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Dosimetric Verification of Grid Radiotherapy Using Three Ionization Chamber Detectors o Dosimetry

Najah A. Alanizy[1,4*], Ehab M. Attalla[2], Ahmed M. Abdelaal[3], Mohamed N. Yassen[4], Medhat W. Shafaa [4]

[1] *Aljwad Rdiotherapy Center, Baghdad, Iraq*

[2] *National Cancer Institute, Cairo University, Egypt*

[3] *Radiotherapy Department, Nasser Institute For Research and Treatment, Cairo, Egypt*

[4] *Physics Department, Medical Biophysics Division, Faculty of Science, Helwan University, Cairo, Egypt*

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Abstract:

This study aims to provide verification between measured and calculated radiation dose using three different ionization chamber detectors in Grid plans to select the best ones To the best of our knowledge, this is the first practical experiment in such subject. Grid radiotherapy is an unconventional method for bulky tumors treatment. It is characterized by a single-fraction and high radiation dose. Ten cases (scenarios) were selected to achieve Grid plans by MLCs, with a single dose of 1500-2000 cGy. Three ionization detectors were employed to measure the maximum, mean, and point doses (cGy), and match them with those calculated by the linear accelerator used in this study. The results showed significant differences among the three detectors in measuring the maximum and mean doses, with p-value = 0.0016 and 0.06, respectively. While the differences among the measured three detectors and calculated doses for the point dose were non-significant, p = 0.12. The variation in the results of the corresponding percentage between calculated and measured doses depended on the type and position of the detector, the scattering, and the leakage of the radiation. In conclusions, the Semi-flex chamber gives the best results.

Keywords: Grid, radiotherapy, verification, dosimetry

التحقق من الجرعات للعلاج الإشعاعي بالشبكة باستخدام ثلاثة كواشف بغرف التأين لقياس الجرعات

نجاح عبد المنعم عليوي[1,4*]، ايهاب معروف عطا الله[2] ،احمد موسى[3]، محمد نبيل ياسين [4]، مدحت شفاء [4]

[1] مركز الجواد(ع) لعلاج الاورام، بغداد، العراق

[2] المعهد القومي للاورام ،جامعة القاهرة ، القاهرة ، مصر

[3] قسم العلاج الاشعاعي ،معهد ناصر للبحوث والعلاج ،القاهرة، مصر

[4] قسم الفيزياء ، شعبة الفيزياء الحيوية الطبية ، كلية العلوم ، جامعة حلوان ، القاهرة ، مصر

*Email: najahalanizy@yahoo.com

الخلاصة

الهدف من هذا البحث هو دراسة وتقيم قياس الجرعات الاشعاعية بواسطة ثلاثة انواع من الكواشف للإشعاع المتأين في تقنية العلاج الاشعاعي الشبكي . العلاج الاشعاعي الشبكي هو طريقة غير تقليدية للأورام الضخمة والذي تتميز بجرعات عالية وبجرعة واحدة . اخترنا 10 حالات (سيناريوهات) لتخطيط شبكة radiotherapy بأورام مختلفة. تم استخدام ثلاثة كواشف للإشعاع المتأين لقياس قيم الجرعات ومقارنتها مع تلك المحسوبة بواسطة المعجل الخطي الذي تم استخدامه في هذه الدراسة .تم تصميم Grid radiotherapy بواسطة MLCs واعطاء جرعة واحدة (1500–سنت2000 راد) تم تقييم المطابقة بين الجرعة المحسوبة بالمعجل الخطي والجرعات المقاسة باستخدام ثلاث كواشف مختلفة لقياس للإشعاع .اختلفت النتائج بين اجهزة كشف الاشعاع الثلاثة واظهرت تباين ذو قيمة للجرعات الاشعاعية القصوى والمتوسطة حيث كان احتمالية الاختلاف p =0.0016, 0.06 للجرعة القصوى و 0.06 لمعدل الجرعة .بينما كان الفرق بين الكواشف الثلاثة المقاسة والجرعات المحسوبة للجرعة النقطية حيث كانت الاحتمالية 0.12. يعتمد التباين في نتائج النسبة المئوية المقابلة بين الجرعات المحسوبة والمقاسة على نوع وموضع الكاشف المستخدم والتشتت وتسرب.في الختام أعطي الكاشف شبه المرن افضل النتائج.

Introduction

Nowadays, oncologists are facing a remarkable problem when using radiotherapy for the treatment of dense and bulky tumors. Bulky tumor is difficult to treat by traditional radiotherapy because many normal tissues and organs at risk (OARs) could still receive doses higher than their tolerance dose [1]. These observations led to the emphasis on finding new insights into modified fractionation treatment, such as Grid radiotherapy. This method uses a single, high dose to increase the dose and enhance local tumor control, thereby treating patients with advanced and bulky tumors [2]. In this model, an open X-ray field is set to divide multiple tiny radiation beams, using an external block. This block is fabricated from lead metal or cerrobend alloy. It can also be created by using the MLCs system that is found in the Linear Accelerators (Linacs) machine [3].

The Grid RT is an efficient curative and palliative technique of multiple narrow beams of radiation used for cancer treatment. A high single dose of 1500-2000 cGy is used in Grid radiotherapy. In addition to the direct effect on DNA, the impacts of high-dose radiation on the tumor microenvironment may play a role in tumor control by inducing damage in irradiated cells and adjacent non-irradiated cells by bystander and abscopal effects [4].

Also, this method had various impacts on tumor cells re-oxygenation, vascular damage, and immunological interactions [5]. Previous research reported the high potential to protect normal tissues using this method, while various kinds of tumor were treated [6-7].

Ahmad *et al*. [8] studied the commission of a Grid block radiotherapy treatment and verification using the record and verify system in different radiation fields. They noticed that the percentage difference between the results of the Grid block technique calculated by the Treatment Planning System (TPS) and the measured data with the PinPoint ion chamber was 3.6% for the small field size 5x5 cm2. Also, they reported that the Grid radiotherapy method based on MLCs is easy to use, given the MLCs found in the linear accelerator (Linac).

Another study by Jin *et al*. [9] used an MLCs-based 3D Grid-therapy technique which generates ablative high-dose radiation that can be delivered to many small spheres (Grid design in their study) for large tumors. Virtual phantom was mapped by TPS using Gafchromic (external beam therapy 3 EBT3) film (International Specialty Products, Wayne, NJ) to measure the delivered dose distribution by a Linac machine. The measured dose distribution by EBT3 film showed a good agreement when compared with the dose distribution by TPS. Also, they recommended studying Grid radiotherapy clinically to validate the safety and efficacy [9].

Experiments with this procedure revealed outstanding tumor response results, which enhanced the motivation to continue technological developments in this field [10].

This study aims to compare dosimetric data calculated by TPS with those measured by three types of the ionization detectors in Grid plans to select the best detector, which will use the dosimetry of the Grid plan radiation to deliver a high dose to the tumors accurately and precisely. Our study represents the first practical experiment in this subject.

Materials and Methods

This study was carried out in the Nasser Institute for research and treatment, department of Medical Physics, Cairo, Egypt, from February 2020 to May 2021. Ten cases of bulky tumors of diameter > 6 cm from various cancer types and sites were selected. Each case was scanned with a CT simulator (Siemens, Somatom AS, Garmany) that has 24 rotating multi-slices. The CT images were sent to the sim working station (Monaco, Elekta, Sweden) for delineation of the bulk mass tumor and the adjacent OARs.

Ionization chambers detectors

1- *Farmer Ionization Chamber (30010, PTW, Freiburg, Germany)*
This chamber is designed for measurements with high reproducibility in air, solid phantom, or water phantom. It is suitable for absolute dosimetry of photon, electron, and proton beams at radiotherapy(Sensitive volume = 0.6 cm3, sensitive radius = 3.05 mm and length = 23.0 mm.
2-Pinpoint Ionization Chamber Detector (31014, PTW, Freiburg, Germany)
This is an ultra-small cylinder with an inner diameter of 2 mm and a size of 0.016 cm3. It is used in small field measurements for dose calculations in radiotherapy.
3- *Semiflex Ionization Chamber Detector (3101, PTW, Freiburg, Germany)*
This is a tiny cylinder with 5.5 mm inner diameter and 0.125 cm3 volume. The wall material is graphite with a protective acrylic cover. It is used as a standard therapy chamber for measuring doses.

2- Spatially fractionated RT (Grid) design

To design a Grid plan for each case, a field of the radiation beam was divided by MLCs into multiple sub volumes, where the area of each open and close sub-field is 1 cm^2 and the distance from center to center of open or close subfields is 2 cm in any direction. A single dose 1500 or 2000 cGy with an energy level of 6 or 10 MV X-rays (depending on the tumor size and depth) was employed, as shown in Figure 1.

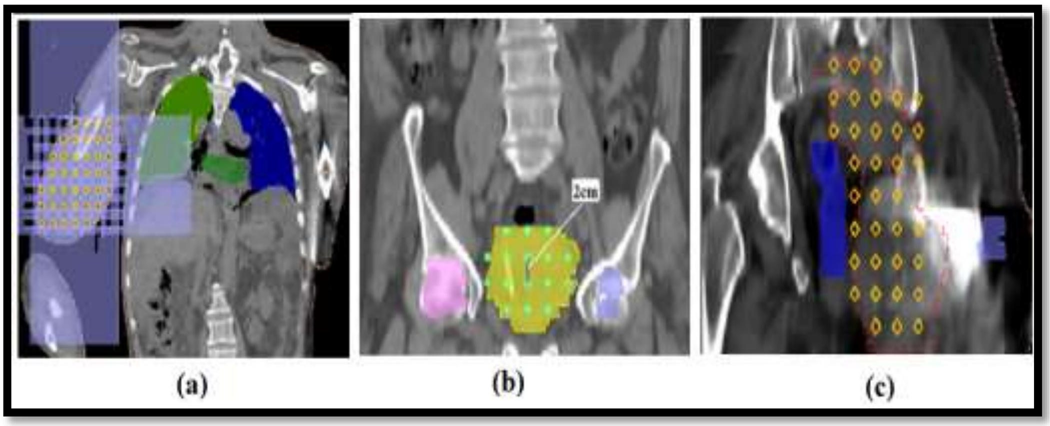

Figure 1: Screenshots for coronal views for 3 cases in sarcoma tumor (A), Bladder tumor(B), and pelvic tumor(C), taken from Monaco TPS, Nasser Institute, Cairo, Egypt.

3- Criteria for dosimetric measurement and calculation

Three different ionization chamber detectors (Farmer, Sim-flex, and Pin-point) were used to measure radiation doses by Ion Beam Application (IBA) (Schwarzenbruck, Germany) with Perspex sheets (phantom) in the Grid plans. The ion chamber was placed in an isocenter point of an open area of the radiation field, as shown in Figure 2-a and 2- b, and to the scan CT as shown in Figure 2 c. The CT scan images were exported to the Monaco workstation sim. All data of all parameters for each Grid plan were transferred from the TPS to the phantom. Next, the TPS calculated the dose in phantom with ion chamber, which was represented as the target of the Grid plan.

Each plan on the phantom was calculating the doses and exporting them to the Mosaic medical network. To measure the radiation doses, the solid phantom with ion chamber was irradiated in the Linac, as shown in Figure 2-d. For each Grid plan, the difference between the measured and calculated doses in solid phantom was evaluated by comparing their data from the chamber reading. These steps were repeated for each detector with each Grid plan.

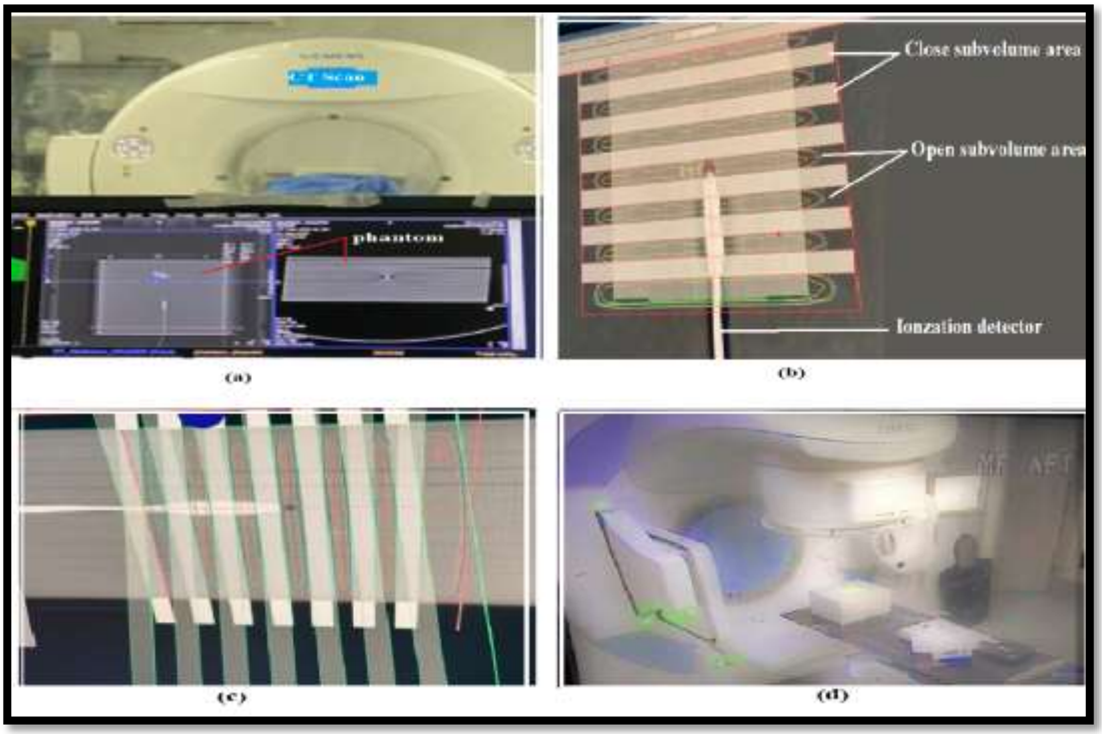

Figure 2: Screenshots for CT scan detector with detector (a), setting a detector in the center of open subfield area (hot spot area) (b and c), and setting up of detector with phantom in treatment room linac (d).

4- Match percentages of measured and calculated doses

The comparison of the calculated and the measured radiation doses for Grid plans was performed based on equation (1).

$$MP = Dcalc – D meas / D meas \times 100\% \quad \ldots\ldots\ldots \quad (1)$$

where MP is the match percentage, while Dcalc = the value of the radiation dose calculated by the TPS, cGy; Dmeas = the values of radiation dose measured by the three detectors. This equation was aligned with the Technical Report Series TRS-430 [11].

5- Statistical analysis

The analysis of results was achieved by using SPSS version 24 to describe the data for the three different detectors with Grid plans. The mean and standard deviation (SD) for dosimetric data were calculated. The coefficient of variation (CV) to compare between detectors was applied. Basically, CV<10 is very good, 10-20 is good, 20-30 is acceptable, while CV>30 is not acceptable. Moreover, the nonparametric Friedman test was calculated to compare the three different doses measured by the detectors and the differences were considered significant when the p-value was < 0.05.

Results and Discussion

Table 1 shows a comparison the mean ± SD of the match percentage of the (maximum, mean, and point) radiation doses measured by three different ionization chamber detectors, using Eq. (1), with those calculated by TPS for the various (scenarios) Grid plans. Also, the coefficient of variation between match percentage was calculated.

The data listed in this table showed a low match percentage in pinpoint detector, where the CV values for maximum, mean and point dose were 9.05%, 10.5% and 9.01%, respectively, which could be attributed to the fact that the pinpoint detector has a high sensitivity of low doses that found in shield area by MLCs in Grid plan. Therefore, this leads to higher values of measured than calculated doses [12].

The results showed that the doses measured by Farmer and Semiflex detectors (maximum, mean, and point) radiation doses were in a very good match with the doses calculated by TPS, where the CV values were (7.9%, 8.38% and 5.04%) and (4.17%, 5.27% and 3.51%,), respectively, as shown in table 1; the lower value of CV, the more precise the estimate. Several factors affected these results; for instance, the type and the position of the tumor and the position of MLCs to protect OARs in Grid radiotherapy [13]. In addition, the setup and shifting of the chamber into an open area according to each case was different, as shown in Figures 1 and 2.

Our results agree with that obtained by Abdelaal *et al.* [14], who studied radiation doses outside the boundary of the radiation field by using Pin-point and Semi-flex ionization chambers. They found that the measuring radiation doses were increased by 6% and 5.5% for Pinpoint and Semi-flex, respectively, with the increase in field size.

Table 1: The variation of the match percentage between measured dose by Farmer, Semiflex and Pinpoint ionization chambers with that calculated doses by TPS for (maximum, mean, and point doses cGy) for different (scenarios) Grid plans.

	Mean ± SD		
Detector	Maximum dose	Mean dose	**Point dose**
Farmer	90 ± 0.07	87 ± 0.07	**89 ± 0.04**
Semiflex	94± 0.03	87± 0.04	**92 ± 0.03**
Pinpoint	81 ± 0.07	76 ± 0.07	**81 ±0.07**
		CV	
Farmer	7.9	8.38.	**5.04**
Semiflex	4.17	5.27	**3.51**
Pinpoint	9.05	10.50	**9.01**

In addition, our results are in agreement with the findings reported by Ahmad *et al*. [8], who observed up to a 10% difference in measuring for a 5-mm beam of radiation. This is due to the quantity of scattered radiation which is directly proportional to field size.

In contrast, in the present study, the measured values of the maximum and point radiation doses using Farmer detector were lower than those calculated by TPS. This outcome is in agreement with the findings of El Shahat *et al*. [15], who conducted the dosimetric analysis for small field 1x1 cm^2 and reported that the measured doses in the phantom were less than those calculated by TPS. These results were related to the notion that the electronic equilibrium was not adequate for complete photons scattering from the Linac of photon beam energy 6 MV.

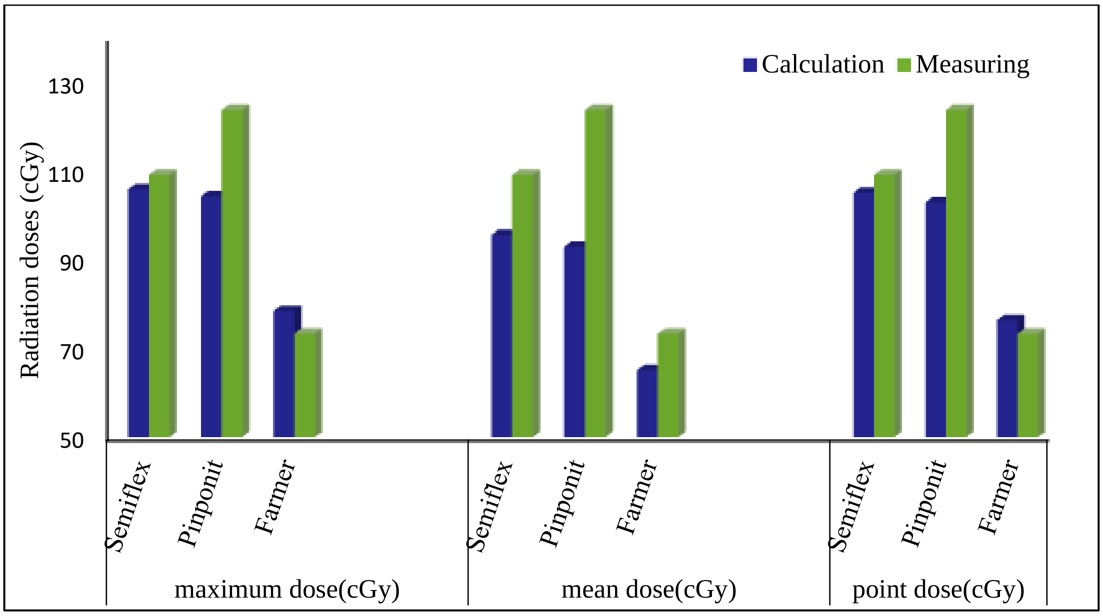

Figure 3: The variation of the mean of the (maximum, mean and point) radiation dose calculated by TPS (blue color) with measured radiation doses (green color) by three different ionization chambers.

Figure 4 shows significant differences between the doses measured by the three detectors (Farmer, Semiflex and Pinpoint) used in the Grid plans. The maximum and mean doses were different at p-value = 0.0016 and 0.06, respectively. While the difference between the measured doses by the three detectors and the calculated point dose was non-significant ($p = 0.12$), when we placed each detector in the correct point in the open sub-area of the radiation field, as shown in Figure 2 –b. This result agrees with Escudé *et al*. [16].

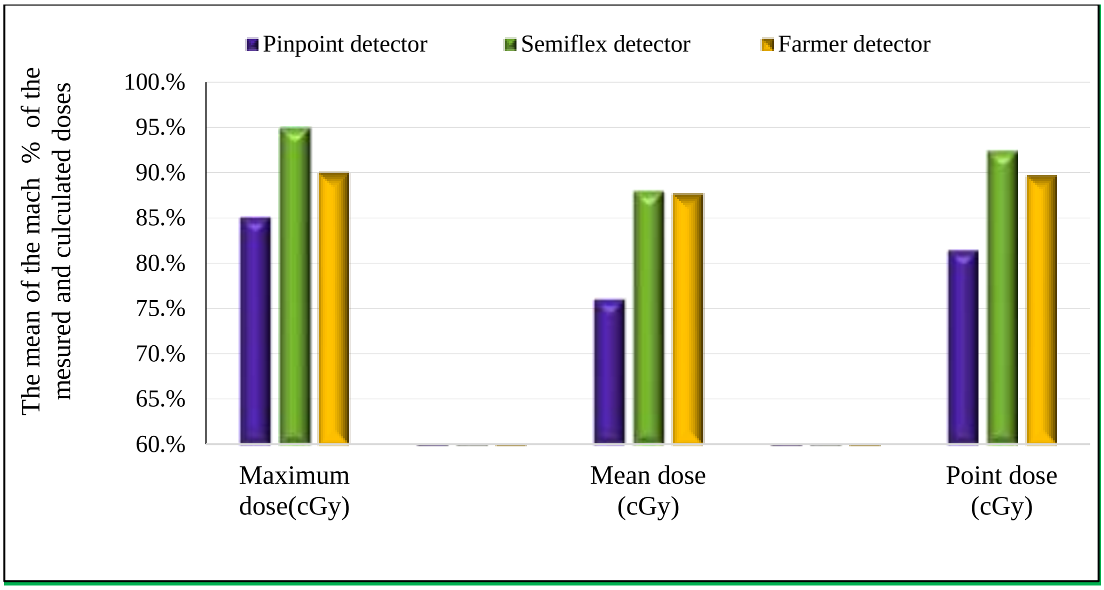

Figure 4: The variation of the mean of the match percentage of the maximum, mean and point (cGy) radiation doses calculated by TPS with the measured radiation dose using three ionization chambers.

These results of this study agree with the mechanical setup of the Grid plan with MLCs, where the Grid field is divided into many sub volumes by MLCs, which leads to increase radiation leakage through the MLCs; therefore, the ionization detectors measured radiation doses higher than that dose calculated by the TPS [13]. Also, factors like leak of photons from the Linac's head, collimators of the beam, and filters flattening (head scattering) caused increases in the measured doses [17]. Other researchers mentioned that the increase in the field size increases the surface dose, which is attributed to the scattered radiation. All these factors tend to have measured doses values higher than the calculated ones [18]. These property tend to increase the measured radiation doses to values higher than the calculated doses, leading to low match percentage [11].

Conclusions

Grid radiotherapy for bulky tumors using a high radiation dose requires accuracy and careful dosimetry verification by specialist staff of dosimetry and radiotherapy. Also, careful consideration must be taken of the selection and setting of the ionization detectors. We found a large variation in dosimetry in this study. Semiflex chamber provided the best results.

Future work

Grid radiotherapy applied by high dose needs more dosimetric studies; for example, gamma evaluation and biological studies on the outcomes of the equivalent uniform dose and biological equivalent dose on tumor and normal cells.

Conflict of Interest: The authors declare that they have no conflicts of interest.

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