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Evaluation Study of IMRT Plans in Octavius and Slaps Phantoms

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Abstract: Intensity-modulated radiation therapy (IMRT) is considered one of the important techniques for the treatment of cancer patients so, the object of this work is to evaluate (IMRT) plans. This process required a specific dosimetry system but in this work, we used an Octavius phantom 2D array of detectors 1500(T10044). Firstly, calibrated this system by measuring square field sizes 5, 10, 15, and 20 for three-photon energies 6MV, 10MV, and 15MV in coronal, sagittal, and axial phases for plan views. we used an Elekta (An Agility synergy platform) linear accelerator in the South Egypt Cancer Institute (Assiut University, Egypt) with steep and shoot technique in IMRT. We verified 20 patients with IMRT plans using the MONACO computer treatment planning system (TPS) which can be calculated by using the Monte Carlo algorithm which is used only in (IMRT). We fulfill Two verification plans for each patient, one applied on 4D PTW Octavius phantom with true gantry angles of IMRT plan and the other plan applied on solid waterproof slaps phantom with zero (0°) gantry angle in all beams of the plan. The comparing data between measured and calculated doses for the two concerned plans will analyzed by the PTW MEPHESTO VERISOFT PATIENT PLAN VERIFICATION software program. Two measuring processes will be run the first one applied with local dose (all doses of calculated volume) and global dose (maximum dose of calculated volume) each of them was calculated in 2D, 3D, and 4D. Only 4D will be performed calculation in Octavious Phantom with true angles planes. indicate that the Gamma (γ) average (the gamma passing rate (GPR)) identity during applying different types of gamma analyses in 2D and 3D for true angles Octavious planes firstly for a global maximum of calculating volume respectively are 98, 99, and 4D 98.3. in local dose 2D, 3D, and 4D respectively are 89, 94.6, 91.6. secondly, The results for 2D, and 3D in slaps phantom planes with zero gantry angle in global max and local dose are respectively 99.7, 99.8, 88.6, 74.5. The Gamma passing rate (GPR) in the verification of IMRT planes is dependent on the angles of plans, so the detectors in the 2D array depend on the gantry angle these are whether in global max dose or local dose otherwise, the Gamma passing rate (GPR) in global max are greater than in local dose. In conclusion, our study shows that the effectiveness of IMRT plans is dependent on the angles of the plan, and the detectors used in the 2D array are dependent on the gantry angle.

Keywords: Intensity Modulated Radiation Therapy, Octavious phantom 2D array, MONACO (TPS), Gamma passing rate (GPR).

1 Introduction

Intensity Modulated Radiotherapy (IMRT) is an advanced type of three-dimensional Conformal Radiotherapy (3D-CRT) that enhances the composite dose distribution by delivering modulated effects to the patient from any part of the treatment radiation beam Fig (1). With each treatment dose, IMRT (with a multi-leave collimator MLC) devices can change the radiation beam intensity around the tumor (target volume) Fig (2). Therefore, the machine provides highly precise doses over a whole tumor. IMRT is delivered using either the multi-segment step-and-shoot (which was used in this work) or the dynamic mode of MLC operation. In the static IMRT (step-and-shoot mode), the intensity of modulating fields is delivered through a series of small segments, like subfields, with a uniform intensity. According to this approach, the radiation beam is only activated when the MLC leaves are fixed in each of the prescribed subfield positions (segment). Thus, when the radiation beam is on, there is no motion in the MLC. A more advanced and modern approach is the dynamic MLC technique (called sliding window). Where the following

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profile along the moving direction of a leaf pair is created by sweeping the leaf pair with different openings over the field when the beam is always on [1-8].

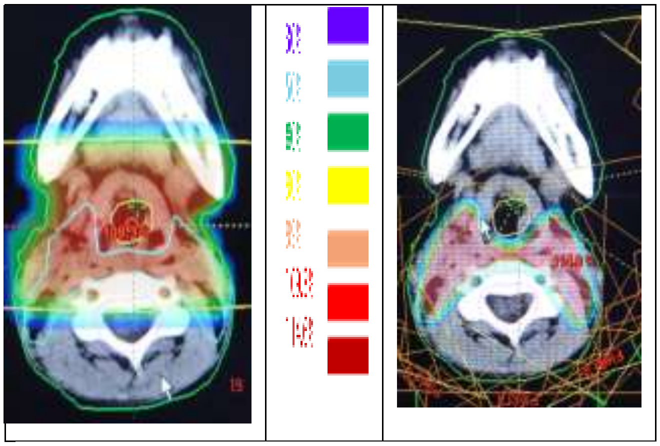
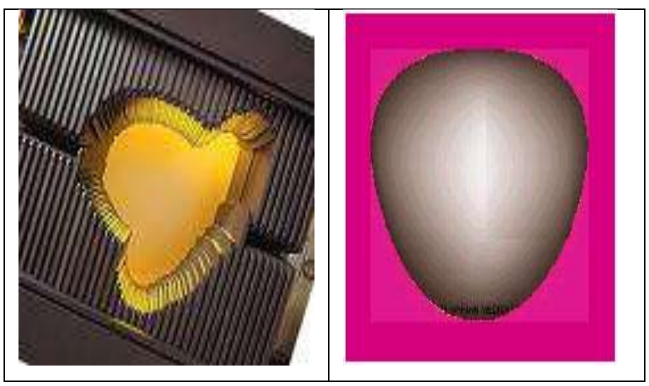


Fig.1. indicates the difference between the isodose distribution in IMRT (left side) and 3DCRT (right side) of the dose distribution in one cut in a head and neck case.



A-(shaping of MLC opening) **B-(opening of regular collimator in tumor)**

Fig.2. indicated that the difference between shaping MLC (A) and regular collimator (B).

Intensity modulation is achieved using MLC modulation (static or dynamic mode) as a linear accelerator (LINAC) per incident angle. The planned process is electronically transmitted to the synchronized MLC and LINAC for treatment delivery. A LINAC control system ensures that the treatment planning and transportation processes are accurate and efficient for data transfer [9].

Since 1990, conformal radiation therapy has used intensity modulation (IMRT) to deliver transportation systems. The transportation IMRT delivery system can be divided into fixed (step and shoot segmental system) and moving gantry (sliding window or dynamic system). The distribution doses of IMRT are more heterogeneous than in three-dimensional (3D) plans. This is due to the utilization of complex fields that comport different degrees of modulation doses [10].

Quality assurance (QA) for IMRT verification plans is a crucial process to check and detect the accuracy of IMRT plan dose calculations. Furthermore, it is important to ensure the accuracy of clinically relevant errors in radiation delivery. Some crucial components must be considered when clinically implementing IMRT. These include the treatment planning system (TPS), commissioning and acceptance of the delivery device system, and implementing a comprehensive plan [10]. There are several types of dosimetry systems utilized in IMRT QA measurements. These include film dosimetry, ion champers for absolute dosimetry, arc check dosimetry systems, delta 4 systems, 2D array champers used for solid slaps (cubic phantoms), and Octavius phantoms Fig 4b.

The gamma index (γ) is the ratio of the dose difference (measured and calculated doses (DD)) and the distance to agreement (DTA) between the outlined and measured plan for each point of interest [18]. Evaluation of gamma index (γ) has become a suitable way to evaluate measured distributions in 2D array detector systems against the dose distribution expected by treatment planning systems (TPS). The criteria for the calculation for each point in the evaluated distribution is a metric that combines dose difference (DD) and distance to agreement (DTA) [11].

In QA details work the total percentage points that have verified $\boldsymbol{\gamma} < 1$ (for a given DD/DTA criteria) is calculated, and then a pass/fail threshold is established [12-14]. As recommended by the American Association of Physicists in Medicine (AAPM) [10]. If the (γ) gamma index or gamma passing rate is equal to or less than 1, the criteria limits or tolerance limits were not exceeded. When it was greater than 1, the measurement result was outside the tolerance range [1].

This study aims to evaluate IMRT using Octavious Phantom in comparison with other devices in some features. This approach is accurate and covers more areas than slaps or other devices. Moreover, the dose is delivered with the same efficiency and accuracy as in the proposed plan. Finally, the patient's exposure time to radiation is reduced. This provided study emphasizes the accuracy of the IMRT technique for complex plans

2-Material and Methods

1. Linear Accelerator

All IMRT plans in this study are carried out on the ELEKTA SYNERGY PLATTFORM linear accelerator with an agility head. This device is for treating, delivering, and transporting ELEKTA SYNERGY, which is an extraordinary achievement. Patients with different tumor sites can receive treatments on various disease sites such as the head and neck, esophagus, brain, rectum, and prostate cancer (Fig. 3) [15].

Fig.3. Elekta synergy platform linear accelerator with agility head.

2. Treatment Planning System (TPS)

A Monaco TPS (version 5.11.03) with the Monte Carlo algorithm is used for all calculations with a grid size of 3 mm. All measurements were taken using a PTW ion-chamber array (PTW, Freiburg, Germany) with an Octavius phantom on an Elekta Synergy platform linear accelerator, as shown in Figure 3. 6 MeV energy was applied and maintained a surface skin distance (SSD) of 84 cm, which was achieved by positioning the chamber array 16 cm away from the center of the phantom. The couch and collimator positions were set at zero angles, and the QA was carried out using true or zero gantry angles according to the proposed plans.

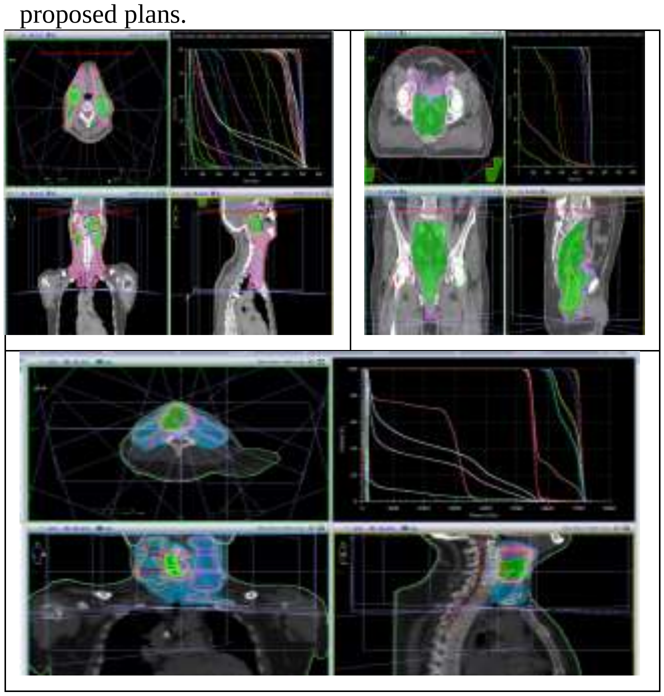


Fig.4. indicated two IMRT planes (A, C) for two Head & neck cases, and (B) for posted cases in transfer, DVH, coronal, and digital respectively.

3. PTW 2D array Detectors

The 2D array has a detector array with 1405 ionization chambers on an area of 27 x 27 cm^2 (size 4.4 x 4.4 x 3 mm^3). The old ionization chamber technique prevents the impacts of detector aging. It is appropriate for use with the OCTAVIUS 4D system (the modular phantom for IMRT). The 2D array system is suitable for a wide energy range, is easier to position with the Couch Fix Positioning Tool, has large field scanning coverage, is reproducible, and is quick. Moreover, it has a unique checkboard detector layout(all leaves are detected, 100% field coverage, with two measurements via simple couch shift Gold Standard ionization chambers as detectors) [16].

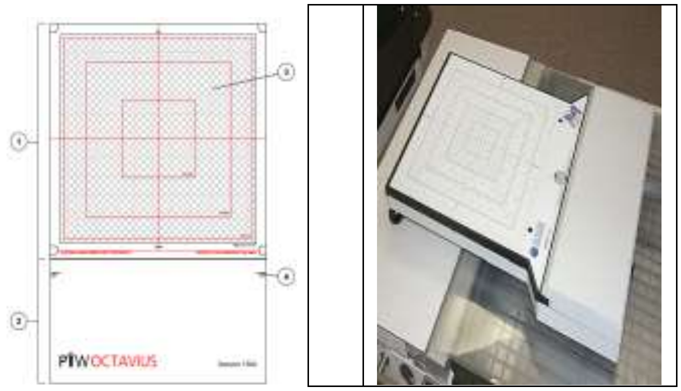


Fig.5.indicated a 2D array in (A) these elements indicated that: 1. Area of ionization chambers (27 cm x 27 cm), 2. Electronics area, 3. sitting of ionization chambers, 4. Mark for use in the rotation unit of the OCTAVIUS 4D system and (B) indicated PTW 1500 champers 2D array experimentally

4. Octavius phantom

Octavious phantom is used for the 4D dosimetry system for rotational patient plan verification. The phantom rotates with the gantry simultaneously and measures the dose in the entire volume as a function of time and gantry angle. Furthermore, it analyzes the results in all planes (axial, sagittal, coronal). The previous phantom was calibrated by measuring the different field sets up 5×5, 10×10, 15×15, and 20×20 with three different photon energies (6 mv, 10 mv, and 15 mv) at zero angles of gantry, collimator, and couch (the at ssd 84 cm) [17].

Measured output factors for different energy

The factor of the detector variation response for accelerator output to all energies that can be used must be considered for all measurement (verification) sessions in the IMRT QA measurement dose (dose calibration measurement compared to the standard) [18-19]. These factors were measured using CT images for the two phantoms (Octavious and Slaps) and then transferred to the treatment planning system (TPS) to confirm IMRT plans for these phantoms (considering the density for each phantom as shown in Table 1). As in radiation oncology physics standards [10].

Can be measured these factors by using a field size (10×10) cm with three energies (6, 10, and 15MV), a field with a depth of 16 cm, and ssd 84 cm for measuring the monitor unit (MU) in all energy for each phantom (shown in table 1). Two (QA) plans were used: an Octavius phantom plan (with true Gantry or treatment angles) and a Slaps phantom plan (with a zero Gantry angle). These two plans were then transferred from TPS to the software program (VERISOFT) for measuring the difference between the Octavious and slap phantom plans. The Octavious phantom was set in the treatment room (linear accelerator room), then connected to the interface amplifier with a 2D array and the Octavious phantom. For the Octavious and Slap phantoms in balanced positions, the setup of SSD was 84 cm. The phantom output doses were taken for each energy as shown in Table 1.

Table (1): indicated density Monitor unit for three energy in two phantom.

Phantom	Density	6MV	10MV	15MV
Octavious	1.016	156	136	127
Slap	1.045	163	134	123

Evaluation of IMRT plans

20 different IMRT plans were evaluated for different patients with head & neck, abdomen, and pelvis cancer in the treatment planning system (TPS; MONACO).

By using the Octavious phantom, the TPS plan with true angles was measured. After that, the phantom was replaced by the Slap phantom, and the TPS plan was evaluated with a zero Gantry angle. All of the previous data was stored in the measurement software (VERISOFT PATIENT PLAN VERIFICATION). Finally, the TPS plans (calculated) were compared with the measured plans for the Slap Phantom (2D) and the Octavious Phantom (2D, 3D, and 4D). The gamma index (γ) was measured for each plan through this comparison from **global** to **local doses**. The previous steps were repeated to measure the gamma index (γ) in 2D, 3D, and 4D, although in local doses.

3 Results and Discussion

Calibration of phantom

Based on our research and analysis in QA of phantom we have selected four square field sizes (5×5, 10×10, 15×15, 20×20) at three different photon energies (6, 10, and 15) MV with zero angles of (gantry, collimator, and couch) and SSD 84cm. Calculating gamma index or gamma pass rate (γ) by Verisoft software evaluation algorithms in three plans 2D (coronal, sagittal, and axial) in global and local dose plans. Our results show that the calculated doses were accurate and consistent across all plans and field sizes. These findings demonstrate the effectiveness and reliability of Verisoft software algorithms for radiotherapy treatment planning.

When talking about these results we can see that the 2D coronal plan is the best and optimum plan because it is the isocenter plane all gamma index (γ) results in up to 90% in all field sizes and energies that we measured this is equally in local and global plan doses. The coronal plane is in front in a direction of the incident beam into 2D array matrices champers in X direction so it is considered the optimum plane for using film evaluated in IMRT plans as a detector in only 2D plans, but the ability of Octavius phantom and very soft program to reconstructed in 3D plans so we can measured (sagittal and transfer) plans in Y and Z direction and for 3D dose matrix. The readings in sagittal and transfer plans may be less than 90% The PTW Verisoft IMRT verification software has the option of calculating the 2D and 3D gamma index (γ) from all the measured/ dose points. The 3D gamma index (γ) is calculated using a sphere of DTA (dose to agreement) instead of film. The algorithm evaluates points not only in a plane (coronal, sagittal, and transferee) but also at points in adjacent planes

Table (2): indicates the gamma index (γ) in QA phantom In three plans (Coronal, sagittal, and transverse) respectively in global and local plan doses.

Energy	Field size	Coronal		Sagittal	transverse		
		(γ) Global	(γ) Local	(γ) Global	(γ) Local	(γ) Global	(γ) Local
6MV	**5×5**	**99.6**	**95.8**	**96**	**90.6**	**93.1**	**85.7**
	10×10	**100**	**97.7**	**99.4**	**94.4**	**99**	**94.5**
	15×15	**99.9**	**97.3**	**96.9**	**93**	**93.8**	**87.5**
	20×20	**98.9**	**90**	**98.3**	**87.8**	**98.9**	**88.8**
10MV	**5×5**	**100**	**99.6**	**94.7**	**93.2**	**92.9**	**87.4**
	10×10	**93.3**	**81**	**98.7**	**93.3**	**97.9**	**83.2**
	15×15	**99.2**	**93.7**	**97.6**	**87.5**	**98.5**	**91.1**
	20×20	**97**	**87.6**	**96.7**	**85.3**	**98.6**	**86.9**
15MV	**5×5**	**100**	**98.6**	**98.5**	**97.5**	**99.3**	**98**
	10×10	**99.5**	**95.3**	**99.7**	**97.8**	**91.1**	**99**
	15×15	**99.6**	**96.4**	**99.7**	**95.7**	**99.7**	**95.4**
	20×20	**99.9**	**98.2**	**98.5**	**92.9**	**97**	**93.4**

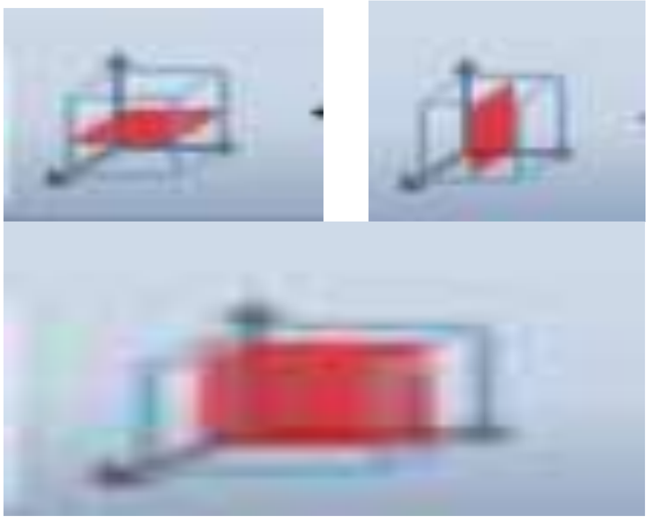
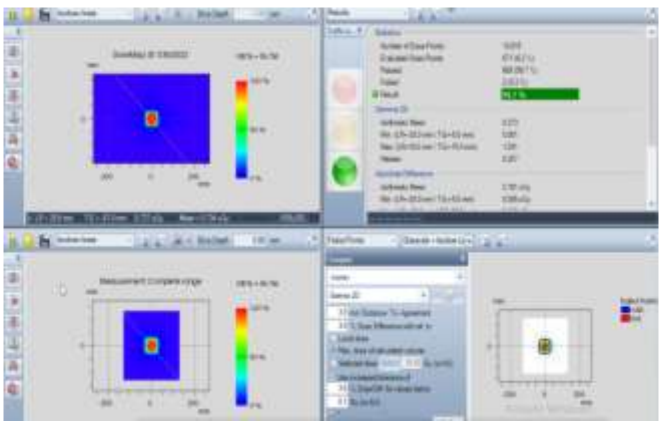
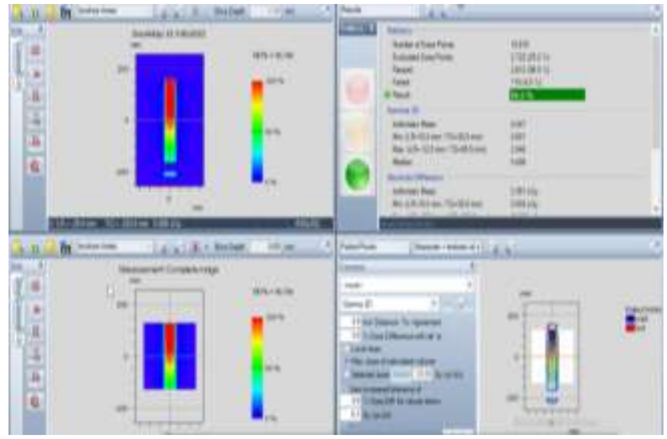


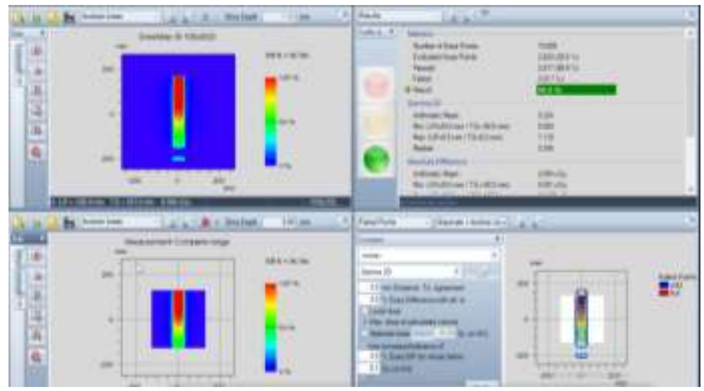
Fig.10.indicates the incident field size in three plans (coronal, sagittal, and transverse) respectively.



(A)



(B)



(c)

Fig.11. indicates the shortcut view in the VERISOFT program for calibration phantom in coronal, sagittal, and transverse plans respectively.

Table (3): indicates the average gamma index (γ) ratio in global and local doses in three plans (2D, 3D, and 4D) respectively in Octavious phantom and 2D, 3D only plans in slaps phantoms.

	Global OCT			Local OCT			Global Slaps		Local slaps	
	2D	3D	4D	2D	3D	4D	2D	3D	2D	3D
Aver(γ)	96.8	97.7	97	90	94.4	92.2	99.6	99.7	92.6	85.3
SD (γ)	3	2.5	2.7	4.7	3	3.2	0.7	0.5	5.3	11.8

There is not only study supported or recommended the true angular geometry in (1) In a gamma index (γ) in IMRT verification with a zero gantry angle or true geometry exhibited a higher pass percentage (γ) than IMRT with true gantry angles. The 2D array ion chamber used for IMRT verification has angular dependence, which lowers the verification accuracy with true angle or when the array is used to measure actual beam angles.

Recently came across a recommendation from the AAPM TG-218 (10) that caught my attention. They suggested using global normalization instead of local normalization, as it's considered to be more clinically relevant. They also found that local normalization can be more stringent than global normalization when it comes to routine IMRT QA. However, local normalization can still be useful during the IMRT commissioning process and for troubleshooting IMRT QA.

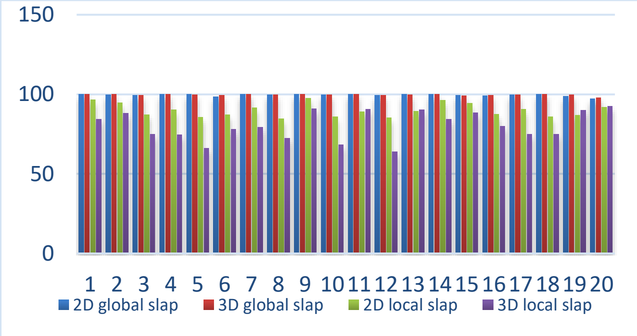


Fig. 13: indicated the difference between gamma index (γ) passing rate in Global and Local dose normalization in 2D and 3D of slap phantom respectively.

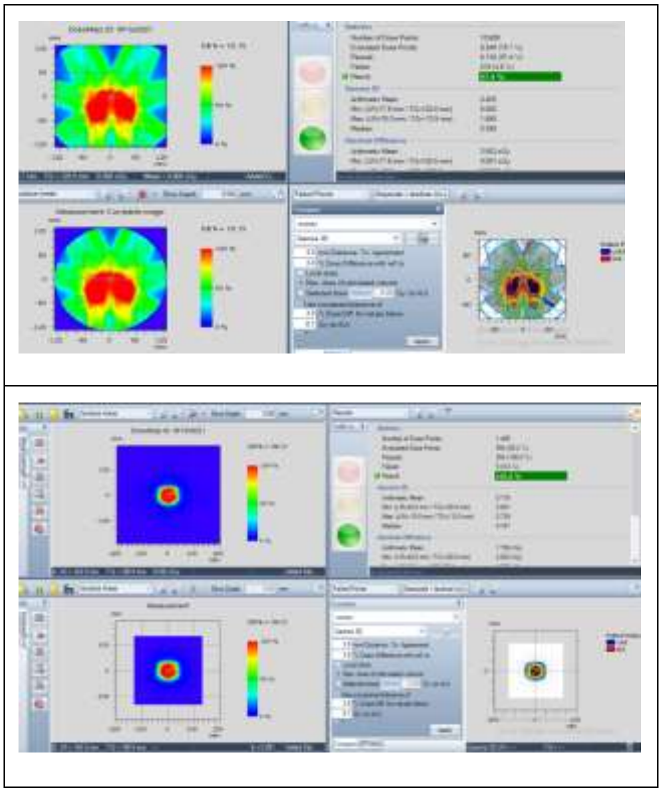


Fig.5.shows the comparison between Octavious plan (A) with true gantry angle and slaps plan (B) with gantry= 0°. also indicated Gamma resulted and distribution dose in 3D phantoms (D).

4 Conclusions

Gamma passing rate (GPR) in the verification of IMRT planes is dependent on angles of plans, so the detectors in the 2D array depend on the gantry angle these is whether in global max dose or local dose otherwise, the Gamma passing rate (GPR) in global max are greater than in local dose. In conclusion, our study shows that the effectiveness of IMRT plans is dependent on the angles of the plan, and the detectors used in the 2D array are dependent on the gantry angle.

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