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The Effect of Total Fields' Area and Dose Distribution in Step and Shoot IMRT on Gamma Passing Rate Using OCTAVIUS 4D-1500 Detector Phantom

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ABSTRACT

Introduction: Quality assurance is necessary for every IMRT plan.Octavius 4D-1500 detector phantom is one of the new phantoms for determining the treatment plan quality. This study aimed to examine the IMRT plans using the Octavius 4D-1500 to determine if it is a reliable, dependable, and durable.

Material and Methods: IMRT QA conducted for 30 cases: HN and pelvis. The Monaco TPS used for treatment planning. The treatment plans were then applied to the Octavius 4D-1500 phantom (virtually and actually), the γ-index was calculated in VeriSoft program to evaluate the IMRT plans.

Results: Significant differences were observed between the measured and calculated dose distributions for HN and pelvic plans, while the treatment sites did not affect the GP rate. The results of the global GP were higher than the local GP, regardless of the study criteria. The HN plans showed a more significant difference than the pelvic plans. The HN plans, a strong significant correlation was found between the total fields 'area and %GP in both global and local analyses, while in the pelvic plans, there was only a significant association with the local %GP.

Conclusion: The measured dose distributions significantly different from calculated distributions. The relationship between the fields ' area and %GP was inverse. In the HN plans, a significant correlation found between the total fields 'area and %GP in both global and local, while only local %GP in the pelvic plans was significant correlation. Overall, the Octavius 4D-1500 detector phantom might be applicable for assessing the QA of IMRT plans.

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Introduction

Intensity-modulated radiation therapy (IMRT) has become a standard technique in radiotherapy. Considering the complexity of this technique, quality assurance (QA) is necessary for verifying the dose distribution measurements in the patient's body and comparing them with the dose distribution determined by the treatment planning system (TPS) [1,2]. IMRT is used to deliver a highly conformal dose distribution to the target organ, while minimizing the dose received by the adjacent normal tissues, with multiple subfields due to modulation by multileaf collimators (MLCs) [3].

The dose distribution in IMRT planning has a steep dose gradient [4]. In step-and-shoot IMRT (SS-IMRT), treatment is carried out by irradiating many fields (beams), with each field fixed and subdivided into a set of subfields (segments). These segments are created by the MLC leaves, and treatment is delivered to the patient in a stack of segments one by one (with various shapes and intensities) to reach the desired intensity modulation, with the accelerator switched off and the leaves moving to create the next segment. After the segments are formed, the accelerator is switched on; this procedure is carried out without an operator's intervention [5]. Also, without appropriate equipment, high-quality patient care cannot be achieved or maintained. Therefore, QA of SS-IMRT plans by TPS software tools is necessary [6].

The Octavius 4D detector phantom is a newly developed system [7-9], in which dose distribution is analyzed using the gamma index (γ-index). This system has become one of the most commonly used

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tools to quantitatively determine the differences in dose distributions, especially when comparing computed and measured dose distributions, which is common in QA of IMRT [9]. The system measurements combine the gamma criteria, that is, dose deviation (ΔD) and distance to agreement (DTA), into a single dimensionless metric. Currently, the most common gamma passing rate (%GP) is equal to or greater than 95% of the measured points, with the γ-index ≤1 for 3% ΔD and 3 mm DTA [9,10].

Some researchers have conducted the QA of linear accelerators (LINAC) and used the γ-index in their calculations. In this regard, Chong et al. in 2011 [11] defined suitable action levels for the IMRT QA plans, using a 2D diode array detector. Also, the QA measurements of treatment plans have been performed at various sites (e.g., brain, head and neck [HN], chest, abdomen, pelvis, bone, and spine), using MapCHECK (Sun Nuclear Co., Melbourne, FL, USA). The planned and measured doses were compared by the γ-index, with a total ΔD of 3% or DTA of 3 mm. They recommended action levels for the passing rates of 90% and 87% in LINAC-based IMRT and tomotherapy plans, respectively.

Moreover, Van Esch et al. in 2014 [7] characterized the new Octavius 2D-1500 ionization chamber (IC) detector array in different phantoms, ranging from solid water sandwich setups to complex cylindrical Octavius 4D detector/phantom combinations. The measurements were carried out at 6 and 18 MV, and the calculations were performed in TPS with the analytical anisotropic algorithm. They concluded that the Octavius 1500 array had two main advantages over its 729 array predecessors, that is, its stability in instantaneous measurements and its higher detector density (by two folds) because of its arrangement in a checkerboard panel design. On the other hand, Vieillevigne et al. compared the measurements with TPS-computed doses, using the γ-index (2%/2 mm and 3%/3 mm), and agreements of at least 90% and 95% were found in all pixels, respectively. They also analyzed the effect of error for dose distributions and they concluded that detectors had the potential to detect errors with almost the same threshold.

However, it is not certain whether QA before treatment can remove the errors of delivery. Therefore, in this study, we aimed to examine the IMRT plans, using the Octavius 4D-1500 detector phantom to determine if this device is reliable, dependable, and durable.

Materials and Methods

This study was approved by the Institutional Review Board (IRB) of the College of Medicine of Al-Nahrain University, Baghdad, Iraq. The study was carried out at Baghdad Center for Radiotherapy and Nuclear Medicine. Thirty patients were included in this study, including five patients with pelvic tumors and 25 patients with HN tumors. All patients were diagnosed by an oncologist. The patients underwent CT simulation, and their data were imported to Monaco TPS version 5.1. They were treated with the SS-IMRT technique, using the Elekta (Stockholm, Sweden) LINAC (6 MV) for all treatment plans. Next, the collected data were imported to VeriSoft version 7.1 to evaluate the plan quality with the Octavius 4D-1500 detector phantom (PTW, Freiburg, Germany).

The 2D detector array of Octavius 4D-1500 detector phantom was composed of a matrix of 1405 vented cubic ionization chambers (center-to-center distance, 0.7 cm), and the active area of ionization chambers was 27×27 cm^2. The 2D detector array was inserted into a motorized cylindrical polystyrene phantom (diameter, 32 cm; length, 34.3 cm). The phantom synchronously rotated with the gantry. The inclinometer, attached to the gantry, was connected to a control unit and transferred the movement information to the Octavius 4D-1500 detector phantom. No correction factors were needed, as the beam always hit the 2D detector array perpendicularly. The PTW VeriSoft version 7.1, containing a 3D dosimetric data grid, was used to process the data. This package allows for dose measurements in three planes (axial, sagittal, and coronal) by 2D, 3D, and volumetric γ-index (both local and global). In this study, the acceptance criteria of 3%/3 mm were used for the volumetric gamma analysis [12]. The effects were investigated for both local and global gamma analyses [13].

Statistical analysis

Data analysis was conducted in SPSS Version 24. To describe the data, percentage, mean, standard deviation, and range (minimum and maximum) were measured. Student's t-test was used to evaluate differences between two independent mean values, and paired t-test was used for evaluating differences in sets of values (or two dependents variables).Moreover, Spearman's Rho was performed to determine the strength of association between two variables. P-value less than or equal to 0.05 was considered statistically significant.

Results

Generally, IMRT is a very complicated technique. This study was carried out to evaluate the SS-IMRT plans by the LINAC machine, using the Octavius 4D-1500 detector phantom. Common parameters were used to test the quality of treatment by comparing the measured and calculated dose distributions and determining the volumetric local and global %GP, as well as the total fields 'area. The gamma analysis criteria (ΔD/DTA) were 3%/3mm, and the dose threshold was 5%.

Dose distribution

The dose distribution for radiotherapy was calculated point by point, using local spatial interpolation. Also, the measured dose distribution by the Octavius 4D-1500 detector phantom and the calculated distribution by TPS were determined. The point dose was calculated in cGy and compared with measured point dose at isocenter location for each plan, as summarized in Table 1. The results showed that the pelvic plans had a higher mean value than the HN plans, and there was a significant difference between the calculated and measured dose distributions for the HN and pelvic plans (P=0.00001 and 0.04377, respectively). The results of HN plans showed a more significant difference than the pelvic plans. Also, the findings showed no significant difference in the dose distributions, depending on the treatment site. Moreover, the local and global %GP results were analyzed. The global %GP was 94.96±6.524 and 97.28±1.849 for the HN and pelvic plans, respectively. The local %GP was 89.428±8.232 for the HN plans and 89.36±4.327 for the pelvic plans, as shown in Figure 1. Moreover, the overall local and global %GPs for dose distribution were determined. It was found that the local %GP was 89.4166±7.7198, and the global %GP was 95.35±6.0650.

Table 1. Analysis of the calculated and measured dose distributions at the isocentric point

Radiation site	Calculated dose (cGy)	Measured dose (cGy)	P-value
HN	131.464±22.0559	127.302±21.327756	0.00001*
Pelvis	170.034±45.7753	163.946±42.1932	0.04377*
P-value	0.1683	0.1584	
*Significant at P<0.05.			

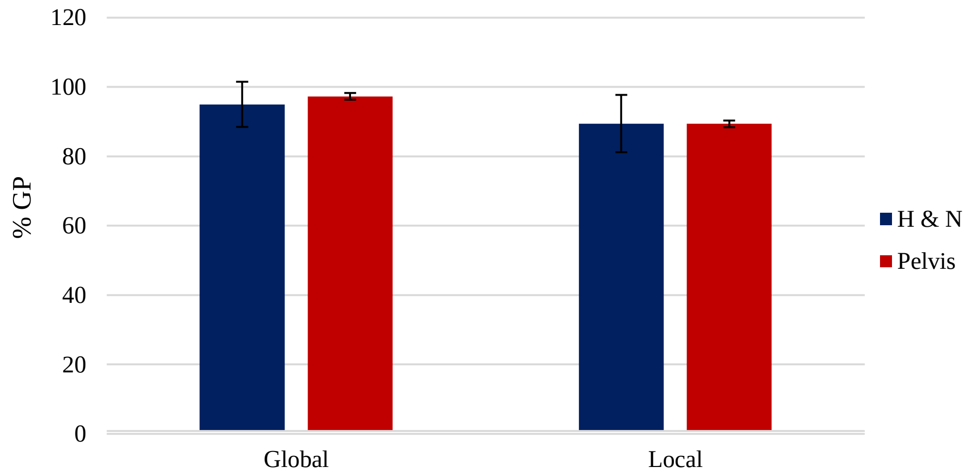

Figure 1. Comparison of the mean global and local %GP for the measurements obtained by the Octavius 4D-1500 detector phantom

Table 2. The relationship between the total field area of plans and the local and global %GP

Local				
Radiation site	Total field area (cm^2)	%GP	r_s	P-value
HN	775.2292±583.3373	89.428±8.23	-0.6332	0.00068*
Pelvis	1089.452±402.0041	89.36±4.32	-0.9	0.03739*
Global				
Radiation site	Total field area (cm^2)	%GP	r_s	P-value
HN	775.2292±583.3373	94.96±6.52	-0.7715	0.0005*
Pelvis	1089.452±402.0041	97.28±1.84	-0.3	0.62384
*Spearman's rho correlation coefficient (significant at P<0.05).				

Correlation and sensitivity of local and global %GP

Generally, %GP is considered as a common metric for comparing the measured and calculated doses of treatment plans. It determines what percentage of the measured points in the plan matches the calculated points in the phantom, based on certain criteria. This metric depends on various criteria, mainly ΔD and DTA. The dose threshold of the plan is also taken into consideration. Overall, the %GP increases with more permissive ΔD/DTA criteria. In other words, it represents the percentage of dose distribution point data of gamma index that meets or fails the criteria. In this study, we also examined the correlation between %GP and the total fields 'area.

Relationship between the total fields 'area of SS-IMRT plans and %GP in different treatment sites

The treatment plans were classified, according to the treatment site (HN and pelvis). Next, the correlation between %GP (both local and global) and the total fields 'area of the measured dose was examined. The total area was determined and verified to improve the future treatment planning and improve the program verification results. The findings showed that in the HN treatment plans, there was a strong significant correlation between the total fields 'area and %GP (both global and local). On the other hand, in the pelvic plans, a significant correlation was only found with the local %GP, and there was no significant correlation with the global %GP, as summarized in Table 2.

Discussion

A QA protocol is necessary in studies on radiation therapy, and the TPS parameter needs to be determined. To ensures safe patient care, the estimated dose and the actual dose of TPS should not exceed 3%. However, without the appropriate equipment, high-quality patient care cannot be achieved or maintained. Tumors occur in many locations of the body in different shapes. Generally, the treatment process can be costly for individuals and impose economic burdens if radiation cannot be effectively delivered to the tumor site with minimum side effects. Therefore, it is necessary to maintain strict criteria to compare the measured and calculated doses, as recommended in reports by the AAPM Task Group 119 and 218, as well as the literature [13-18].

Dose distributions

The method of quantitative assessment between measured dose distribution and the TPS-estimated dose distribution is an important factor in IMRT QA. The mean comparison of the calculated data by TPS and Octavius 4D-1500 detector phantom indicated a more significant difference in the HN plans (25 plans) than the pelvic plans (5 plans), which may be due to variations in the number of patients included in the study. The HN treatments generally involve small target volumes and require significant modulations. The %GP values for dose distribution were nearly similar in our study, which is in line with the results reported by Kiley B. Pulliam et al. in 2014 [19] on dosimetry and QA over six years. In their study, the local and global %GP rates were 97.7% and 99.3%, respectively. Also, our findings are consistent with the report by the AAPM group TG 119 on %GP (3%/3 mm) [17]. The highly modulated plans exhibited large dosimetric errors for absolute doses with a biplanar diode array and six control points. The results showed that the local %GP was below 90%, and the global %GP was 97-99%.

Moreover, Lei Dong et al. in 2003 [20] reported a global %GP of 97.7%. Nevertheless, our global %GP (95.35%) was lower than previous studies, which might be attributed to the larger number of studied cases in previous research. Also, different treatment sites might have affected our results, as HN is considered a small target volume, whereas the pelvis is considered a large target volume. Overall, the agreement between the calculated and measured doses depends on many factors, such as the shape of the target, dose constraints, density of dosimeters, MLC leaf width, organs at risk, and field aperture.

One of the advantages of gamma index is that it represents the pass/fail quantity of dose distribution delivery. A gamma index value higher than 1 such (1.01) indicates failure dose gradient whereas a gamma index value of less than 1 can pass the test with 3%/3 mm. They both involve checkup of point dose failures of plan in low-dose and steep-dose gradients, exceeding tolerance by 3%/3 mm. Overall, a point which fails the γ-index by 0.03% or 0.03 mm must not be taken into consideration by a substantially wider margin. Therefore, not only the percentage of dots, which are not accessed, should be considered, but also the total gamma value, percentage of accepted point doses over a gamma value of 1.5, gamma histogram, and other potential statistics needs to be examined. The γ-index measurements, based on the ΔD and DTA criteria (e.g., 4%/3 mm, 3%/3 mm, 3%/2 mm, 2%/3, and 2%/2 mm), can also help us find and modify the sources of contradiction.

Correlation and sensitivity of local and global %GP rates

A 3%/3 mm requirement for verifying the gamma index-based IMRT treatment planning [21] has been introduced since the earliest days of IMRT. Previous studies found an association between the outcomes of gamma algorithm verification results and the intensity modulation process [22]. Bailey et al. in 2011 [23] evaluated and compared the measured doses in 79 HN and 25 IMRT prostate fields. The %GP values were determined using the ΔD/DTA parameters, gamma analysis, and absolute comparison of dosages at both local and global levels. They reported a differential passage rate between the global and local normalization methods for individual prostate and HN plans. For 2%/2 mm and 3%/3 mm criteria, the prostate %GP was 80.4% and 96.7% in global normalization and 66.3% and

90.8% in local normalization, respectively (10% dose threshold). On the other hand, the average %GP in the HN plans was 77.9% and 93.5% for the global standardization and 50.5% and 70.6% for the local standardization, respectively.

The American association of physics in medicine in publish in their report (AAPM TG-218) suggestion that global gamma index standardization is scientifically more important than that of local gamma index standardization. In local normalization, the IMRT QA can be extended to IMRT commissioning and IMRT QA troubleshooting, and the GP-10 Review can be used to avoid the wide range of doses in very low-dose zones. Generally, the GP analysis is based on a 10% GP level [18]. Differences and restrictions of MLC and accelerator design among various manufacturers, including the head design process and accelerator/equipment size, affect the accuracy of IMRT delivery. The IMRT QA verification results may also affect the design of IMRT dosimetry devices, tumor sites (e.g., HN vs. prostate), complexity of IMRT strategies, execution and measurement errors, and tolerance [18].

Relationship between the total fields 'area of SS-IMRT plans and GP rate according to the treatment site

The total fields 'area was classified, according to the treatment site. The analysis showed no significant correlation in the global GP for the pelvic plans, which might be due to the small number of cases. Overall, as the fields 'area increased, the GP rate decreased. In this regard, Shizhang Wu et al. 2018 [24] conducted a study on 924 IMRT plans for global %GP. Their analysis was conducted on the maximum fields 'area. The overall correlation with %GP was found to be significant (r_s= −0.166, P<0.001), which is partially consistent with our results. Considering the treatment site, they found a negative correlation with the maximum fields 'area of the HN, chest, abdomen, and pelvis.

The GP rate may be related to the size of tumor and other factors. Our findings may be more significant by assessing large prospective IMRT plans. The cause of variation in the results and the insignificant correlation of global %GP with the total fields 'area may be attributed to the limitations of the effective measurement area in the Octavius 2D detector array, limitations of the calculation method in a wider area, or area limitations when the fluence is delivered by TPS.

Conclusion

We concluded that the SS-IMRT technique an important planning technique for acquiring homogeneous dose distribution, and the plan quality can be tested using the Octavius 4D-1500 detector phantom; therefore, this detector phantom is effective for the QA of the SS-IMRT technique. The gamma index readings varied, depending on many parameters, including the global and local %GP and the fields 'area. These parameters were found to be very important in treatment planning for both HN and pelvic areas. Overall, the %GP can shed light on dose distributions in the Octavius 4D-1500 detector phantom. Also, the relationship between the total fields 'area and %GP was inverse; in other words, with an increase in the total fields 'area, the %GP decreased.

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