD_{Max}) and DTA. The DTA could be set as the distance that shows the same absorbed dose between the point of measured data and the nearest point in the distribution of calculated dose [20].

An ellipsoid surface is chosen to represent the acceptance criterion.

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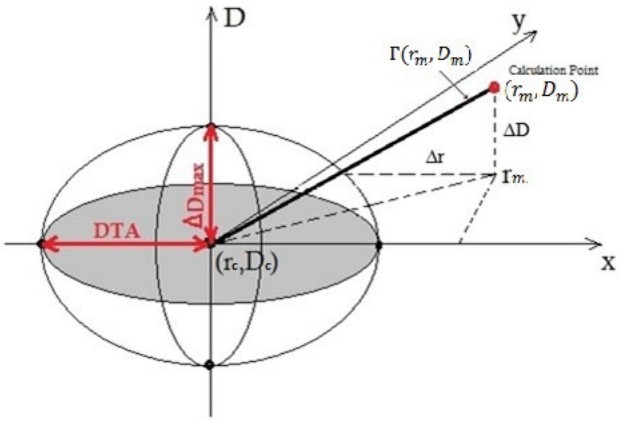

Figure 1: The principle of gamma verification: x, y, D positions and dose dimension; DTA (Distance To Agreement), ΔD_{max} (Max. dose deviation), Δr, ΔD local position and dose divergence of analyzed point.

The defining surface is given by the equation:

$$1 = \sqrt{\frac{(\Delta r)^2}{(DTA)^2} + \frac{(\Delta D)^2}{(\Delta D_{Max})^2}} \quad (1)$$

Where

$\Delta r = |r_c - r_m|$: The distance between the calculated (r_c) and measured (r_m) point.

$\Delta D = D_m(r_m) - D_c(r_c)$: The dose difference at r_m relative to calculated dose D_c in r_c.

The compared distribution to match the reference dose in r_r, requires containing at least one point (r_m, D_m), i.e. one point for both:

$$\gamma(r_m) = \min\{\Gamma(r_m, D_m)\} = \min\left\{\sqrt{\frac{|r_c - r_m|^2}{(DTA)^2} + \frac{|D_m(r_m) - D_c(r_c)|^2}{(\Delta D_{Max})^2}}\right\} \quad (2)$$

The accuracy of compatibility is determined by the point with the smallest deviation from the reference point, i.e. the point of Γ (r_m,D_m) is minimum. The minimum value is the quality index $\gamma(r_m)$ of the reference point.

The pass–fail criterion therefore becomes:

$\gamma(r_m) \le 1$ Calculation passed,

$\gamma(r_m) > 1$ Calculation failed.

This method is the dose distribution quality final estimation. The passing criteria values, as shown in the examples, are ΔD_{Max}=3%/DTA=3 mm based on our photon beams internal clinical standards. The utilization of statistical techniques to improve processes is called Statistical process control (SPC) that permits a process variability measurable analysis with a confirmation to find and prevent problems earlier. A main concept in Statistical process control is a control chart that could be applied to differentiate between common and special cause variations. There are various types of control charts present in SPC, e.g. (XmR chart) [21]. The control chart: (XmR chart) two kinds of charts; one of individual measured values (X chart) and one difference of moving range (mR chart). The moving range (mR_i) is used to determine the control and points that lie within the control limits [22, 23]. A typical mR chart makes use of two consecutive data points for the determination, the mean moving range, $\overline{mR}$ between sequential calculations of dose difference [24].

$$mR_i = |x_i - x_{i-1}|, \overline{mR} = \frac{\sum_{i=2}^{n} mR_i}{n-1} \quad (3)$$

The upper limit of control chart (UCL) for the mR chart is calculated by:

$$LCL = \bar{x} - 3\frac{\overline{mR}}{1.128} = \bar{x} - 2.66 \cdot \overline{mR} \quad (4)$$

Center line $\bar{x}$, is the mean difference between calculated and measured, n number of calculations.

The lower limit of control chart (LCL) for the X charts is calculated by:

$$LCL = \bar{x} - 3\frac{\overline{mR}}{1.128} = \bar{x} - 2.66 \cdot \overline{mR} \quad (5)$$

Methods and Materials

All measurements in this study are done in the linear accelerator (Varian Clinac IX; Varian Medical Systems, Palo Alto, CA). The PDP software is commissioned for portal dosimetry in TPS Eclipse (version11, Varian, Palo Alto, CA, United States), (At Hospital of Ain Shams University, Cairo).

Portal dosimetry

Portal Vision aSi1000 imager panel of Varian Clinac is used, with a pixel dimension and spatial resolution of 1024 × 768 and 0.392 mm per pixel, respectively. EPID is a useful tool in the QA process with good evaluation abilities, the Portal Vision Exact-Arm (Medical Systems of Varian). The linear accelerator includes an aS1000 Portal Vision imager and comprises of a 8 mm thickness main plate, a thin copper slice (1 mm), a 0.5 mm phosphor film. The evaluation of EPID can provide several evaluation parameters, such as the average value of the gamma index, the maximum value of the gamma index and the largest sized connecting area with a gamma index >1. The calibration of EPID is done, where radiation beam is linked to calibration units (CU). The calibration is executed with 100 Monitor Unit (MU) and open field of 10 × 10 cm^2. The EPID response is graded to the extent that 1 CU is matched to 1 MU delivered.

2D array detector (OCTAVIUS Detector 1500)

The OCTAVIUS Detector 1500 (OD1500) is the same as for the OCTAVIUS Detector 729 (OD729). The OD1500 is a detector matrix for verification and quality control (QC) of IMRT by using VeriSoft software. The plane-parallel detectors are 4.4 mm × 4.4 mm × 3 mm in size, with spacing (center-to-center) of 7.1 mm. The total numbers of ion chambers are 1405 arranged in a chessboard matrix, giving a field size with an ultimate dimension of 27 × 27 cm^2. The Verisoft software enables physicists to compare radiation dose distributions in IMRT verification plan with those calculated by TPS. The software subtracts matrices of measured and calculated points of an IMRT beam and visualizes the results. Software executes the method of gamma evaluation and defines variation between a calculated and measured plan as well. In our study, this measured dose is compared with dose calculated by TPS and imported into VeriSoft.

Gamma analysis

The proportion of point dose within a passing gamma criteria field, is known as gamma index (GI), is calculated for every patient.

The QA plans for absolute point dose measurements are created for the planar dose distributions computed by TPS. For each plan, comparison of predicted and measured dose of 3%/3 mm gamma criteria (DD & DTA). The criteria validation accepted as section with $\gamma \leq 1$ to be 97%. Then for each field, three gamma scaling parameters, are estimated (to calculate the mean and standard deviation); maximum γ (γ_{max}), average γ (γ_{avg}) and area gamma ($\gamma_{\% \leq 1}$).

All measurements are performed on portal dosimetry and IX accelerator Varian with nominal 6 and 18 MV photon beams. In the present study, we applied a 300 MU min^{-1} fixed pulse rate that is used in clinical practice. Quality assurance (QA) is done for photon energies (6 and 18 MV) linear accelerator Varian Clinac IX (Varian Medical Systems, Palo Alto, CA). The quality assurance program involves the following basic checking for mechanical and radiation system: Daily QA, Monthly QA and Annual QA. The IMRT plans ten head and neck (H&N), one cervical spine, and fourteen pelvises are selected, The verification of the planned dose distribution for another 19 VMAT plan (31 Fields) using both the portal dosimetry and 2D array detector resulted in comparable values of gamma criteria (3%/3 mm) for each plan and all fields. In treatment plans of our study, we applied low photon energy 6 MV, dose calculation is done at a grid size of $2.5 \times 2.5 \times 2.5$ cm^3 via Algorithm of Anisotropic Analysis (AAA). The verification plan of portal dose, for each IMRT/VMAT plan, is applied at (source-to-detector distance SDD=100 cm) for portal dosimetry position, where the distribution of photon beam dose is calculated for every field with no patient. The acquired images by integrated mode are modified to determine the distribution of photon beam dose in CU at the position of portal dosimetry. The mean and standard deviation for all the gamma parameters are calculated and compared. The TPS verification predicted and delivered dose distribution from the same IMRT/VMAT plans are done for each field using a separate method comprising of EPID analyzing software. The gamma index analysis is utilized to compare calculated dose distribution to measured dose distribution, with passable criteria of 3%/3 mm are used for the evaluation. I-mR charts are in control according to the control tests that can determine control and points with control limits.

Results and Discussion

Quality assurance for (Varian Clinac IX) linear accelerator

Mechanical test summarized in Table 1, this test measured by the idealized intersection of collimator, gantry and couch rotation axes. Light field system, collimator, and gantry readout calibration. Measured and tolerance values for each parameter are shown. The measured values were found to be within values provided by the acceptance test of machine and in a good agreement within the tolerance values of the published data of comparable Linac [25]. Radiation test summarized in Table 2, determines the reproducibility, Build-up Depth, Photon Beam Flatness and Photon Beam Symmetry were checked. The measured values were found to be within values provided by the acceptance test of Varian Clinac IX Linac machine and in a good agreement within the tolerance values of the published data of comparable Linac [25].

No.	Check	Item	Part	Tolerance	Measured	Remarks
1	Mechanical isocenter	1	Collimator isocenter	1mm radius	0.9 mm	From 90° to 270°
		2	Couch isocenter	1mm radius	0.9 mm	From 90° to 270°
		3	Gantry isocenter	1mm radius	1 mm	Through 360°
2	Collimator and Gantry readout	1	Collimator readout	± 0.5°	0.2°	0
				± 0.5°	0.3°	90
				± 0.5°	0.2°	270
		2	Gantry readout	± 0.5°	0.4°	0
				± 0.5°	0.2°	90
				± 0.5°	0.3°	180
				± 0.5°	0.4°	270
3	Light field system	1	Light field & Cross hairs	± 2 mm	4.1 x 4 cm^2	4 x 4 cm^2 0°, 90°
					9.99 x 10 cm^2	10x10 cm^2 0°, 90°,180°, 270°
					30.1 x 30 cm^2	30 x 30 cm^2 0°, 90°
		2	Symmetric jaw readout	± 1 mm	1 mm	5 x 5 cm^2, 100 cm

Table 1: Mechanical checks for Varian Clinac IX Linac.

No.	Check	Item	Part	Tolerance	Measured	Remarks
1	Radiation Isocenter	1	Collimator Isocenter	1 mm	1 mm	G=0°, C=0°, 25 MU at 0°, 90°, 265°, and 355°
		2	Gantry Isocenter	2 mm	1.3 mm	3 x3 cm^2 0°,90°
					1.2 mm	15x15 cm^2 0°,90°
					1.5 mm	30x30 cm^2 0°,90°
2	Light versus radiation field congruence	1	Light fields and crosshairs	± 2 mm	1.1 mm	3 x3 cm^2 0°,90°
					1.6 mm	15x15 cm^2 0°,90°
					1.2 mm	30x30 cm^2 0°,90°
3	Photon energy & depth of ionization	1	Buildup depth	1.5 ± 0.2 cm	1.5	depth ionization curve or add 1mm sheets
		2	Ionization percentage	± 66.5 %	66.30 %	10x10 cm^2 at depth 10 cm
4	Photon Flatness	1	Radial (X) Axis	± 3%	2.8%	10x10 cm^2 , 100 cm, depth 10 cm
		2	Transversal (Y) Axis	± 3%	2.9%	10x10 cm^2 , 100 cm, depth 10 cm
5	Photon Symmetry	1	Radial (X) Axis	± 2%	2%	10x10 cm^2 , 100 cm, depth 10 cm
		2	Transversal (Y) Axis	± 2%	2%	10x10 cm^2 , 100 cm, depth 10 cm

Table 2: Radiation checks for Varian Clinac IX Linac.

DD, DTA 3%, 3 mm	Gamma Criteria	No. of field	Range Statistic	Minimum Statistic	Maximum Statistic	Mean Statistic	Std. Dev. (SD) Statistic	Variance Statistic
Portal Dosimetry	$\gamma_{\%\leq 1}$	177	2.10	97.90	100.00	99.41	0.67	0.67
	γ_{max}	177	2.14	1.21	3.35	2.11	0.56	0.56
	γ_{avg}	177	0.14	0.15	0.29	0.23	0.03	0.00
2D array Detector	$\gamma_{\%\leq 1}$	177	2.50	97.37	99.87	98.55	0.79	0.62
	γ_{max}	177	1.79	1.16	2.95	1.65	0.45	0.21
	γ_{avg}	177	0.15	0.19	0.34	0.27	0.04	0.00

Table 3: Descriptive Statistics of gamma criteria (3%, 3 mm) for each IMRT plan and all fields evaluated by portal dosimetry and 2D array detector.

Control limits	2D array detector			Portal Dosimetry (EPID)		
	$\gamma_{\%\leq 1}$	γ_{max}	γ_{avg}	$\gamma_{\%\leq 1}$	γ_{max}	γ_{avg}
Upper control	100.971	2.655	0.3987	100.757	3.418	0.3384
Lower control	96.121	0.653	0.1461	98.075	0.796	0.1168
Mean value ($\bar{x}$)	98.546	1.654	0.2724	99.416	2.107	0.2276
Moving range ($\overline{mR}$)	0.912	0.376	0.0475	0.504	0.493	0.0417

Table 4: The Statistic of gamma criteria (3%, 3 mm) for IMRT plans, evaluated by portal dosimetry and 2D array using control chart limits and moving range.

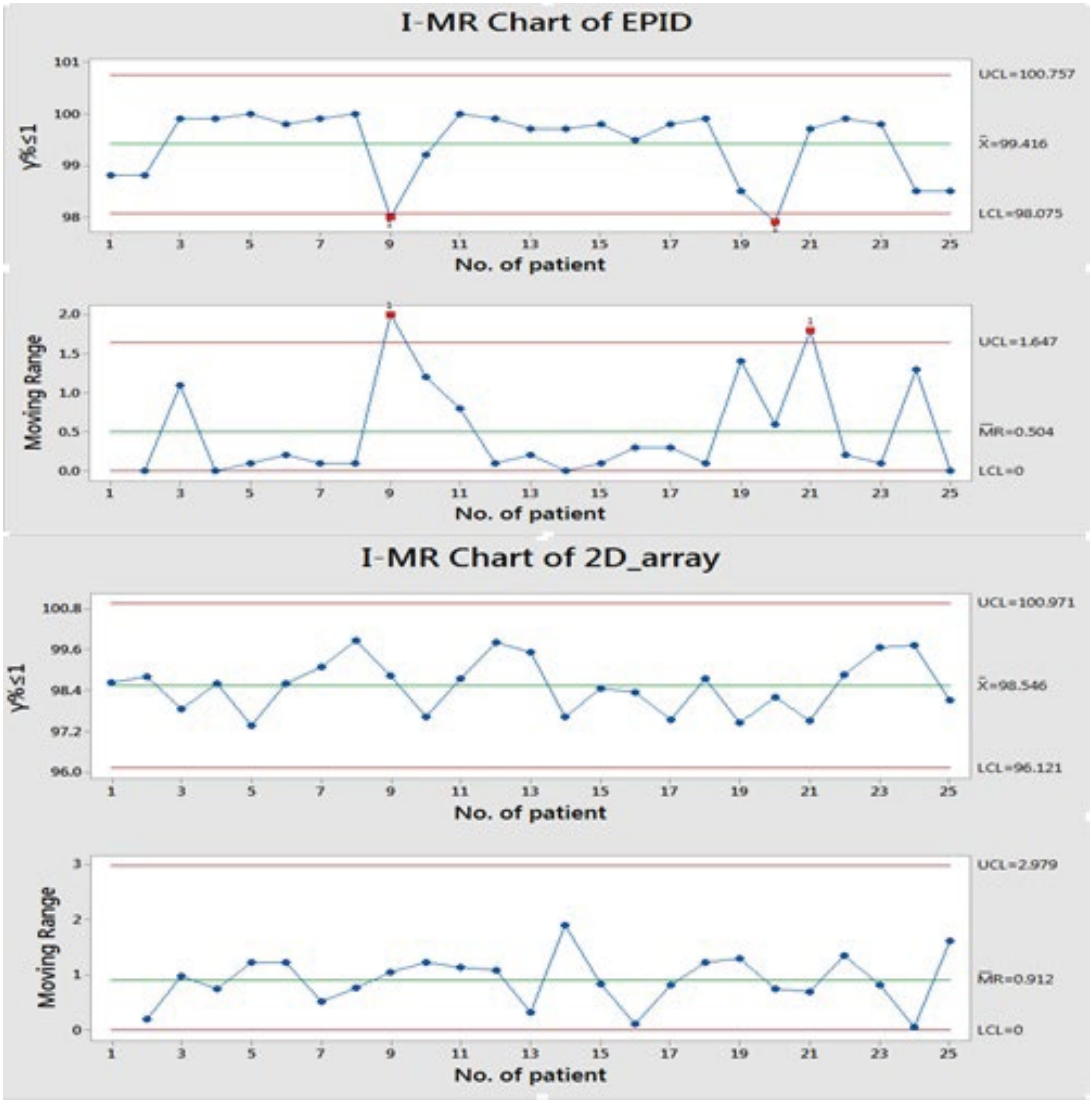

Figure 2: The control chart mean and moving range (mR) of variation Average Gamma ($\gamma_{\%\leq 1}$) of 2D array and EPID for various patients.

Dose measurements using gamma criteria for IMRT

For 25 patients IMRT plan (177 fields), was compared to decide the criteria that should be used: 3%/3 mm DD/DTA. This criteria was chosen to obtain and observe as much information as possible. Then DD between the measured dose of Linac. (Varian) and calculated dose in TPS was assessed. The mean and standard deviation (SD) of $\gamma_{\%\leq 1}$, γ_{max} and γ_{avg} estimated from all fields of each IMRT plan, using EPID and 2D array ion chamber are depicted in Table 3. PDP predicted and EPID measured photon dose distribution agrees with mean ± SD value for $\gamma_{\%\leq 1}$=99.41 ± 0.67%, γ_{max}=2.11 ± 0.56%, and γ_{avg} =0.23 ± 0.03%, respectively. Independent verification of the planned dose from the same IMRT fields using 2D array ion chamber also resulted in comparable values of $\gamma_{\%\leq 1}$= 98.55% ± 0.79%, γ_{max}=1.65 ± 0.45% and γ_{avg} = 0.27 ± 0.04%. The gamma criteria (3%, 3 mm) for all fields were more controlled and used as default for pre-treatment verification.

Sharma et al. [6] reported the results were very good agreement between calculated and measured dose distribution in all plans with overall mean ± SD gamma values: $\gamma_{\%\leq 1}$=99.43% ± 0.68%, γ_{max}=2.02 ± 0.66 and γ_{avg}=0.24 ± 0.04 respectively. McDermott et al. in their study of 20 prostate plans (five fields /plan) using in-house developed EPID dosimetry software reported overall mean $\gamma_{\%\leq 1}$=98.7%, γ_{max}=2.52 and γ_{avg}=0.39. However, all parameters are well within the clinically acceptable values. The control chart analysis was performed on the average plan of 25 patient using gamma criteria 3%/3 mm, 2D array and EPID. The calculated control chart limits of three gamma values, $\gamma_{\%\leq 1}$, γ_{max} and γ_{avg} as shown in Table 4, and Figure 2. The goal of quality assurance (QA) is to minimize systematic errors in order to maintain the quality of a certain process. Statistical process control (SPC) had been utilized for QA in radiation therapy.

Dose measurements using gamma criteria for VMAT

The verification of the planned dose distribution for another 19 VMAT plan (31 Fields) using both the portal dosimetry and 2D array detector resulted in comparable values of gamma criteria (3%/3 mm) for each plan and all fields as displayed in Table 5, mean ± SD values are $\gamma_{\%\leq 1}$=99.42% ± 0.67%, γ_{max}=2.11 ± 0.56 and γ_{avg}=0.19 ± 0.05 using portal dosimetry, and $\gamma_{\%\leq 1}$=99.36% ± 0.53%, γ_{max}=1.65 ± 0.45 and γ_{avg} =0.22 ± 0.05 using 2D array detector. Figure 3 show that gamma index (3%/3 mm) based on passing rates for verification of various tumour at comparison between portal dosimetry and 2D array. The control chart analysis was carried out on the 31 fields using gamma criteria 3%/3mm for each plan, portal dosimetry and 2D array as shown in Table 6 and Figure 4, therefore the portal dosimetry is more controlled in pre-treatment verification of quality assurance.

DD, DTA	Gamma Criteria	No of field	Range	Minimum	Maximum	Mean	Std. Deviation	Variance
			Statistic	Statistic	Statistic	Statistic	Statistic	Statistic
	$\gamma_{\%\leq 1}$	25	2.1	97.9	100	99.42	0.67	0.45
3%, 3 mm Portal Dosimetry	γ_{max}	25	2.14	1.21	3.35	2.11	0.56	0.31
	γ_{avg}	25	0.17	0.13	0.3	0.19	0.05	0
2D array Detector	$\gamma_{\%\leq 1}$	25	1.75	98.12	99.87	99.36	0.53	0.28
	γ_{max}	25	1.79	1.16	2.95	1.65	0.45	0.2
	γ_{avg}	25	0.18	0.14	0.32	0.22	0.05	0

Table 5: The Statistics of gamma criteria (3% /3 mm) for each plan and all fields estimated using portal dosimetry and 2D array detector.

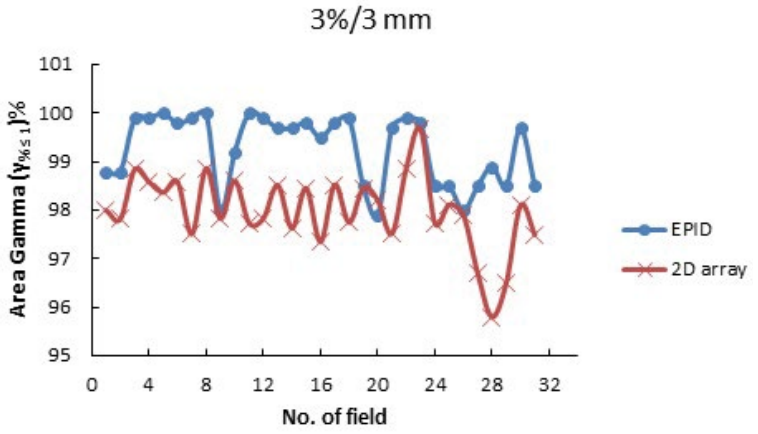

Figure 3: The gamma index (3%/3 mm)-based passing rates for various tumour at comparison between EPID and 2D array.

Control limits	2D array detector			Portal Dosimetry (EPID)		
	$\gamma_{\%\leq 1}$	γ_{max}	γ_{avg}	$\gamma_{\%\leq 1}$	γ_{max}	γ_{avg}
Upper control	100.120	2.769	0.3398	100.719	3.559	0.3081
Lower control	95.876	0.750	0.0951	97.829	0.820	0.0900
Mean value ($\bar{x}$)	97.998	1.759	0.2174	99.274	2.190	0.1990
Moving range ($\overline{mR}$)	0.0.798	0.380	0.046	0.543	0.515	0.041

Table 6: The Statistics of gamma criteria (3%/3 mm) for VMAT plans, evaluated by portal dosimetry and 2D array using control chart limits and moving range.

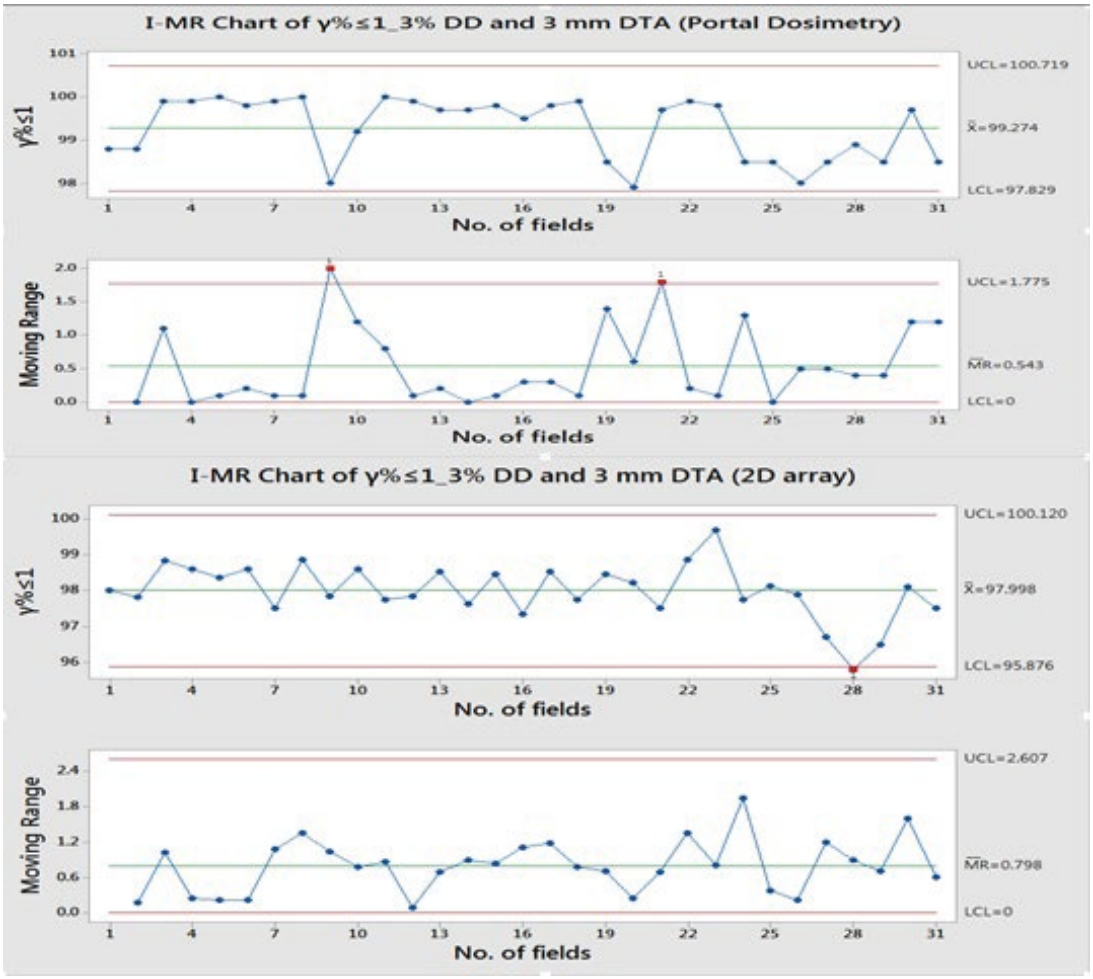

Figure 4: The control chart mean and moving range (mR) of variation area gamma ($\gamma_{\%\leq 1}$) of 2D array detector and portal dosimetry (PD) for various tumours.

Conclusion

In this Research article, the use of statistical process control to compare treatment plans in radiotherapy for the same patient is illustrated. The relationship between descriptive statistics of gamma criteria 3%/3 mm and control charts for IMRT/VMAT plans gives the same results (using portal dosimetry or 2D array) of mean and standard deviation. The control chart is an effective tool to detect uncontrolled variation. If the chart indicates that the process is under control, then it can be safely used. However, if the chart indicates that the process is not under control, the pattern will assist the medical physicist to determine the source of variation, then eliminate it and bring the result back into control simultaneously. The control charts were found to be a beneficial method for verification assessment for patient-specific QC. The portal dosimetry was found to be more accurate compared to 2D array detector.

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