The Correlation of Total MU Number and Percentage Dosimetric Error in Step and Shoot IMRT with Gamma Passing Rate Using OCTAVIUS 4D-1500 Detector Phantom

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Abstract

Background: Step and shoot (SS) IMRT treatment technique is one of the modern planning techniques used in radiotherapy. It conforms to the dose to the possible minimum as to the OARs. Dosimetric error calculations used to estimate the sensitivity of reading and the dose difference between TPS and phantom detector. Monitor units (MUs) are measured by monitor chambers, which are ionization chambers that measure the dose delivered by a beam and are built into the treatment head of radiotherapy linear accelerators. Material and Method: Thirty cases of two regions (25 HN and 5 pelvic cases) performed with SS IMRT using MONACO5.1 Treatment Planning System (TPS). Then the QA tested using OCTAVIUS 4D-1500 phantom in Baghdad Center for Radiotherapy and Nuclear Medicine, Baghdad, Iraq. Gamma index and %GP calculated index by comparing the actual QA (using Octavius) with virtual QA (using MONACO TPS). Dosimetric error percentage with local %GP and the total Monitor Unit (MU) correlation with global and local %GP were measured. Results: The %GP was ≥95%, where 20% for local %GP for all cases and 73.3 % for global passing rate. A significant correlation found between the %DEs resulted in the %GP for both local and global. There was a correlation between the total MUs for global %GP. For a local %GP, it was statistically not correlated with MUs. Conclusion: There is a correlation found between dosimetric error percentage (%DE) and %GP for both local and global. There is a correlation between the total Monitor Unit (MU) and global %GP but not with local.

Keywords: IMRT, Dosimetric Error, Monitor Unit, Octavious-4D, Gamma Passing Rate


1. Introduction:

Most treatments in conventional radiotherapy (CRT) or 3D-CRT technique are delivered with external radiation beams, these treatments are of uniform intensity (fluence) across the field size. The treatments in the IMRT technique are also delivered with external radiation beams but of non-uniform intensity (fluence) across the field, in which this non-uniform intensity is delivered to the patient from any given treatment beam position to optimize the composite dose distribution. IMRT provides an extra freedom degree (i.e. intensity modulation). That is the primary difference between IMRT treatment and 3D-CRT so the IMRT technique is a suitable choice which external beam RT for some cases. Step and shoot (SS) IMRT technique also called "stop and shoot" or "segmental", is an MLC-based IMRT delivery method with fixed beams [1-3].

The output of the linac machine measured by a unit called monitor unit (MU). A monitor unit (MU) is a measure of machine output for radiation therapy such as a linear accelerator or an orthovoltage unit. [4]

One of the newest quality assurance (QA) devices is the Octavius-4D detector phantom which is a 2D array consists of a matrix of 1500 vented ionization chambers distant 10 mm from the center to center, embedded in a 25 x 25 cm² field size array and warmed up by 200 MU. The phantom array dimensions are 32 cm diameter and 34.3 cm length, with 29 kg weights and has wireless inclinometer in which rotates with the LINAC’s gantry so that the panel of ionization chambers array remains perpendicular to the radiation beam at all times during the radiation delivery: [2]; [3][5].The inclinometer that sets on the gantry connected to a control unit and transfers the information about the movement to the Octavius phantom and every 200 ms the acquires dosimetric data recorded. Data are processed by the software package PTW VeriSoft (Version 7.1) that contains a 3D grid of dosimetric data. One of its benefits is that it can evaluate the with different metrics, by local and global γ-index which is the standard technique used to evaluate the agreement between planned and measured dose with 3D for the whole volume (volumetric) use distance to agreement (DTA) and dose difference (DD) criteria [6].

Planar dose distributions acquired during pretreatment verifications, RT Plan and RT Dose (DICOM file containing all the information about the dose distribution) exported from TPS, were loaded on the software of phantom. To calculate dosimetric error percentage (%DE) the following equation used:

\[
\%DE = \frac{|D_{\text{measured}} - D_{\text{calculated}}|}{D_{\text{calculated}}} \times 100 \quad \ldots \ldots \ldots \ldots \ldots (1)
\]

Where \(D_{\text{measured}}\) is the dose value resulted from phantom software and \(D_{\text{calculated}}\) is the value of dose showed in TPS [7].

Aim of this study: This study aimed to investigate the sensitivity of OCTAVIUS 4D phantom for the measurements of a dose delivered to the patient and to find the relationship between the MU with %GP with IMRT technique.

2. Materials and Methods:

The study was done in Baghdad Center for Radiotherapy and Nuclear Medicine and approved by the Institutional Review Board (I.R.B.) of Al-Nahrain University/ Medical College, Baghdad, Iraq. Thirty patients included in this study and diagnosed by specialized oncologists and radiologists, 25 of them were
head & Neck and 5 with pelvis tumor and. They underwent CT simulation and their data imported to TPS Monaco to be planned with step and shoot IMRT technique and treated by synergy Elektalinac with 6 MV energy applied for all fields. Data are processed by package PTW VeriSoft (Version 7.1) and the software contains a three-dimensional grid of dosimetric data. Then their data transported to the quality assurance device Octavius-4D detector phantom which is a 2D array with an of 1500 matrix inside ionization chambers distant 10 mm from the center to center, embedded in an array with a 25 x 25 cm² field size and when it works it warmed up by 200 MU. The array is inserted into a motorized cylindrical polystyrene phantom with 32 diameters and 34.3 cm length. The phantom rotate synchronously with the gantry as a real planning treatment goes on. The inclinometer that sets on the gantry connected to a control unit and the acquired data about the movement transfers the Octavius phantom every 200 ms. The radiation beam hits the detector array perpendicularly and no correction factors needed for output data. It can evaluated different metrics of dose with both global and local and gamma index in 2D, 3D for the coronal, sagittal, and axial axes three axes and volumetric analysis for the whole volume. The gamma analysis was evaluated the acceptance criterion of 3%/3 mm. The local and global gamma analysis included in this study with a threshold of about 5% concerning the maximum dose.

3. Statistical Analysis

Analysis of data was carried out by using the available statistical package of Statistical Packages for Social Sciences- version 24 (SPSS-24). Data were presented in simple measures of percentage, mean and standard deviation. Spearman rho test for correlation calculator. Scattering distribution curve used for correlation. Statistical significance was considered whenever the p-value was equal or less than 0.05

4. Results:

When an IMRT technique was introduced, the need for QA calculation became challenging and more dependent as an integral part of patient treatment planning. IMRT technique is very complicated; especially in Iraq. This research was done for verifying the IMRT plan which is being carried out by LINAC machine using OCTAVIUS 4D for the first time in Iraq.

This study included common parameters used to improve the quality of the patient’s treatment such as the correlation of %GP with dosimetric error percentage (%DE), and the total number of MU.

4.1 The correlation and sensitivity of Local and Global Gamma Passing Rate.

The %GP considered as a common metric for comparing measured to the calculated dose of treatment plans its passing rate use as an indication for how the percentage of measured points of the plan that match the calculated points of plan in phantom within certain criteria. It depends on many criteria; mainly the ΔD, the DTA; and the dose threshold of the plan is also taken into consideration. It increases with more permissive of ΔD/DTA criteria. Simply it's the percentage of dose distribution points data of gamma index that passes or failed the criteria. In this study, we only include the passing rate and test the correlation with dosimetric error, the total number of MUs. The results of %GP pass the score ≥95% where 20% for local %GP for all cases and 73.3 % for global passing rate. Statistically, it's found that their results are significant at p-value< 0.011115, which means that the QA of OCTAVIUS 4D-1500 detector phantom is quite good at these percentages.
4.2 Dosimetric Error

To investigate the validity of linac the %GP of IMRT dosimetric verification and their correlation and sensitivity with dosimetric error percentage (%DE); between isocentric dose distribution calculated from TPS and was measured by VeriSoft software of OCTAVIUS 4D-1500 detector phantom. All over the cases involved. The results show that there is a significant correlation between the %DEs resulted in that affect the %GP for both local and global as shown in table (1).

<table>
<thead>
<tr>
<th>%DE (%)</th>
<th>Local</th>
<th>%DE (%)</th>
<th>Global</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mean ± SD</td>
<td>3.674 ± 1.7561</td>
<td>89.4167 ± 7.7198</td>
<td>3.674 ± 1.7561</td>
</tr>
<tr>
<td>r</td>
<td>-0.3849</td>
<td>-0.39133</td>
<td></td>
</tr>
<tr>
<td>P-Value</td>
<td>0.03264*</td>
<td>0.036174*</td>
<td></td>
</tr>
</tbody>
</table>

*Pearson Correlation, the result is significant at p < 0.05.

4.2 Total Number of MUs of IMRT plans and %GP

The total number of MUs which is the sum of all the fields’ MUs in the plan were included in this study to test if there is a correlation between it and local and global %GP. Analysis of correlation was carried out. There was a significant correlation between the total numbers of MUs for global %GP. For a local %GP, it was found out statistically that it is not correlated with MUs as explained in the table (2).

<table>
<thead>
<tr>
<th>Total MU</th>
<th>Local</th>
<th>Total MU</th>
<th>Global</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mean ± SD</td>
<td>595.037±239.6737</td>
<td>89.4167 ± 7.7198</td>
<td>595.037±239.6737</td>
</tr>
<tr>
<td>rs</td>
<td>-0.32862</td>
<td>-0.48006</td>
<td></td>
</tr>
<tr>
<td>P-Value</td>
<td>0.07622</td>
<td>0.00726*</td>
<td></td>
</tr>
</tbody>
</table>

*Spearman rho Correlation, the result is significant at p < 0.05.

A linear relationship tested with the scatter plot for MUs and %GP for local and global as shown in figures (1) and (2) respectively. The MUs on the x-axis and %GP is the ordinate. The $R^2$ results are 0.0624 and 0.0991 for local and global %GP, respectively. Results mean that as the total number of MUs increased, the passing rate decreased.
5. Discussion:

AAPM Task Groups 119, 218 and other studies recommended the necessary strict criteria to compare measured and calculated values. The TPS configuration parameters should be measured. The calculated dose from TPS and the measured absolute dose from the phantom should not deviate more than 3% to ensure safe treatment. [8 - 10].
5.1 The correlation and sensitivity of Local and Global %GP.
Since the early days of IMRT; a 3%/3 mm criterion was established as the standard for gamma index-based IMRT treatment plan verification [11]. Previous studies observed that the correlation between results of verification obtained with the help of the gamma algorithm and the method of intensity modulation [12].

Bailey et al. [13] compared measured dose plans with calculations for 79 HN and 25 prostate IMRT fields. Passing rates were calculated using $\Delta D/\Delta T$A, gamma evaluation, and absolute dose comparison with both local and global normalization. They reported the passing rate spread for the individual prostate and HN fields with the greatest differences observed between global and local normalization methods. For 2%/2 mm and 3%/3 mm (10% dose threshold), the prostate %GPs were 80.4% and 96.7% for global normalization and 66.3% and 90.8% for local normalization, respectively. On the other hand, the HN %GPs were 77.9% and 93.5% for global normalization and 50.5% and 70.6% for local normalization, respectively.

The AAPM TG-218 recommended for using global normalization it is deemed more clinically relevant than local normalization. And for local normalization, they found that it is more stringent than global normalization for routine IMRT QA. It can be used during the IMRT commissioning process and for troubleshooting IMRT QA [10]. When using a 10% threshold allows the gamma index analysis to ignore the large area or volume of dose points that lie in very low-dose regions which, if included, would tend to increase the passing rate when global normalization is used [10].

The accuracy of IMRT delivery can be affected by differences and limitations in the design of the MLC and accelerators among the different manufacturers, including the treatment head design, as well as the age of the accelerator/equipment. Also, IMRT dosimetry QA equipment design, tumor sites (e.g., HN vs. prostate), the complexity of the IMRT plans, uncertainties, inaccuracies and tolerances in the planning, delivery, and measurement may affect the IMRT QA verification results [9-11].

5.2 Dosimetric Error (%DE)

The dosimetric error tested with both global and local %GP shows moderate correlation ($r$ is a negative value in 0.3 range) nearly statistically significant values indicated that there are small errors happened for IMRT QA %GP. If the %GP is only dependent on the study; it revealed that there is no problem in the plan, but when compared to the dosimetric errors the results changed. The results are agreed with Benjamin E. Nelms et al 2011[14] Benjimin E. Nelms, Heming Zhen, and Wolfgang A. Tom who studied the dose error for pre-treatment IMRT QA to check the sensitivity of %GP with Pinnacle TPS (Philips Radiation Oncology Systems, Fitchburg, WI) using 6 MV x-ray beams from Varian _Palo Alto, CA_ linear accelerators with 120-leaf. They used many criteria of $\Delta D/\Delta T$A; one of them is 3%/3mm with a 10% threshold. They conclude that there is a lack of correlation between conventional IMRT QA performance metrics (%GP) and dose differences in critical anatomic regions-of-interest. The most common published acceptance criteria have insufficient or at least unproven, but, predictive power for per-patient IMRT QA. They recommended using the correlation to test the result of a dosimetric error with the dose measurements as Van Dyk suggests.

Results in agreement with the paper published in 2014, X JIN et al [15] studied the Correlation between %GP and a clinical dosimetric difference in VMAT with 3%/3mm $\Delta D/\Delta T$A and 10% threshold. The data was obtained by ArcCHECK (Sun Nuclear Corporation, Melbourne, FL) for 20 patients with nasopharyngeal cancer (NPC) and 20 patients with oesophageal cancer. %DE were calculated from planned dose-volume histogram (DVH) and patients’ calculated DVH, and measured by 3DVH software (Sun Nuclear Corporation). They found out that there is a lack of correlation between %GP and %DE for pre-treatment VMAT dosimetric evaluation.

Also, a weak correlation proved between %DE and % GP in research for M. Stasi et al 2012 [7]. Their findings showed that mean %GP; calculated by using both $\gamma$-local and $\gamma$-global normalization, and
the acceptance criteria 3%/3 mm were within the thresholds level 5% using IMRT. It delivered by a sliding window multi-leaf sequencing method. All plans had been created using Varian Eclipse TPS v.8.0 (Varian Medical Systems, Palo Alto, CA) and the treatment was delivered using a 6 MV linear accelerator Clinic 600 C/D (Varian Medical Systems, Palo Alto, CA) equipped with a Millennium 120 multileaf collimator (MLC). This agreed also with our results.

In this study, we included the local %GP too. The variation in results could be related to many factors including mainly the type of linac, phantom and TPS system; MLC type and number, beam shaping, and higher dose threshold used.

5.3 Total Number of MUs of IMRT plans and %GP

One of the main purposes of the QA procedure is to determine that the leaf sequence and MUs correctly delivered to the patient in the planned treatment as they were delineated on the imaging study. Results show that the %GP decreased with increasing MUs, which indicates that highly modulated plans had slightly worse QA results. MU verification is an important QA step in RT and it presents a challenge for step-and-shoot IMRT technique. It is standard practice to verify the MU calculations independently before the start of patient treatment. The total number of MUs has an advantage over single beam MU number in that the measured dose distribution or dose “pattern” is usually similar to that in the original patient plan from TPS. This can be useful in selecting the measurement points or in visualizing potential dose errors. MU settings are directly linked to the planned target dose and the actual patient dose delivered by the treatment plan.

Our results agreed with Shizhang Wu et al., 2018 [16]. They study 924 IMRT plans implemented in a Varian Trilogy accelerator with cylindrical water phantom and Mapcheck software. The ΔD/DTA criteria are (3%/3 mm) and 10% threshold. They found a negative correlation between the %GP and the total number of MUs ($r_s = -0.456, P < 0.001$) for global only. As the total number of MUs increased, the passing rate decreased. And for scattering plotting the $R^2 = 0.14834$. The small difference in results due to using a different dose threshold value.

The total MUs of IMRT planning reflects the level of treatment efficiency. The higher the total MUs, the lower the treatment efficiency, meanwhile a lower pass rate is accompanied by the higher total MUs. The higher number of fields and MUs in each field results in a higher total MU, which affects the treatment efficiency and the passing rate. Therefore, the total number of MUs should be controlled in clinical treatment plan optimization. Not only can the passing rate be high, but also the treatment efficiency can be improved, which has certain practical clinical significance. After optimization, the number of MUs per field can be reduced, and the passing rate can be increased by processing the fluence of each field.

Some reasons might affect the passing rate include artificial positioning, data collection, and instrument positioning. Also, the calculation accuracy during planning system modeling, the measurement range of the OCTAVIUS matrix, and the positioning accuracy of the accelerator MLC. If the difference is small and has little clinical impact; If the difference is large, the plan needs to be re-planned the verification data will be recorded, and the plan will be executed.

Conclusion:

We conclude that the IMRT technique for linac using Octavius 4D-1500 results is accepted for homogeneous dose distribution which means that Octavius 4D is effective as an IMRT QA device. Gamma index readings changed according to many parameters including global and local gamma passing rate, the total number of the monitoring unit. These parameters are one of the most on treatment planning in the treatment sites of our study for both H&N and pelvis. The gamma passing rate could give an idea about the dose distribution in Octavius 4D. By measuring the dosimetric error the Octavius device shows good
sensitivity for errors of dose delivery from linac using IMRT. The total MU relationship results are inverse with %GP which means when the MU increased, the %GP decreased.

References:


