



# Dose verification of intensity modulated radiotherapy in head and neck tumors

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## Technical Report

### Abstract

**Purpose:** To evaluate the agreement between measured and calculated doses for head and neck tumors using different gamma criteria and to establish quality assurance protocol for the delivery of IMRT in The National Cancer Institute in Cairo. **Methods:** The dose is calculated for 30 patients using CMS Treatment Planning System. The ionization chamber (0.6 cm<sup>3</sup> Farmer type) is used for point dose measurements. The 2D-array (PTW 729) and GafChromic films (EBT2) are used for 2D graphical dose distribution. Four different gamma criteria of dose difference (DD) and distance to agreement (DTA) (3%/3 mm, 3%/5 mm, 4%/4 mm and 5%/5 mm DD / DTA) are selected. These criteria are evaluated while suppressing the dose of 10%, 20% or 30% from dose distribution. **Results:** Point dose evaluations using the ion chamber ranged from -2.6% to 3.7% (mean and standard deviation of  $0.46 \pm 1.7$ ). Significant differences are observed between the films and 2D-array for all criteria except the 3%/5 mm criteria ( $96.89 \pm 2.2\%$  vs.  $94.81 \pm 4.2\%$  ( $p < 0.01$ )). **Conclusion:** Differences may exceed about 3% when the ionization chamber is present in steep dose gradient regions. The present results suggest the gamma criteria of 3%/5 mm as the most suitable criteria for IMRT quality assurance. This gamma criterion of 3%/5 mm favorably exceeds 95% in case of maximum dose while suppressing the dose of 20%. The use of 2D-array can reduce the IMRT QA workload.

**Keywords:** Quality Assurance; Intensity Modulation; Ionization Chamber; 2D-Array; GafChromic Films

### Introduction

The standard quality assurance (QA) for IMRT before the patient treatment is to use an ionization chamber for absolute dose measurements and 2-dimensional (2D)-array or films for relative dose evaluation.<sup>1,2</sup> During the introduction of intensity-modulated beams applied for IMRT, the physics community started to perform more extensive verification in 2D (planes) and even in 3D (volumes). Burman *et al*<sup>3</sup> introduced a concept for IMRT verification. Kron *et al*<sup>4</sup> performed a check of absolute dose calibration in a slab phantom. This study found that the dose delivered to the ICRU reference point was correct in all centers. They also found that the absolute dose calibration and the mean dose in the

target volume were  $\pm 5\%$  for all participating centers. Dong *et al*<sup>5</sup> completed a dosimetric verification of 200 cases of head and neck using ionization chamber for patient-specific quality assurance. Most treatments were delivered using the step-and-shoot multileaf collimator with a 6-MV photon beam. The measured difference was greater than 3.5% for 14 cases. Low and Dempsey<sup>6</sup> typically used 5% and 2-3 mm as tolerance values of the  $\gamma$ -distribution during their clinical evaluation. In a more recent study Childress *et al*<sup>7</sup> analyzed about 850 films resulting from IMRT plan verification. Their results showed no dependence on energy, accelerator or treatment site, but varied for the different QA phantoms and treatment planning systems applied in their study. Their preferred gamma index tolerance criteria were 5% and 3 mm. Saminathan *et al*<sup>8</sup> investigated the use of 2D-array compared to films in the verification of IMRT. Their measurements showed that the 2D-array could be used to quantify absolute dose and could be also used for routine quality assurance checks like flatness, symmetry, field width, and penumbra of the linear accelerator beam.

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IMRT is an optimal technical approach for the treatment of head and neck tumors. This is because of the presence of anatomically critical structures close to the targeted cancer tissue.<sup>9, 10, 11</sup> This complex technique requires a highly efficient treatment-verification process.<sup>4</sup> The IMRT delivery quality assurance mostly consists of delivering the IMRT plan to a phantom and then comparing the 2D dose distribution calculated by the treatment planning system (TPS) with the dose measured using 2D-array or films.<sup>1, 2, 12, 13, 14, 18</sup>

A “reasonable” choice of a specific combination of gamma evaluation and acceptance criteria should be based on the accuracy of the applied measurement procedure, its workload, and the ability to detect problem areas in the intended dose distribution. Combinations of gamma evaluation and acceptance criteria depend on many factors including the dosimetric equipment, calculation and measurement grid, and the data analysis software. It is therefore virtually impossible to provide general recommendations applicable for all situations.<sup>13</sup> For these reasons, the goal of this work is studying the compatibility of IMRT dose calculations for head and neck tumors in TPS with dose measurement in Linac at the National Cancer Institute, Cairo, Egypt. Several tests are performed using ionization chamber, 2D array ionization chambers and films. Ionization chamber is used for point dose measurements. 2D array ionization chambers and films are used to display 2D graphics of dose measurements. This is to establish a protocol to present a complete QA process, evaluate the usefulness of the investigated methods and suggest the use of faster and more efficient dosimetric tools for the dose verification in IMRT technique in our institute.

## Methods and Materials

### QA Tools

The dose measurements are done in rectangular parallel slabs of water equivalent phantom. The phantom dimensions are  $30 \times 30 \times 25$  cm<sup>3</sup>. Three different tools are used in this study:

1. Ionization Chamber: 0.6 cm<sup>3</sup> farmer type ion-chamber and unidose electrometer (PTW, Freiburg, Germany) are used for point dose measurements.<sup>12, 13, 14, 15</sup> A sandwich setup of water equivalent PTW RW3 plates with a stack of 15 cm below and 10 cm above the ionization chamber are used. The phantom arrangement is scanned in CT with slice thickness of 0.5 cm. The scanned phantom is imported via DICOM to XIO treatment planning system.
2. 2D-array: PTW 2D-array 729 consisting of a plan matrix of  $27 \times 27$  air-filled ionization chambers is used (PTW, Freiburg, Germany). The detector spacing (center to center) is 1 cm. The dimensions of each detector are  $0.5 \times 0.5 \times 0.5$  cm<sup>3</sup>.

3. GafChromic films: EBT2 GafChromic films, each of dimensions  $8 \times 10$  inches, are used (ISP-USA). The irradiated films are scanned with Vidar VXR-16 Dosimetry PRO scanner. MEPHYSTO mc2 software (PTW, Freiburg, Germany) is used for film analysis. Films are stored in light-tight envelopes under constant atmospheric conditions. The same time difference is maintained between the film irradiation and scanning. Edges of the films are not included in the region of interest to avoid artifacts.

2D-array and films are used for dose verification for treatment planning system.<sup>12, 13</sup> The same setup of water equivalent PTW RW3 plates used for point dose measurements is used for 2D-array and film measurements. The phantom is irradiated using the same monitor units and same beam setup as the patient treatment setup with Elekta Precise linear accelerator (step-and-shoot IMRT delivery). 2D-array and films display 2D graphics and transfer the acquired data to the Verisoft software. Doses are calculated in cGy for 30 patients by inverse planning optimization using CMS XIO treatment planning system version (4.40). Seven beams are calculated for every plan. The number of segments may exceed about 120 segments for a head and neck plan. All of the measurements are performed on step and shoot Elekta Precise® linear accelerator.

### Verisoft software

The Verisoft software assists physicists in comparing dose distributions in IMRT verification phantom with dose distributions computed by radiotherapy treatment planning system. Matrices of measured and calculated points of an IMRT beam are compared by subtracting the matrices and visualizing the results. The software supports the gamma evaluation method, it helps in locating hot and cold spots and determines maximum and average deviation between a calculated and measured plan.

In this study, the Verisoft verification software is used to compare gamma distribution for calculated dose (cGy) using TPS and measured dose using films and 2D-array. This is to find out what percent of pixels passing certain criteria imitate a good quality plan. Two tests are performed for the comparison between measured dose from Linac and calculated dose from treatment planning system. The first one included using four different gamma criteria for local dose. These criteria are 3%/3 mm, 3%/5 mm, 4%/4 mm and 5% dose difference (DD)/5 mm distance to agreement (DTA). It is performed by the suppression of the dose below either of 10%, 20% or 30% from the maximum of the reference matrix. The second test included using the same four gamma criteria but, in this case, for maximum dose. A comparison between local and maximum dose for every gamma criteria is then performed.

## Results & Discussion

### Point dose measurements:

The differences between the measured doses by ion chamber and that calculated for 30 patients (210 fields) using XIO TPS are expected to range from -2.6 % to 3.7 % for whole plan (mean and standard deviation equal  $0.46 \pm 1.7$ ) for head and neck tumors. In the home protocol one would expect the ionization chamber measurement to be within 3% of calculated dose. If the result gives a variation higher than 5% the QA procedure is repeated. If the variations are between 3% and 5%, the films or 2D-array can be used for evaluation. The present results show that 96% of ion chamber measurements vary less than 5% from calculated dose and about 75% of ion chamber measurements vary less than 3 % from calculated dose (Figure1). Dong *et al.*<sup>5</sup> reported that the mean difference between measured and calculated doses was greater than 3.5 %. Chung *et al.*<sup>16</sup> stated that the average difference between measured and computed dose at isocen-

ter for a gantry angle 0° for Head and Neck tumors was  $-0.55 \pm 1.51$ . This corresponded to a range of variation of -4.1% to +3.9%. Fenoglietto *et al.*<sup>17</sup> reported a value of  $1.33 \pm 3.22\%$  for the difference between measured and calculated dose for head and neck tumors. Syam Kumar *et al.*<sup>15</sup> reported also that a 0.6 cm<sup>3</sup> ionization chamber gave 2.23% of the measured isocenter absolute dose which was comparable to the calculated plan. In the present results the differences may reach a maximum of 9% for an individual field. It has been cited that this difference might reach a maximum of 10%.<sup>13</sup> This large error most probably emerges from the variation in intensities of modulated beam resulting from the positioning of the ion chamber in the penumbra region of intensity map of the field. This may occur because of the size of farmer type ionization chamber or due to the charged particles equilibrium around the ion chamber (Figure 2). The same observation is reported by several authors.<sup>15, 18, 19, 20</sup>

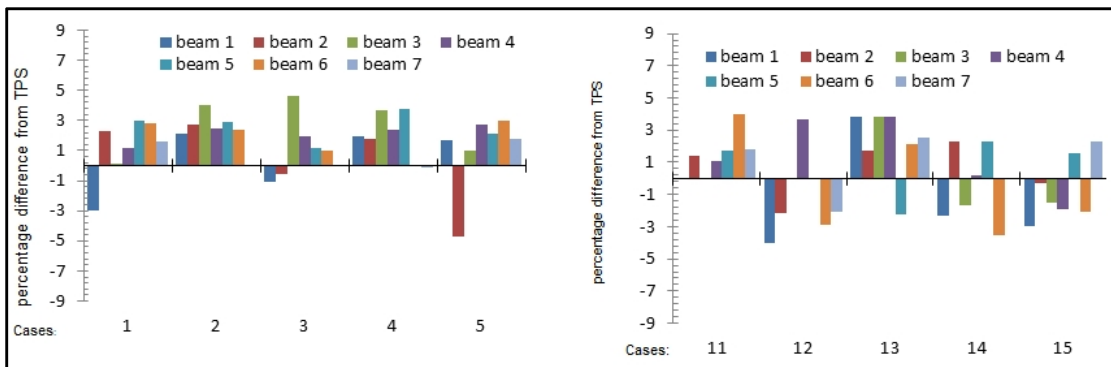


FIG. 1: Examples of relative difference in dose values between measured dose using 0.6 cm<sup>3</sup> ionization chamber and calculated dose using XiO TPS.

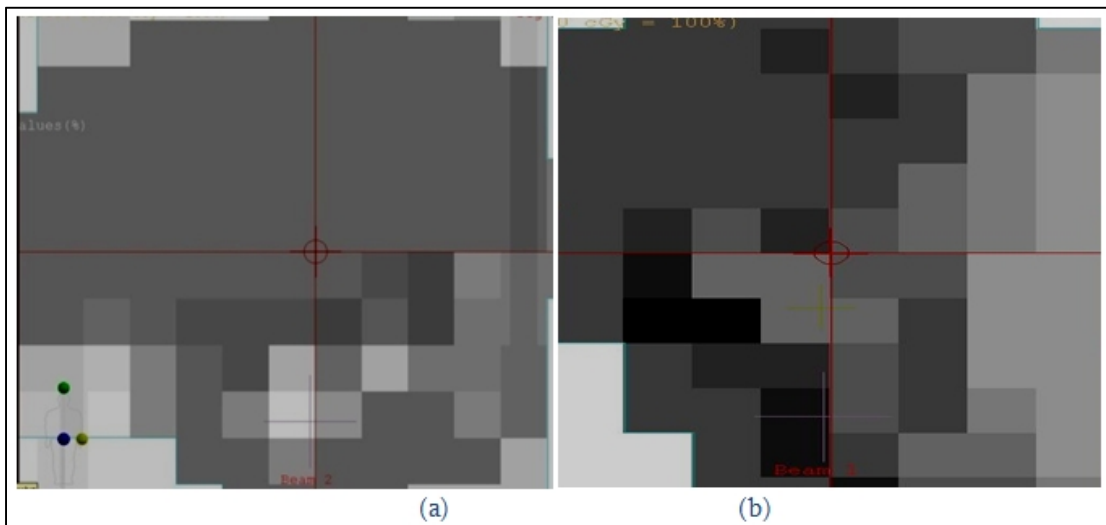


FIG. 2: Comparison between two fields having different intensities for head and neck IMRT cases: A large variation in intensity in the position of ion chamber can be seen.

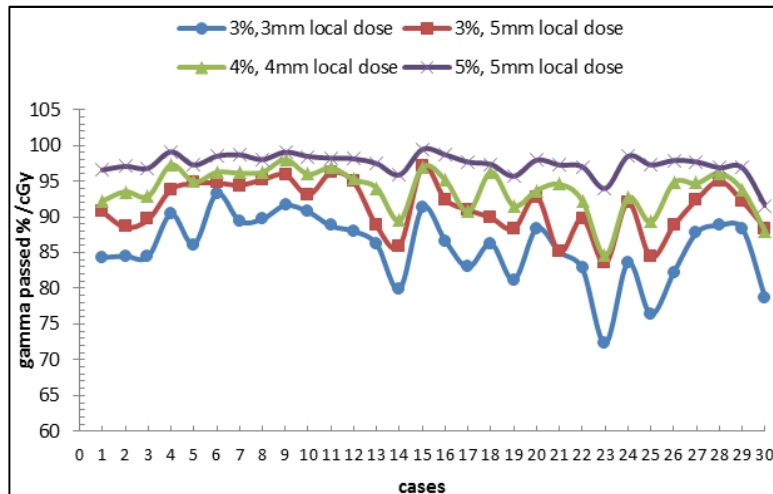
**Dose measurements using 2D-array**

Four different gamma criteria (dose difference(DD) /distance to agreement (DTA)) for 30 patients of Head and Neck tumors are compared to decide which criteria is to be used : 3%/3 mm, 3%/5 mm, 4% /4 mm and 5% /5 mm DD/DTA. Each of these criteria has been suggested elsewhere.<sup>2, 7, 21, 22</sup> The choice of the criteria is made so that as much information as possible can be obtained and observed. The dose differences between measured dose (in Linac) and calculated dose (in TPS) are evaluated while suppressing the dose of 10%, 20% or 30% from dose distribution. A comparison between the results obtained for all gamma criteria is given below:

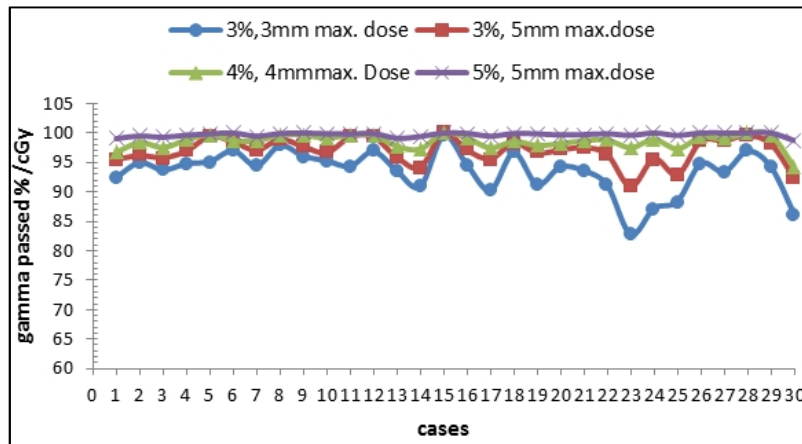
- I. Local dose: The comparison between four different gamma criteria while suppressing the doses below 10%, 20% or 30% for 30 patients of head and neck tumors is performed. The criteria of 3% / 3 mm shows gamma passed % < 90%. On the other hand, the criteria of 5% /5 mm shows gamma passed % greater than 95% for all suppression doses (10%,

20%, and 30%). **Figure 3** shows the gamma criteria of local dose excluding the lowest 20% of the dose distribution.

- II. Maximum dose: the gamma passed % dropped below 90% at 3% DD, 3 mm DTA, nevertheless the average data for each criterion has gamma passed % values exceeding 90%. Day *et al.*<sup>22</sup> used the gamma criteria of 4% DD and 4 mm DTA with the lowest 10% of the dose distribution excluded from all gamma and DTA analyses for head and neck cases using 2D-array for the quality assurance (QA) of IMRT. Their result was 99.7% for the average gamma pass rate. While Zhang *et al.*<sup>23</sup> found that the points passed ratio was more than 90% for 13%/3 mm gamma criteria. The authors did not specify whether their published results were calculated for maximum dose or local dose. **Figure 4** shows the gamma criteria of maximum dose excluding the lowest 20% of the dose distribution.



**FIG. 3:** The gamma criteria of local dose excluding the lowest 20% of the dose distribution using 2D array.



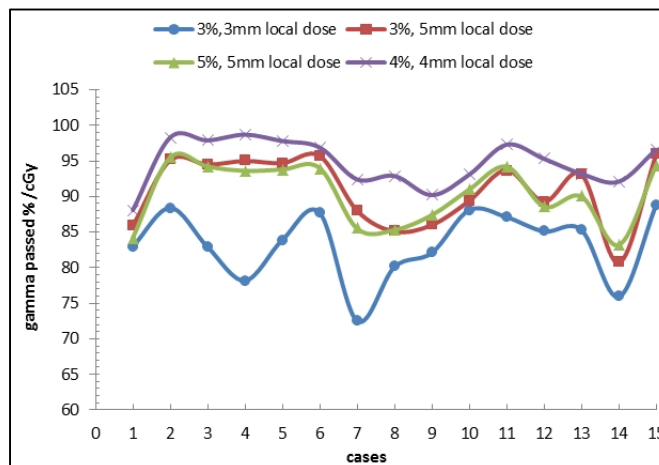
**FIG. 4:** The gamma criteria of maximum dose excluding the lowest 20% of the dose distribution using 2D array.

A comparison between local and maximum doses for different gamma criteria:

- I. When using gamma criteria of 3% DD 3 mm DTA and suppressing dose below 10%, the average and standard deviation for local dose of gamma index are  $81.70 \pm 6.28$  while those for maximum dose of gamma index are  $92.48 \pm 4.60$ . In case of suppressing the dose below 20% the average and standard deviation for local dose are  $85.67 \pm 4.74$  and for maximum dose are  $93.42 \pm 3.64$ . By increasing the value of suppressing dose below 30% the obtained data of average and standard deviation for local dose are  $86.40 \pm 5.51$  and for maximum dose are  $93.03 \pm 3.60$ . From the above mentioned results, it is clear that the maximum dose data always show better results compared to local dose for all gamma values. This large reported difference between the gamma values obtained for maximum dose compared to local dose necessitates that different authors clarify whether their published results are calculated for maximum dose or local dose.
- II. The calculations of average and standard deviation values for the other criteria (3%/5 mm, 4%/4 mm and 5% /5 mm) are listed in **Table 1**. All show greater gamma passed % values for maximum dose compared to local dose.

**TABLE 1:** The average and standard deviation values for the all gamma criteria using 2D-array.

Suppressing dose(cGy) below	3%/3 mm			
	local Dose		Maximum dose	
	Avg.	Stdv	Avg.	stdv
10%	81.96	6.28	92.48	4.60
20%	85.67	4.74	93.42	3.64
30%	86.40	5.51	93.03	3.60
	3%/5 mm			
	local Dose		Maximum dose	
	Avg.	Stdv	Avg.	Stdv
10%	89.81	4.11	96.72	2.78
20%	91.32	3.67	96.89	2.20
30%	91.78	3.69	96.65	2.32
	4%/4 mm			
	local Dose		Maximum dose	
	Avg.	Stdv	Avg.	Stdv
10%	90.91	4.41	98.17	2.65
20%	93.82	3.05	98.53	1.22
30%	94.10	3.69	98.37	1.32
	5%/5 mm			
	local Dose		Maximum dose	
	Avg.	Stdv	Avg.	Stdv
10%	95.7	2.65	99.46	1.32
20%	97.38	1.57	99.71	0.33
30%	97.66	1.90	99.65	0.38



**FIG. 5:** The gamma criteria of local dose excluding the lowest 20% of the dose distribution using film.

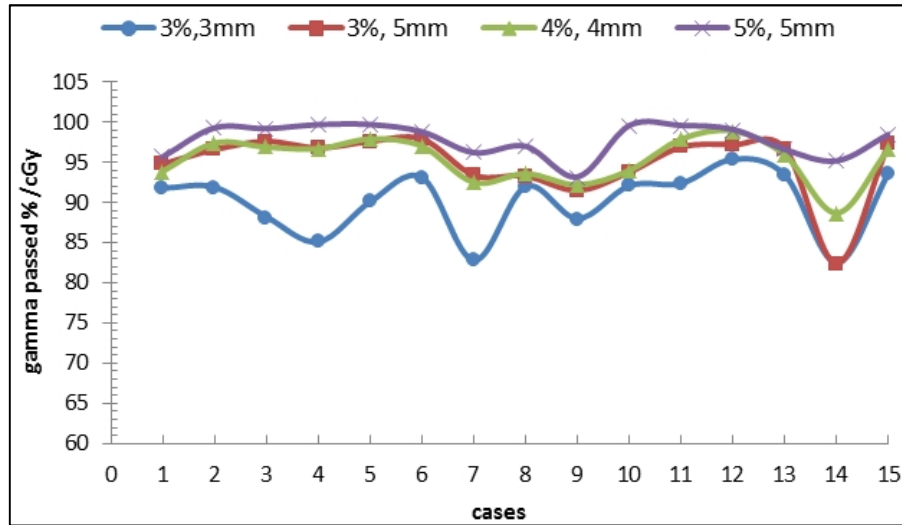


FIG. 6: The gamma criteria of maximum dose excluding the lowest 20% of the dose distribution using film.

#### Dose measurements using Gafchromic EBT2 Films

The same gamma criteria used in 2D-array measurements are applied for 15 head and neck cancer patients using Gafchromic EBT2 Films in order to compare efficiency of the different tools (2D-array vs. Gafchromic EBT2 Films). The obtained results are presented below:

- I. Local dose: Similar to 2D-array, the data shows the highest gamma passed % values (gamma passed % > 90%) for the 5% DD and 5 mm DTA gamma criteria while suppressing the dose below 30% for all gamma criteria. Also the criteria of 3%/3 mm yield gamma values below 90% as in the case of 2D-array. The gamma criteria of local dose excluding the lowest 20% of the dose distribution using Film are shown in **Figure 5**.
- II. Maximum dose: The acceptance limits for  $\gamma$  calculation are obtained for all gamma criteria. Unlike 2D array, the criteria of 3 % DD and 3 mm DTA yield values of gamma passed % less than 90% when suppressing the dose below 10 % only. All gamma criteria show highest values when suppressing the dose below 30%. Anjum *et al.*<sup>2</sup> compared between planned dose and irradiated dose distribution using GafChromic films. The gamma criteria of 3% dose difference (DD) and 3 mm distance to agreement (DTA) used for head and neck tumors in 96.3% of cases gave a gamma passed percent  $\geq 75\%$ . The gamma criteria of maximum dose excluding the lowest 20% of the dose distribution using Film are shown in **Figure 6**.

The calculation of average and standard deviation values for

all criteria (3%/3 mm, 3%/5 mm, 4%/4 mm and 5%/5 mm) are listed in **Table 2** all show greater gamma passed % values for maximum dose compared to local dose.

The results obtained with 2D-array are compared with numerous fluence distributions obtained with Gafchromic films for all criteria. Only minor differences in the value of gamma passed % are found. The data indicate a better performance for 2D-array compared to film. The results are within 0.4% to 3.3% for local dose and 1.6% to 4.3% for maximum dose. This is an expected result due to the possible errors resulting from scanning, temperature, and the dose to optical density calibration of the film. Ahluwalia and Saini<sup>24</sup> preferred the 2D-array than film and states that the differences between them were within 3 to 5%. Létourneau *et al.*<sup>25</sup> also preferred the 2D-array than film because the use of 2D-array could reduce the IMRT QA workload. Saminathan *et al.*<sup>8</sup> investigated the using of 2D-array in verification of IMRT comparing the data with films. The measurements and evaluation provided that 2D-array could be used for quantifying absolute dose and could also be used for routine quality assurance checks like flatness, symmetry, field width, and penumbra of the linear accelerator beam.

#### Comparison between film and 2D-array

##### Local dose

Statistical comparison between film and 2D-array for all criteria values while suppressing the 10%, 20% and 30% doses are carried out using Duncan multiple range test at  $p < 0.01$ . Significant differences are observed between the films and 2D-array only for 3%/3 mm criteria (for 10% dose suppression), 4% /4 mm and 5%/5 mm criteria (for 10% and 20% dose suppression).

**TABLE 2:** The average and standard deviation values for the all gamma criteria using film.

Suppressing dose(cGy) below	3%/3 mm			
	local Dose		Maximum dose	
	Avg.	Stdv	Avg.	stdv
10 %	80.19	4.73	88.45	4.04
20 %	83.27	4.69	90.17	3.86
30 %	84.51	6.07	90.57	4.98
	3%/5 mm			
	local Dose		Maximum dose	
	Avg.	Stdv	Avg.	Stdv
10 %	88.74	3.70	93.88	3.56
20 %	90.92	4.40	94.81	4.23
30 %	91.63	5.05	94.98	4.66
	4%/4 mm			
	local Dose		Maximum dose	
	Avg.	Stdv	Avg.	Stdv
10 %	88.66	4.24	94.29	3.28
20 %	90.69	3.73	94.98	3.74
30 %	91.51	4.32	95.13	4.19
	5%/5 mm			
	local Dose		Maximum dose	
	Avg.	Stdv	Avg.	Stdv
10 %	92.54	3.73	97.23	1.79
20 %	94.72	3.14	97.83	1.97
30 %	95.33	3.47	98.03	2.21

**Maximum dose**

Statistical comparison between film and 2D-array for all criteria values while suppressing the 10%, 20%, and 30% doses are carried out using Duncan multiple range test at  $p < 0.01$ . Significant differences are observed between the films and 2D-array for all criteria except the 3%/5 mm criteria.

**Conclusion**

It is clear that the maximum dose data always show better results compared to local dose for all gamma values which are performed by films and 2D-array. The films and 2D-array for local dose show best values for 5% DD and 5 mm DTA for gamma passed % > 90%. Also the best values are obtained when suppressing the dose below 30% for all gamma criteria. The criteria of 3%/3 mm show gamma values below 90%. For maximum dose when using the film, the criteria of 3% DD and 3 mm DTA give values of gamma passed % less than 90% when suppressing the dose below 10% only. All gamma criteria produced the highest values when suppressing the dose below 30%. Unlike film when using 2D-array, the average data for each criterion has gamma passed % exceeding 90%. This large reported difference between the gamma values obtained for maximum dose compared to local dose necessitates that different authors

clarify whether their published results are calculated for maximum dose gamma index or local dose gamma index.

The data indicate also a better performance for 2D-array compared to film. The results obtained with 2D-array are compared with numerous fluence distributions obtained with Gafchromic films for all criteria. Only minor differences in the value of gamma passed % are reported. These differences are within 0.4% to 3.3% for local dose and 1.6 % to 4.3 % for maximum dose. This is an expected result due to the possible errors resulting from scanning, temperature and the dose to optical density calibration of the film. The use of 2D-array can reduce the IMRT QA workload. Based on the results of this work, the criteria of 3% DD and 5 mm DTA while suppressing the dose below 20% are recommended. These criteria are also reported by Anjum *et al.* <sup>2</sup>. Under this criterion the percent of pixels passing gamma is > 95% in case of maximum dose.

**Conflict of interest**

The authors declare that they have no conflicts of interest. The authors alone are responsible for the content and writing of the paper.

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