RESEARCH ARTICLE

Editorial Process: Submission:03/31/2023 Acceptance:08/07/2023

Problems Affecting Accurate Dose Measurement in Small-Field for Linear Accelerator

Abdullah Megahed[1], Gamal M. Hassan[2], Khairy T. Ereiba[3], Elsayed M. Alashkar[3]*

Abstract

Background: The use of relatively narrow fields has become necessary with the advent of intricate and accurate radiation therapy delivery dose to patients; therefore, small-field dosimetry faces several difficulties. Both dose calculations and measurements require to be performed with extra care, due to the uncertainty that might be increased by using such small field sizes. **Material and Methods:** In this study, we investigated the effect of detectors size on the dosimetry of small fields [starting with radiation fields from (1cm x 1cm), (2cm x 1cm), and (3cm x 1cm)...etc., up to (4cm x 5cm) and (5cm x 5cm)]. We used the linear accelerator and different types of ionization chambers i.e. [Farmer FC65-P, CC13, and CC01 (pinpoint)] an addition to semiconductors i.e. (IBA Razor diode)], and we investigated all detectors to read the absorbed dose in water under the reference conditions (field 10cm x10cm, SSD 100cm and depth 10cm). **Results:** While measuring the absolute dose under reference conditions, all detectors had a non-significant difference of less than ±2%, except for the Razor diode, which showed a significant difference of ± 5%. On the other hand, when small fields were measured, we discovered a significant difference of 48%, compared to the Razor diode. **Conclusion:** The Razor diode is more stable in small-field dosimetry than other detectors. Also, the Razor Diode is intended for relative dosimetry but, it shall not be used for absolute dose measurements.

Keywords: Absolute Dose- small field dosimetry- ionization chamber- razor diode

Asian Pac J Cancer Prev, **24 (8)**, 2757-2764

Introduction

The majority of cancer patients will require radiotherapy at some time during their illness, either for curative or palliative purposes, making it an important part of a multidisciplinary cancer treatment approach (Thakur et al., 2022).

With the introduction of novel techniques in radiotherapy such as Image Guided Radiotherapy (IGRT), Intensity Modulated Radiotherapy (IMRT) (Laub and Wong, 2003), Volumetric Modulated Arc Therapy (VMAT) (Wolfs et al., 2018), Stereotactic radiotherapy (SRT) (Beddar et al., 2006), Stereotactic Radiosurgery (SRS) (Pettiet al., 2021), and Stereotactic Body Radiotherapy (SBRT) (Benedict et al., 2010), that can be made the treatment radiation field into small segments and narrow fields to deliver a high radiation dose to the target volumes with limiting damage to the normal tissues for this purpose, there have been many developments in treatment machines. In contrast, this technique has increased the uncertainty of clinical dosimetry and weakened its traceability to reference dosimetry; Conventional Codes of Practice (COPs) such as Technical Reports Series (TRS-398) (Musolino, 2001), the American Association of Physicists in Medicine (AAPM) publication titled AAPM's TG-51 Protocol (Almond et al., 1999).

In radiotherapy, we can define the small field as that field with dimensions smaller than the lateral range of the electrons that contribute to the dose, the Multi-leaf Collimators (MLC) roughly can be made in narrow field sizes up to 1cm x 1cm or less, so at least one of the following three physical conditions are generally considered to determine if an external photon beam can be designated small: (a) Lack of charged particle (Loss of lateral charged particle equilibrium) LCPE. (b) There is partial occlusion of the primary photon source by the collimating devices on the beam axis. (c) The size of the detector like or larger than the cross-sectional beam dimensions at the depth of measurement (Palmans et al., 2018).

The selection of an appropriate detector for dosimetry in small fields is challenging, and it is necessary to choose a suitable detector with the best performance, and not all detections of ionization chambers are sensitive enough to radiation dosimetry (Zhu et al., 2009), also, there is

*[1]Department of Radiotherapy, Shefaa-Alorman Hospital, Egypt. [2]Ionizing Radiation Metrology Laboratory, National Institute of Standards (NIS), Egypt. [3]Physics Department, Faculty of Science, Al-Azhar University, Egypt. *For Correspondence: ph.alashkar@azhar.edu.eg*

no common agreement among researchers on the use of specific detector types. Some studies have investigated the effect of the construction and size of detectors in small radiation fields (Scott et al., 2012; Underwood et al., 2013). Researchers have frequently evaluated the effectiveness of various detectors at dose distribution measurements, but most of them focused only on the stereotactic radiation field created by radiosurgery devices and circular cones, a few studies focused on small fields used in beamlets of linear accelerators.

IMRT and VMAT fields use small segments shaped by MLCs of Linac for dose delivery, so a consensus has been that suitable detectors must be considerably smaller than the field size as it impacts detector readings when charged particle equilibrium (CPE) breaks down around the sensitive volumes of detectors (Das et al., 2008a), which could lead to significant uncertainty in the accuracy of clinical dosimetry (Bich, 2014) compared to traditional radiotherapy, as we pointed out that accurately measuring absolute dose or output factors at an absorbed dose to the water at sub-centimeter fields was very difficult, so the IAEA recommended appropriate detector systems and measurement methodologies at TRS-483 (Palmans et al., 2018). An overview of the issue of LCPE and the changes in photon beam perturbations with decreasing field size were provided. The dosimetry and commissioning of traditional large field sizes starting from 5cm x 5cm and more up to 40cm x 40cm used high photon energy in radiotherapy has been addressed in several reports of the TG-106 (Das et al., 2008b). These and other dosimetry protocols are based on measurements using an ionization chamber of absorbed dose to water, traceable to International Standards of units dosimetry laboratory (PSDL) at reference conditions, such as a conventional field size of 10cm x 10cm (Allisy et al., 2009).

In conventional broad beams, it is derived from a ratio of detector readings due to the practical independence of perturbation correction factors on field size (Alfonso et al., 2008). In small-field dosimetry, however, such independence does not exist, notably for perturbation factors, and an output factor of absolute dose to water measurements will in almost all cases require an output correction factor to the measured detector reading ratio relative to the machine-specific reference field (fmsr). The symbol for a field output factor in IAEA TRS-483 is clinic field (fclin); (fmsr) (Qclin); (Qmsr) and Report of AAPM TG 155 (O'Brienet al., 2016; Palmans et al., 2018). Field output correction factor. A field output correction factor is a correction factor that accounts for the differences between the response of a detector in a non-reference (clinical) field and that in an msr reference field (Das et al., 2021), and accordant to TRS-483 (Palmans et al., 2018) and Joint Committee (Prieto et al., 2015) in uncertainties for small field measurements. It has been shown that measurement uncertainty increases from ±2% at 10cm x 10cm to ±5% at 5cm x 5cm and is smaller than that (Zhao et al., 2022).

Materials and Methods

Detectors specification

Dose distribution measurements were done for different radiation fields from 1cm x 1cm to 5cm x 5cm, in addition to the reference field size of 10cm x 10cm. In measurements, we used the Elekta Synergy linear accelerator with photon energy beams of 6 MV & 10 MV and different types of ionization chambers (FC65-P, CC13, and CC01) and IBA Razor diode detector, with specifications, summarized in (Table 1).

The detectors were calibrated before this study; to insure the high accuracy of the machine output measurements.

Phantom specification

In the present work, the measurements were performed in a water phantom (IBA Blue Phantom), three-dimensional scanning (48 x 48 x 48 cm^3). A common control unit is integrated with the phantom that acts as an interface between the phantom and computer software which allows the ion chamber and IBA Razor (diode) to place remotely controlled.

Electrometer specification

Electrometer: (IBA DOSE-2) is a portable, dual-channel, high-precision reference class electrometer for measurements of absorbed dose.

Methods

The setup was first benchmarked with a set of measurements of the absolute dose under reference conditions in high energy photon beams at10cm depth in a water phantom using 110cm source-to-chamber (SCD) distance or 100cm source-to-surface distance (SSD) and field size (10cm × 10cm), that's showing in Figure 1.

The detector placement is in the parallel direction of radiation field at measuring with the Razor diode and perpendicular direction at other detectors as shown in Figure 2. The measurements based on the IAEA TRS-398 protocol (Musolino, 2001).

The characteristics curves of PDD curve and lateral profiles (at different depths of dmax, d50 mm, d100 mm, and d200 mm) was measured at reference parameters for photon beam energies 6MV and 10 MV as a calibration test of the machine output before beginning of this study as shown in Figure 3, Figure 4, and Figure 5.

Formalism for fields

In this study, we have used formalism based on Alfonso et al., 2008 proposed a new formalism for reference dosimetry of small and non-standard fields that establishes a relationship of Codes of Practice (CoP) applicable to conventional radiotherapy techniques. According to newly proposed techniques, the total dosimetry process is performed in fmsr matched with the conventional 10 cm× 10 cm reference field.

The measurement of absorbed dose to water in reference condition

$$D_{w,Q_{msr}}^{f_{msr}} = M_{w,Q_{msr}}^{f_{msr}} \cdot N_{D,W,Q_0}^{f_{ref}} . K_{Q,Q_0}^{f_{ref}} \cdot K_{Q_{msr}\,Q_0}^{f_{msr},f_{ref}} \qquad (1)$$

$M_{w,Q_{msr}}^{f_{msr}}$ Measured absorbed dose to water in reference field dosimetry (msr) with corrected (pressure, temperature, ion recombination, polarity effects, electrometer factor, and beam quality factor).

$N_{D,W,Q_0}^{f_{ref}}$, the calibration factor of the ionization chamber in terms of absorbed dose to water, performed in Co^{60} beams at the national standards laboratory, $K_{Q,Q_0}^{f_{ref}}$ is beam quality correction factor, and $K_{Q_{msr}Q_0}^{f_{msr},f_{ref}}$ is another correction factor arising from the change of field size, shape, phantom material, and beam quality from the reference condition.

The absorbed dose in small field f_{clin} is different from the reference field f_{msr} so we have a new output factor of small field Ω that's depending on the field size.

$$D_{w,Q_{clin}}^{f_{clin}} = D_{w,Q_{msr}}^{f_{msr}} \, \Omega_{Q_{clin}\,Q_{msr}}^{f_{clin},f_{msr}} \quad (2)$$

$$\Omega_{Q_{clin}\,Q_{msr}}^{f_{clin},f_{msr}} = \frac{D_{w,Q_{clin}}^{f_{clin}}}{D_{w,Q_{msr}}^{f_{msr}}} = \frac{M_{Q_{clin}}^{f_{clin}}}{M_{Q_{msr}}^{f_{msr}}} \cdot K_{Q_{clin},Q_{msr}}^{f_{clin},f_{msr}} \quad (3)$$

IBA Razor diode (chamber) calibrated with measured using the following formula:

$$N_{D,W,Q_{cross}} = \frac{\mathbf{D_{ref}}}{M_{clin}} \quad (4)$$

Monitor unit; ND,W,Q0 this isN_(D,W) in protocol TRS-398 (Laub and Wong, 2003) and AAPM TG-51 (Almond et al., 1999) cross-calibration factor is used reference ionization chamber to measure the dose at the reference field (10cm × 10cm), then used the IBA Razor diode chamber at the same condition obtained by electrometer reading (nC).

In output factor measurement, the typical normalized reference field was much larger than the small fields; to minimize the error one option is to be correct factors are the basic requirement for the calibration (O'Brien et al., 2016; Francescon et al., 2020).

So, the correction factors are implemented using the following equation:

$$\text{Correction Factor} = \frac{\left(\frac{D_{ref}}{D_{diode}}\right) small}{\left(\frac{D_{ref}}{D_{diode}}\right) ref} \quad (5)$$

Results

a-The absorbed dose in the water phantom measured at reference parameters [field size 10 cm × 10 cm,100 cm SSD, 10cm depth in water, and 100 Monitor Unit (MU)]. IBA Farmer 0.65 (ionization chamber) was used for photon energies (6 MV and 10 MV), and the beam quality index (Q0) for high energy photon beams was used according to the relation with the Tissue Phantom Ratio as reported in $TPR_{20,10}$ (Andreo et al., 2002) specified in IAEA TRS-398 [the beam quality Q0 = 0.590 for 6 MV, and = 0.63 for 10 MV].

$$D_{W,Q} = M_Q \, . N_{D,W,Q_0} \, .K_{Q,Q_0}$$

$$D_{W,Q} = M_Q \, . N_{D,W,Q_0} \, .K_{Q,Q_0} \, . K_{tp} \, . K_{pol} \, . K_{ele} \, . K_s$$

For 6 MV

$D_{W,Q,6MV}$= 0.678Gy/MU

For 10 MV

$D_{W,Q,10MV}$= 0.729Gy/MU

b-The IBA Farmer FC 65-P, CC13, and CC01 (Ionization chamber) are calibrated at the National Institute of Standards (NIS). We measured the cross-calibration factor for IBA Razor (diode) at 100cm SSD, 10cm depth in water phantom which has been measured in ten measurements and then took the average measurements for taken the cross-calibration according to TRS-398 (Musolino, 2001).

For 6 MV

$N_{D,W,6MV}^{f\ 10\ X\ 10}$=0.27635Gy/C

For 10 MV

$N_{D,W,10MV}^{f\ 10\ X\ 10}$= 0.2774Gy/C

c- In the study of the variation in different detectors with different narrow field sizes, we have found the following:

In the beginning, when we measured the absorbed dose rate to water at Percentage depth dose (PDD) at Z reference for a field size of 10cm x 10cm, we found that's the doses are almost the same approximately 67% at energy 6 MV and 72 % at energy 10 MV for all detectors except for IBA Razor (diode) and which has a greater doses than the one that was 71.8% at energy 6 MV and 74.8% for energy 10 MV. Secondly, at fields smaller than 4 cm x 4 cm, the detector becomes too larger than the diameter of the radiation field, which leads to LCPE, and, the closer we get to the 1cm x 1cm (Bouchard et al., 2015), the clearer the vision on the loss of charged particle and high overlapping radiation beams, on the other hand, the small detectors size have enough diameter with low overlapping these are shown in Figure 6 for energy 6 MV all detectors, there is a substantial difference as a function of LCPE in small fields from 1 cm x 1 cm bottom up 4cm x 4 cm with a large substantial difference in LCPE in Farmer 0.65 about 48% compared with Razor reads.

In Figu 7 for energy 10 MV we found the same substantial difference as a function of LCPE, with higher substantial at farmer 0.56 compared with energy 6 MV.

Table 1. The Detector Types and the Basic Specifications of Each Detector.

Detector Type	Active volume (cm^3)	Diameter (cm)	Total active Length (cm)
IBA Farmer FC65-P Ion chamber	0.65	0.62	0.23
IBACC13 Ion chamber	0.13	0.6	0.58
IBACC01 Ion chamber	0.01	0.2	0.36
IBA Razor –diode	0.003	0.06	0.4

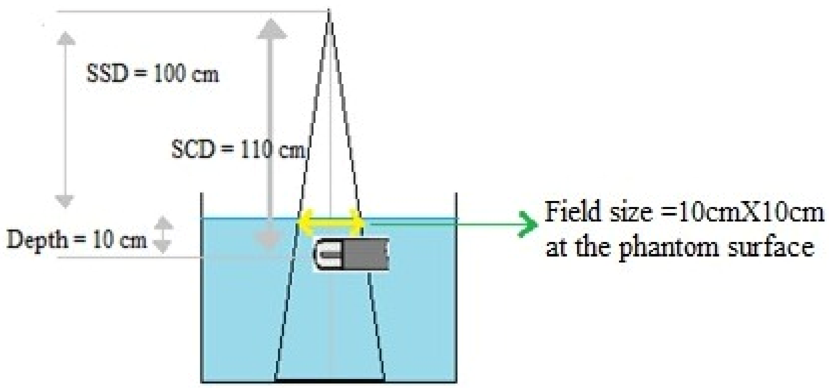

Figure 1. Schematic Diagram Shows the Detector Setup of Measurements under the Reference Conditions According to the IAEATRS-398 Protocol.

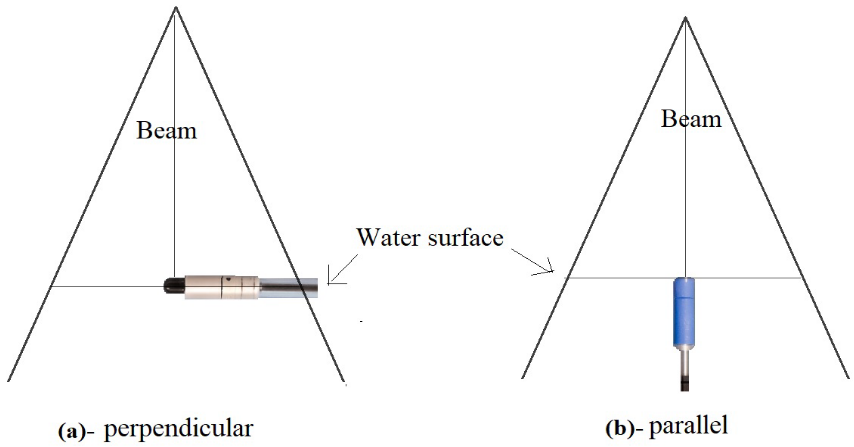

Figure 2. Schematic Diagram Showing the Detector Direction during the Measurements, under the Reference Conditions, (a) showing the perpendicular direction for all detectors, and (b) showing the parallel direction for Razor diode.

d- Correction factor

The correction factor is calculated from this experiment for Razor (diode) chamber by following equation 5 is represented in Figure 8 for energy 6 MV and in Figure 9 for energy 10 MV. The correction factor measured from an experiment was found excellent and in agreement with the literature values for the small field.

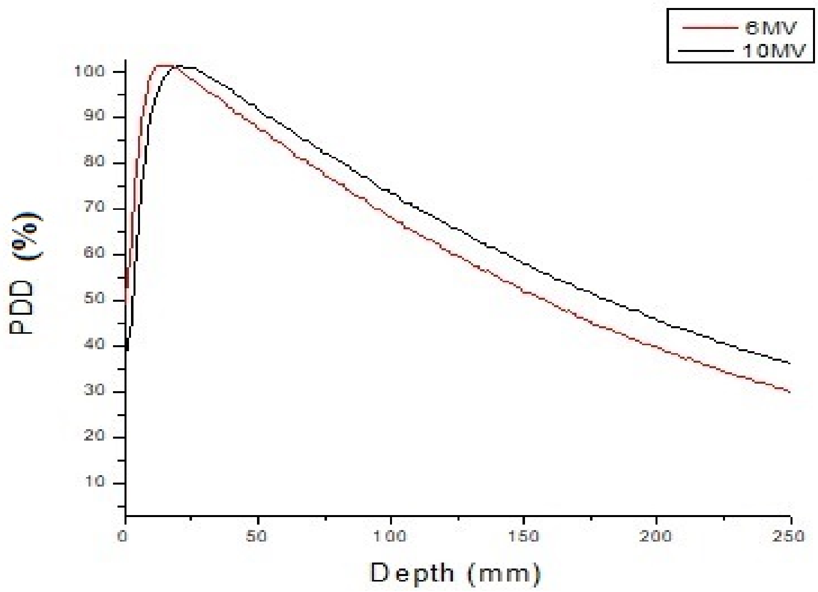

Figure 3. Percent Depth Dose (PDD) as a Function of the Water Phantom Depth, for the Photon Beam Energies of 6 MV and 10 MV.

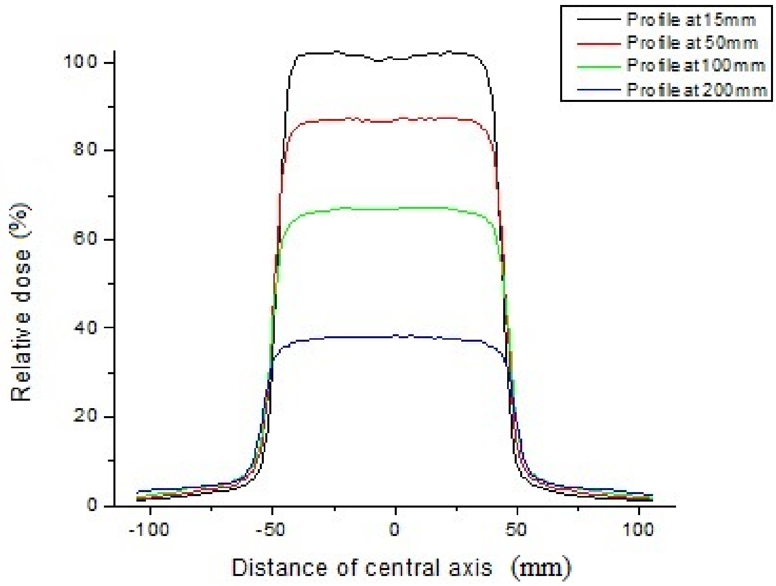

Figure 4. Lateral Beam Dose Profiles Measured in Water Phantom at Different Depths for Photon Beam Energy of 6 mV (dmax, d50 mm , d100mm, and d200mm).

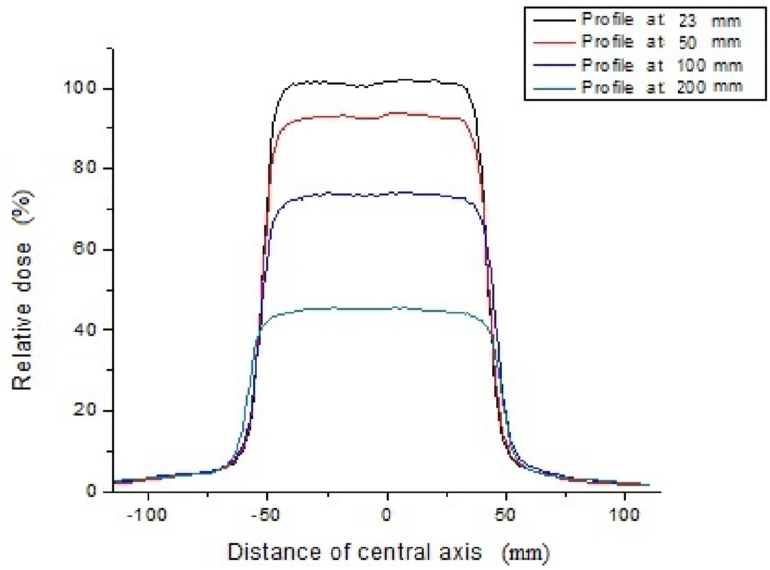

Figure 5. Lateral Beam Dose Profiles Measured in Water Phantom at Different Depths for Photon Beam Energy of 6 MV (dmax, d50 mm , d100mm, and d200mm).

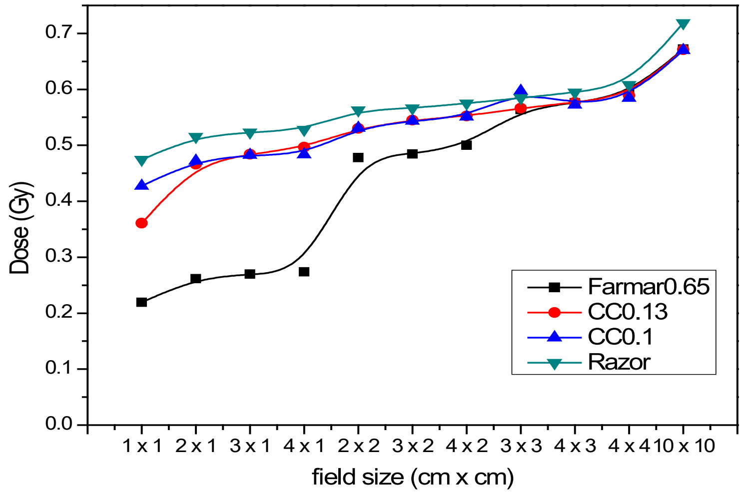

Figure 6. Measurements of the Variation of Relative Dose in a Small Field by the IBA Farmer FC 65-P, CC13, and CC01 (Ionization chamber) with Razor (diode) detector at 6 MV.

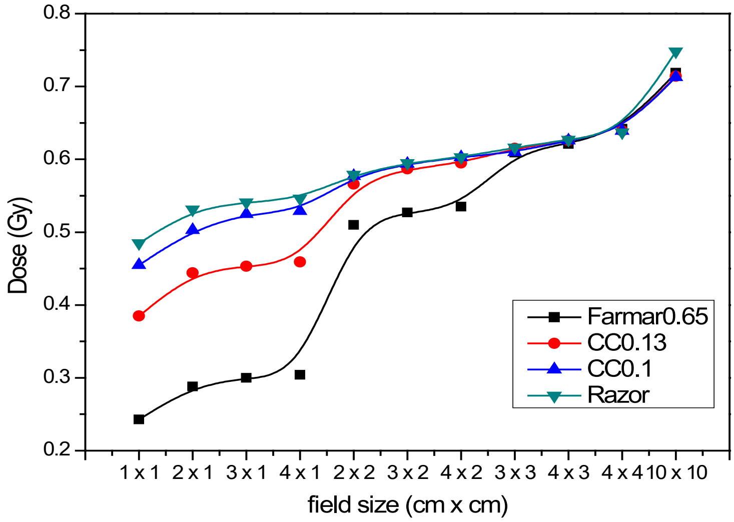

Figure 7. Measurements of the Variation of Relative Dose in a Small Field by the IBA Farmer FC 65-P, CC13, and CC01 (Ionization chamber) with Razor (diode) chamber at 10 MV.

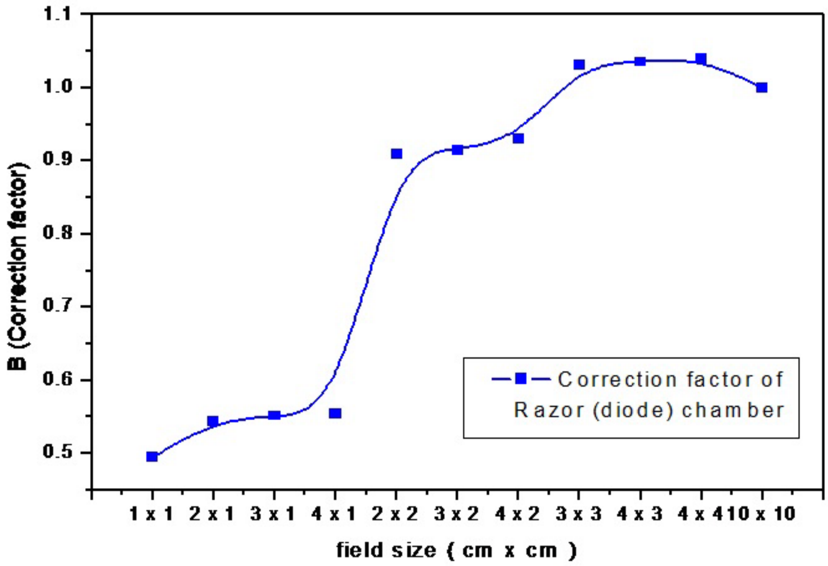

Figure 8. Correction Factor Curve for Razor (Diode) Chamber Using IBA Farmer FC 65-P (Ionization) Chamber at 6 MV.

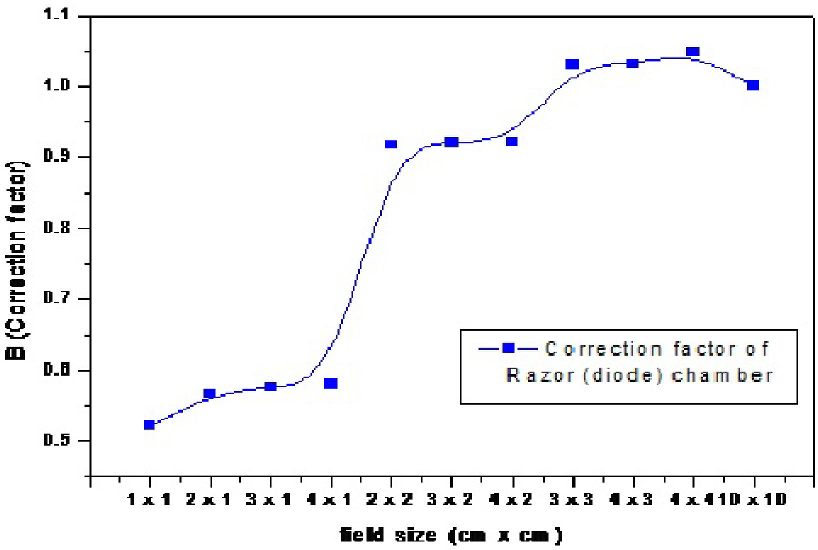

Figure 9. Correction Factor Curve for Razor (Diode) Chamber Using IBA Farmer FC 65-P (Ionization) Chamber at 10 MV.

Discussion

Radiotherapy has been considered as one of the principal modalities in cancer treatment. To begin treatment procedure, several steps should be taken, such as taking a history of patient, considering different modalities to treat, prescription of treatment dose, imaging and target volume definition, treatment planning, quality assurance (QA) and verification of the plan, patient set up, treatment delivery, and verification of its precision (Zarei, and Sheikholeslami, 2017).

The study revolves around the validation process of matching the percent depth dose (%dd) to the beam profile, measuring the absolute dose at the reference condition and small field to different detectors with the study of the Problems affecting accurate Dose measurement in small-field for a linear accelerator.

After the machine validated (%dd, profile beam, TPR 20,10 and ion-chamber calibrated), we noticed that measurement results of all detectors are nearly the same when measuring at reference field size, which implies that the lateral charged particle equilibrium of the radiation field is larger than the diameter of the detector, except Razor diode which higher reading because of its extremely small active size and highly sensitive to radiation, so it's designed to measure relative doses and it's not designed to measure absolute doses.

At the small field size the detector size becomes too larger than the diameter of the radiation field, which leads to loss of lateral charged particle equilibrium, but with the small detectors size have enough diameter with low overlapping these are shown in Razor (diode) read, so it's very suitable for relative dosimetry of photon fields in radiotherapy, particularly at small field sizes; therefore, it becomes necessary to determine the correction factor under different experimental conditions to account for the diode's sensitivity to these parameters and ensure accurate dose measurements.

As the diode is not water equivalent and sensitive to different parameters such as SSD, field size, and angle of incidence. So, we measured the correction factor under different experimental conditions.

In summary, it underscores the similarity in measurement results among the detectors at the reference field size, except for the Razor diode. The Razor diode, with its small size and high sensitivity to radiation, is designed for relative dose measurements and demonstrates higher readings. At small field sizes, the Razor diode remains suitable for relative dosimetry due to its small size and limited overlap with the radiation field. However, the measuring necessitates the determination of correction factors under different experimental conditions for accurate dose measurements.

In conclusion, the variations in the absorbed dose measurements in the water phantom refer to; all the large detectors (in state of the reference field size10cm x 10cm) are suitable values with a non-significant difference of less than ± 2% because the detector is considerably smaller than the field size and the readings of (CPE) didn't break down around the sensitive volumes of detectors, except the measurements performed by IBA Razor diode detector which, show a significant difference ± 5%, for measured quantities. While the dose measurements in the case of small field sizes; showed significantly ±48% compared to the IBA Razor diode; so, the Razor is more stable in small field dosimetry because the size of the detector is small enough diameter with low overlapping.

Author Contribution Statement

All authors actively participated in the work presented in this manuscript. A. M. carried out the practical measurements, writing methodology, and instrumentation. G. M. H. carried out the calibration of the dosimetry tools, writing methodology and analysis of data and results. K. T. E. participated in design, coordination and helping to draft the manuscript. E. M. A. participated in design and writing basic parts of a manuscript. All authors read and approved the final manuscript.

Acknowledgements

We express our appreciation for the Department of Radiotherapy, Shefaa-Alorman Hospital, Luxor, Egypt, for their cooperation and facilitating our use of the machines.

Ethical issue

Not applicable. No animal or human studies were carried out by the authors for this article.

Availability of data

Data is available upon request.

Conflict of interest

The authors declare that they have no conflict of interest in this work.

References

Alfonso R, Andreo P, Capote R, et al (2008). A new formalism for reference dosimetry of small and nonstandard fields. *Med Phys*, **35**, 5179–86.

Allisy PJ, Burns DT, Andreo P (2009). International framework of traceability for radiation dosimetry quantities. *Metrologia*, **46**, 1-8.

AlmondPR, Biggs PJ, Coursey BM, et al (1999). AAPM's TG-51 protocol for clinical reference dosimetry of high-energy photon and electron beams. *Med Phys,* **26**, 1847–70.

Andreo P, Huq MS, Westermark M, et al (2002). Protocols for the dosimetry of high-energy photon and electron beams: a comparison of the IAEA TRS-398 and previous international Codes of Practice. *Phys Med Biol*, **47**, 3033-53.

Andreo P, Huq S, Westemark M, et al (2002). Protocols for the dosimetry of high-energy photon and electron beams: a comparison of the IAEA TRS-398 and previous international Codes of Practice. *Phys Med Biol*, **47**, 3033.

Beddar AS, Biggs PJ, ChangS, et al (2006). Intraoperative radiation therapy using mobile electron linear accelerators: Report of AAPM radiation therapy committee task group no. 72. *Med Phys*, **33**, 1476–89.

Benedict SH, Yenice KM, Followill D, et al (2010). Stereotactic body radiation therapy: the report of AAPM Task Group 101. *Med Phys*, **37**, 4078–4101.

Bich W (2014). Revision of the 'guide to the expression of

uncertainty in measurement'. Why and how. *Metrologia*, **51**, 155.
Bouchard H, Seuntjens J, Duane S, et al (2015). Detector dose response in megavoltage small photon beams. I. Theoretical concepts. *Med Phys*, **42**, 6033–47.
Das IJ, Cheng CW, Watts RJ, et al (2008b). Accelerator beam data commissioning equipment and procedures: report of the TG-106 of the Therapy Physics Committee of the AAPM. *Med Phys*, **35**, 4186–4215.
Das IJ, Ding GX, Ahnesjö A (2008a). Small fields: nonequilibrium radiation dosimetry. *Med Phys*, **35**, 206–15.
Das IJ, Francescon P, Moran JM, et al (2021). Report of AAPM Task Group 155: Megavoltage photon beam dosimetry in small fields and non-equilibrium conditions. *Med Phys*, **48**, 886–921.
Francescon P, Kilby W, Noll JM, et al (2020). Small field dosimetry correction factors for circular and MLC shaped fields with the Cyber Knife M6 System: evaluation of the PTW 60023 micro Silicon detector. *Physics Med Biol*, **65**, 01NT01.
Laub, WU, Wong T (2003). The volume effect of detectors in the dosimetry of small fields used in IMRT. *Med Phys*, **30**, 341–7.
López-Sánchez M, Pérez-Fernández M, Pardo E, et al (2022). Small static radiosurgery field dosimetry with small volume ionization chambers. *Med Phys*, **97**, 66-72.
Musolino SV (2001). Absorbed dose determination in external beam radiotherapy: An international code of practice for dosimetry based on standards of absorbed dose to water; technical reports series no. 398. *Health Physics*, **81**, 592–3.
O'Brien DJ, León-Vintró L, McClean B (2016). Small field detector correction factors kQclin, Qmsr (fclin,fmsr) for silicon-diode and diamond detectors with circular 6 MV fields derived using both empirical and numerical methods. *Med Phys*, **43**, 411.
Palmans H, Andreo P, Huq MS, et al (2018). Dosimetry of small static fields used in external photon beam radiotherapy: Summary of TRS-483, the IAEA-AAPM international Code of Practice for reference and relative dose determination. *Med Phys*, **45**, 1123–45.
Palmans H, Andreo P, Huq MS, et al (2018). Reply to "Comments on the TRS-483 Protocol on Small field Dosimetry". *Med Phys*, **45**, 5669–71.
Petti PL, Rivard MJ, Alvarez PE, et al (2021). Recommendations on the practice of calibration, dosimetry, and quality assurance for gamma stereotactic radiosurgery: Report of AAPM Task Group 178. *Med Phys*, **48**, 733–70.
Prieto J, Alonso AA, de la Rosa R, et al (2015). Adaptive framework for uncertainty analysis in electromagnetic field measurements. *Radiat Prot Dosimetry*, **164**, 422–34.
Reggiori G, Mancosu P, Suchowerska N, et al (2016). Characterization of a new unshielded diode for small field dosimetry under flattening filter free beams. Physica medica: PM: an international journal devoted to the applications of physics to medicine and biology: official journal of the Italian Association of Biomedical Physics (AIFB), **32**, 408–13.
Scott AJ, Kumar S, Nahum AE, et al (2012). Characterizing the influence of detector density on dosimeter response in non-equilibrium small photon fields. *Phys Med Biol*, **57**, 4461–76.
Thakur S, Chawla S, Koirala A, et al (2022). Site Planning of a Newly Installed LINAC along with a Brachytherapy Unit at CMC, Nepal. *Asian Pac J Cancer Care*, **7**, 273-8.
Underwood TS, Winter HC, Hill MA, et al (2013). Detector density and small field dosimetry: integral versus point dose measurement schemes. *Med Phys*, **40**, 082102.
Wolfs CJA, Swinnen ACC, Nijsten SMJ, et al (2018). Should dose from small fields be limited for dose verification procedures? Uncertainty versus small field dose in VMAT treatments. *Phys Med Biol*, **63**, 20NT01.
Zarei H, Sheikholeslami S (2017). The Effect of Protocol- Based Education on Number of Errors in Radiotherapy. *Asian Pac J Cancer Care*, **2**, 37-40.
Zhao W, Yang Y, Xing L, et al (2022). Mitigating the uncertainty in small field dosimetry by leveraging machine learning strategies. *Phys Med Biol*, **67**, 155019.
Zhu TC, Ahnesjö A, Lam KL, et al (2009). Report of AAPM Therapy Physics Committee Task Group 74: in-air output ratio, Sc, for megavoltage photon beams. *Med Phys*, **36**, 5261–91.