Original Article

Physical dosimetry of volumetric modulated arc therapy (VMAT) using EPID and 2D array for quality assurance

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ABSTRACT

Outline: To address the correspondence of measured and predicted doses for different malignant tumours utilizing various gamma criteria and QA for confirmation of VMAT with an EPID and 2D array detector.
Methods: 24 patients with different malignant tumors were treated by VMAT techniques on Varian IX linear accelerator with 6 MV photon beams. Eclipse treatment planning system (TPS) is used to plan Patient's charts. Gamma Index (GI) variation was compared to the procedure of pre-treatment verification in VMAT plans.
Results: The gamma criteria (DD/DTA) of dose difference and distance to agreement for (3%/3 mm), mean ± SD are $\gamma_{\le 1\%} = 99.42\% \pm 0.67\%$, $\gamma_{max} = 2.11 \pm 0.56$ and $\gamma_{avg} = 0.19 \pm 0.05$ by EPID, and $\gamma_{\% \le 1} = 99.36\% \pm 0.53\%$, $\gamma_{max} = 1.65 \pm 0.45$ and $\gamma_{avg} = 0.22 \pm 0.05$ by using 2D array detector.
Conclusions: Specific QA of VMAT patient (using EPID or 2D array) display great possibility to spare time and to verify individual IMRT fields. 3%/3 mm is the most appropriate of gamma criteria (DD/DTA) for VMAT plans quality assurance. Control charts are a beneficial method for verification assessment for patient specific quality control.

1. Introduction

In VMAT which is an advanced technique for intensity modulated radiation therapy (IMRT) [1], treatment gantry rotates around the patient with dynamic changes of radiation beam shape and intensity by multi-leaf collimators (MLCs) and change in gantry speed and dose rate [2,3]. VMAT focuses the radiation on the tumour while protecting healthy tissues. The beams varying intensities are aimed at a tumour and then rotated 360 degrees around the patient. VMAT Treatment involves three basic steps: diagnosis, treatment planning, and delivery. As part of the diagnosis, the medical team generates three-dimensional diagnostic images (usually CT) of the patient's anatomy and then uses these images to specify the dose of radiation needed to treat the tumour [4–6]. This complex delivery of radiation beam to planning target volume (PTV) necessitates a quality assurance (QA) for every arc before treatment of patient by using 2D array or Electronic Portal Imaging Device (EPID) [7]. The 2D array of a huge number of ion chambers has been used for pre-treatment verification of VMAT plans. To compare 2D dose distribution, the notion of distance to agreement (DTA), was 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 predicted plan [8]. 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 substitute's film dosimetry for comparison of 2D dose computation of Treatment Planning System (TPS) and measured doses [9,10]. Portal Dosimetry (PD) has advanced analysis tools for matching the obtained dose image to predicted dose distribution calculated by TPS. Portal dosimetry can merge images to create composite EPID images for analysis [11].

Where the gantry and dose and MLC were varying, the portal dosimetry of different clinical sites from VMAT plans was done. EPID dosimetry is used to directly verify the measured dose distributions by comparing to the reference dose that is calculated from the TPS and portal dose prediction (PDP) of the algorithm achieved in TPS. This verification procedure requires a mathematical comparison using concepts such as dose-difference (DD) and DTA. Therefore, Quality

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assurance (QA) for VMAT has ultimately developed, where results of PD could be compared with separate verification method, using 2D array detector and VMAT analysing software. 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 [12,13], using three parameters namely; *DD, DTA, and Threshold. DD is* a % of near-maximum dose (normally the planned dose), the default value is 3%. Regarding *DTA) (mm),* the default value is 3 mm. *The* threshold value is a fraction of near-maximal dose for each matrix. All values below this threshold value are ignored in the calculation. The tolerance of gamma evaluation: area Gamma $< 1.0 = 97\%$, Maximum Gamma = 3.50, Average Gamma = 0.50 [14].

The GI results of every plan were calculated for the passing criteria, and evaluated 3% DD, 3 mm DTA criteria for passing result by using EPID and 2D array detector, figured out the mean and standard Deviations (Std. Dev.) for every plan [15]. The gamma index (GI) and approval criteria rely on various factors such as the tool of dosimetry, prediction and measurement grid, and the software used for analysis of data. Thus, it is difficult to give overall recommendations for use in different conditions. So, this research aims to identify the compatible of VMAT calculated dose for tumours in TPS with measured dose in Linac. (At Hospital of Ain Shams University, Cairo). These measurements showed that the EPID could determine absolute radiation dose and thus can be used for regular QA checks such as symmetry, flatness, field width, and linear accelerator beam penumbra.

The gamma methods as presented by Low [16], is a comparison of two dose distribution. The deviation between calculated and measured dose distribution for a given treatment plan could be determine by the gamma methods, as shown in Fig. 1, the acceptance criteria are 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 [17–19]. Gamma index is one of the metrics which have been widely used for clinical routine patient specific quality assurance for IMRT, and VMAT. The algorithms for calculating the Gamma index using two software tools: PTW- VeriSoft® as a part of OCTIVIUS dosimeter systems and 3D TPS were assessed. GI and acceptance criteria depend on many factors including the dosimetric equipment, calculation and measurement grid, and the data analysis software.

An ellipsoid surface is chosen to represent the acceptance criterion. The defining surface is given by the equation:

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

(1)

where

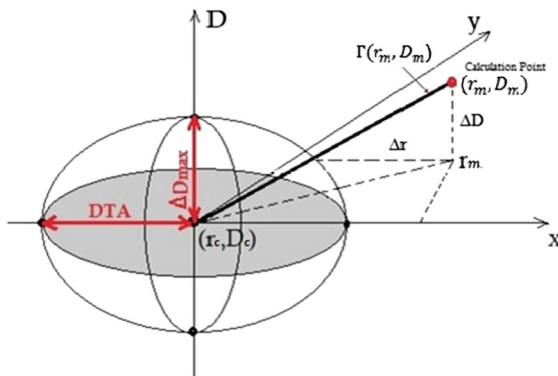$\Delta r = |r_c - r_m|$: The distance between the calculated (r_c) and measured

Fig. 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.

Table 1
Showing data of 1%, 1 mm, 2%, 2 mm 3%, 3 mm and 5%, 5 mm passing criteria of maximum dose of the dose distribution using EPID for 40 fields of various tumours.

No. of field	5% DD and 5 mm DTA	3% DD and 3 mm DTA	2% DD and 2 mm DTA	1% DD and 1 mm DTA
1	100	99.8	99.2	80.8
2	100	99.7	98.7	80.7
3	100	99.7	98.9	87.5
4	100	99.4	97.6	75.8
5	100	99.2	94.5	84.3
6	99.8	97.7	79.1	65.3
7	99.7	97.8	79.1	66
8	100	99.8	98.6	84.9
9	100	99.5	98.3	78.8
10	99.8	98.8	94.2	58.1
11	99.7	98.8	93.8	61.4
12	100	99.9	99.4	86.2
13	100	99.9	99.7	90.2
14	100	100	99.4	88.3
15	100	99.8	98.8	82.2
16	100	99.9	99.2	83.2
17	100	100	99.8	90.4
18	99.7	98	82.8	65.1
19	99.9	99.2	96.6	72.2
20	100	100	99.1	88.2
21	100	99.9	99.7	91.1
22	100	99.7	98.6	83.3
23	100	99.7	99.1	84.1
24	100	99.8	99	85.4
25	100	99.5	91.9	73.9
26	100	99.8	98.6	70.9
27	100	99.9	99.3	76.5
28	99.9	98.5	94	78.7
29	99.8	97.9	84.3	71.7
30	99.9	99.7	96.5	81.3
31	100	99.9	98.7	80.3
32	100	99.8	99.1	84.3
33	100	98.5	94.7	77.5
34	99.9	98.5	95.9	76.1
35	99.9	98	92.7	74.3
36	99.9	98.5	94.6	73.3
37	99.8	98.9	86.2	68.8
38	99.7	98.5	75.5	60.1
39	100	99.7	97.7	77.6
40	99.7	98.5	86.3	63.2

(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, it requires to contain at least one point (r_m, D_m), i.e. one point for which:

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

(2)

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

The pass–fail criterion therefore becomes:

$\gamma(r_m) \leqslant 1$, calculation passed,
$\gamma(r_m) > 1$, calculation failed.

This method is the dose distribution quality final estimation. The criteria is passing as shown for the examples are $\Delta D_{Max} = 3\%/$ 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