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Original Article

Small field dosimetry: Chamber selection and its validation using technical report series-483

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ABSTRACT

Objectives: Small field dosimetry plays a critical role in modern radiotherapy techniques such as IMRT, IGRT, VMAT, SRS, SRT, SBRT, and Tomotherapy, where the goal is to deliver a highly conformal dose to the tumour while minimizing exposure to surrounding healthy tissues. Accurate dosimetric measurements are essential to ensure treatment efficacy and patient safety. While TRS-398 serves as the Code of Practice (CoP) for dosimetry in conventional large field radiotherapy. The objective of the study was to evaluate the performance of these detectors and identify the most suitable one by comparing the measured output factors with reference data.

Material and Methods: In this study, various detectors available in our department were employed to measure output factors for different small field sizes. The measurements were performed according to TRS-483 guidelines, and the obtained output factors were compared against reference data from standardized studies.

Results: Differences in measured output factors were observed among the detectors, particularly in the smallest field sizes. From the comparison keeping Gafchromic film data as the standard it was seen that CC01 is more suitable for 6 MV-FF beam measurement whereas EPD gives least percentage deviation for the output factors of 6 MV-FFF beams.

Conclusion: The results emphasize the importance of choosing an appropriate detector for small field measurements and adhering to TRS-483 recommendations to ensure accurate and reliable dosimetry in advanced radiotherapy applications.

Keywords: CC01, EFD, Ionization chamber, PFD, Small fields, TRS 483

INTRODUCTION

Radiotherapy is one of the major treatment modalities for the treatment of cancer. For conventional radiotherapy like 2DRT and 3DRT, the dosimetry is based on Code of Practice (COP) like TRS-398[1] by International Atomic Energy Agency (IAEA) and TG-51 by American Association of Physicists in Medicine (AAPM). Here, the dosimetry is done in tissue equivalent material, mainly a water phantom, using ionization chambers. Output factors (OF) for large fields are measured keeping 10 x 10 cm² as the reference field where reference conditions stipulated by Code of Practice(COP) s are met.[2] New techniques like IMRT, IGRT, VMAT, SRS, SRT, SBRT, Tomotherapy, Cyberknife, etc deliver dose distribution to small targets where a steep dose gradient is required. Therefore, in these techniques, small fields are widely used.[3] Conventionally, a field size less than 3 × 3 cm² is considered as small field.[4] Small field dosimetry is complex due to the following reasons.[5,6,7]

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A) Loss of lateral charge particle equilibrium (LCPE) in the beam axis.

B) Partial occlusion of the primary photon source by the collimating devices or the beam axis.

C) The size of the detector is similar to or larger compared to the beam dimensions. This causes a volume-averaging effect.

In 2017, the IAEA proposed Technical Report Series TRS-483 for the dosimetry of small fields.[8] The protocol recommends the ideal setup for measuring output in small fields and identifies suitable detectors.

The characteristic of radiation detectors, like size, shape, and material, plays an essential role in their response to photon beams. Therefore, selecting a suitable detector for small-field dosimetry is important for accurate dose measurement. A detector with high spatial resolution, low noise, water equivalence, and low directional and energy dependence is considered the ideal one.[9]

Various dosimeters suitable for small field dosimetry:

The challenges mentioned above make it difficult to select a suitable dosimeter for small-field dosimetry.[10,11] The necessary properties of a desired detector are high spatial resolution, high signal (low noise), low energy dependence, low directional dependence, water equivalence, high stability, and ease of use clinically, as mentioned above. Despite the availability of detectors of various sizes and types, none of them satisfy all the conditions required for the accurate measurement of dose in small fields.[12] Hence, a significant part of the small-field dosimetry is the identification of the ideal detector from the available lot in the institution.[13] This study aims to arrive at the decision of the best suitable detector for small field dosimetry using TRS483 and by taking film dosimetry [14] and the data from standard values.[15] as the reference for the comparison.

MATERIAL AND METHODS

True Beam STx (Varian Medical Systems, Palo Alto, CA-Brainlab AG, Munich, Germany) is a state-of-the-art machine that is capable of treating large as well as small fields. High-definition multileaf collimator (HD MLC) and Flattening Filter Free (FFF) beams are used for stereotactic treatments. The photon beam energies available in the machine are 6 MV, 10 MV, and 15 MV with a Flattening Filter (FF) and 6 MV and 10 MV as FFF beams. The measurements for this study were carried out with 6 MV-FF and 6 MV-FFF beams. The Linear Accelerator (LINAC) was calibrated to deliver 1cGy/MU to water at a depth of maximum dose (d-max) for 10 ×10 cm^2 at Source to Surface Distance (SSD) of 100 cm as per the recommendations of TRS- 398. All field sizes were defined with jaws as per the recommendation of Varian Medical Systems for the commissioning of the Eclipse treatment planning system, version 15.1.[16] Field sizes from 0.8 x 0.8 cm^2 to 3 x 3 cm^2 are considered as a small field for this work. 10 x 10 $cm^2$was considered as the reference field size, and 4 x 4 cm^2 was considered as the intermediate field size as per the recommendations of TRS -483.

Detectors used in the study were the electron field diode detector (EFD, IBA Dosimetry GmbH, Schwarzenbruck, Germany), photon field diode detector (PFD, IBA Dosimetry GmbH, Schwarzenbruck, Germany), and CC01 ionization chamber (IBA Dosimetry GmbH, Schwarzenbruck, Germany) for small field measurements[16] and FC65 (IBA Dosimetry GmbH, Schwarzenbruck, Germany) for the large fields. All measurements were done in the IBA Blue Phantom-2 (IBA Dosimetry GmbH, Schwarzenbruck, Germany) Radiation Field Analyzer and Dose 1 electrometer (IBA Dosimetry GmbH, Schwarzenbruck, Germany). The procedure for measuring the output and output factors was according to the protocol TRS-483. The solid-state detectors, like EFD and PFD, were mounted vertically to the water surface for measurements. CC01 was placed parallel to the water surface.[17] Output factors for different square and rectangular fields were measured. Gafchromic films (KODAK EBT3) were used for comparing the output factor with different detectors. Better accuracy can be achieved by film dosimetry since Gafchromic films do not possess any of the shortcomings listed for ionization or diode detectors.

RESULTS

The measurements of output factors of different field sizes were performed. The field sizes range from 1 x 1 cm^2 to 5 x 5 cm^2. The measurements were done in a varian true beam STx machine using three different kinds of detectors. The energies used were 6 MV-FF and 6 MV-FFF. The corrected and uncorrected output factors were calculated using the formula given in the TRS 483 protocol.

$$\Omega^{\text{fclin,fmsr}}_{\text{Qclin,Qmsr}} = \left[\frac{M^{\text{fclin}}_{\text{Qclin}}}{M^{\text{fint}}_{\text{Qint}}} k^{\text{fclin,fint}}_{\text{Qclin,Qint}}\right]_{\text{det}} \left[\frac{M^{\text{fint}}_{\text{Qint}}}{M^{\text{fmsr}}_{\text{Qmsr}}} k^{\text{fint,fmsr}}_{\text{Qint,Qmsr}}\right]_{\text{IC}}$$

where $\left[\frac{M^{\text{fclin}}_{\text{Qclin}}}{M^{\text{fint}}_{\text{Qint}}} k^{\text{fclin,fint}}_{\text{Qclin,Qint}}\right]_{\text{det}}$ Represents the corrected field output of clinical small field sizes to intermediate field size, typically 4x4cm^2. $\frac{M^{\text{fclin}}_{\text{Qclin}}}{M^{\text{fint}}_{\text{Qint}}}$ Is the Ratio of the detector reading and the term Represents detector-specific output correction factor.

$\left[\frac{M^{\text{fint}}_{\text{Qint}}}{M^{\text{fmsr}}_{\text{Qmsr}}} k^{\text{fint,fmsr}}_{\text{Qint,Qmsr}}\right]_{\text{IC}}$ Represents the link between the intermediate field size and to machine-specific reference field size, normally 10 x 10 cm^2 and $k^{\text{fint,fmsr}}_{\text{Qint,Qmsr}}$ represents a correction factor that accounts for the changes in detecto response due to differences in field size and beam quality.

The Institute of Radio Oncology, Wiener Krankenanstaltenverbund (Weinkav), published their data[18] for the Truebeam STx machine online in 2015 prior to the publication of TRS- 483. They used

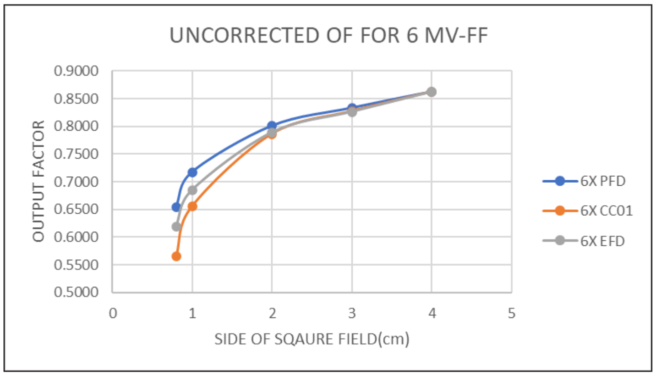

Figure 1: Output factors with field sizes for the 6 Mega Volt Flattening Filter beam measured by using different chambers without applying correction factors as per TRS-483. PD : Percentage deviation, PFD : Photon field detector, EFD : Electron field detector

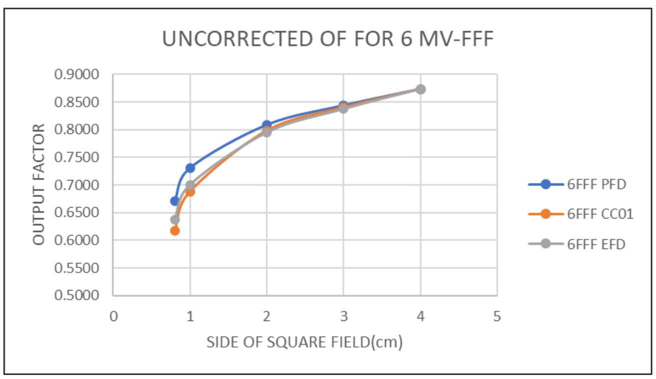

Figure 2: Output factors with field sizes for the 6 Mega Volt Flattening Filter beam measured by using different detectors without applying correction factors as per TRS-483. PD : Percentage deviation, PFD : Photon field detector, EFD : Electron field detector

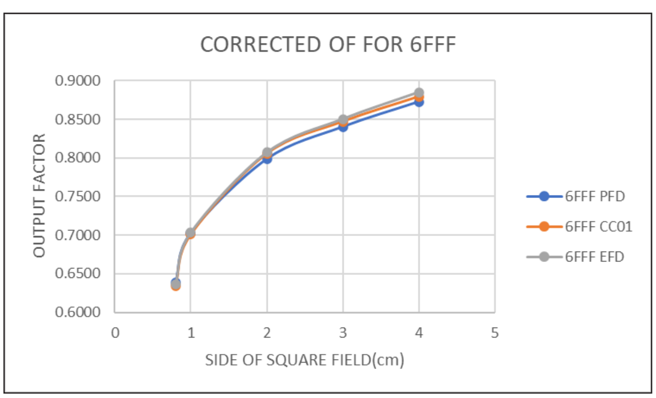

Figure 3: Output factors with field sizes for the 6 Mega Volt Flattening Filter Free beam measured by using different chambers after applying a correction factor for chambers, as mentioned in TRS-483. PD : Percentage deviation, PFD : Photon field detector, EFD : Electron field detector

the scaling technique by using 4 x 4 cm^2as the intermediate reference field size. Since the Kclin correction factor, as in TRS- 483, was not used by them, the uncorrected output factors in the present study were compared to the reference data for assessing the setup adequacy for measurement. Figures 1 and 2 show the uncorrected output factors with field sizes for different detectors and different beams, like 6FF and 6FFF. The output factors corrected using the correction factors provided in TRS-483 for 6FF and 6FFF beams with different detectors like EFD, PFD, and CC01 have been plotted in Figures 3 and 4.

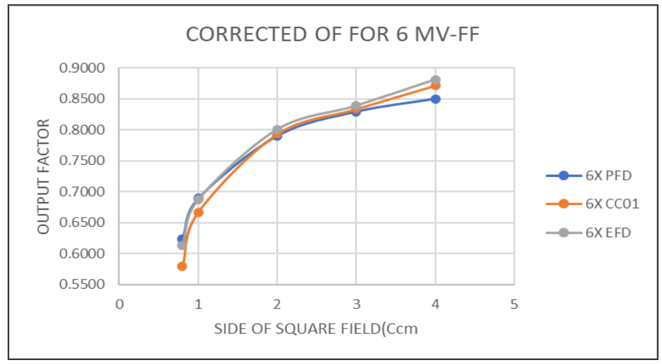

Figure 4: Output factors with field sizes for 6 Mega Volt Flattening Filter beam measured by using different chambers after applying a correction factor for chambers as mentioned in TRS-483.

Percentage deviation from the standard value

Tables 1 and 2 show the percentage deviation from reference data available in the literature mentioned in the reference. Here, we used the uncorrected value to compare with the reference data. From Tables 1 and 2, we can see that the percentage deviation for all three detectors is less than 2% for all field sizes except for the smallest field size of 1 x 1 cm^2. This trend of percentage deviation is similar for both 6 MV-FF and 6 MV-FFF. Also, the percentage deviation greater than one per cent for the smallest field size is for the PFD and CC01 detectors, whereas the EFD detector gives results within one per cent.

Table 1: Percentage deviation (PD) from reference data for 6 MV-FFF beam

Side of square field (cm)	REF	PD PFD	PD CC01	PD EFD
1	0.7019	-4.14589	1.913191	0.257296
2	0.7996	-1.15195	0.157677	0.595784
3	0.8408	-0.35138	0.043038	0.405931
5	0.904	0.280838	0.280838	0.280838

PD : Percentage deviation, MV-FFF : Mega volt flattening filter free, REF : Reference, PFD : Photon field detector, EFD : Electron field detector

Percentage deviation from the standard value

We can see that the percentage deviation for all three detectors is less than 2% for all field sizes except for the smallest field size of 1 x 1 cm² [Table 1 and 2]. This trend of percentage deviation is similar for both 6 MV-FF and 6 MV-FFF. Also, the percentage deviation greater than one per cent for the smallest field size is for the PFD and CC01 detectors, whereas the EFD detector gives results within one per cent.

Table 2: Percentage deviation from reference data for 6 MV-FF beam

Side of square field (cm)	REF	PD EFD	PD CC01	PD EFD
1	0.689357	-4.008	4.8918	0.7021
2	0.791492	-1.1602	0.64231	0.3279
3	0.830319	-0.3409	0.34591	0.4963
5	0.89459	-0.0387	0.03866	0.0387

PD : Percentage deviation, MV-FFF : Mega volt flattening filter free, REF : Reference, PFD : Photon field detector, EFD : Electron field detector

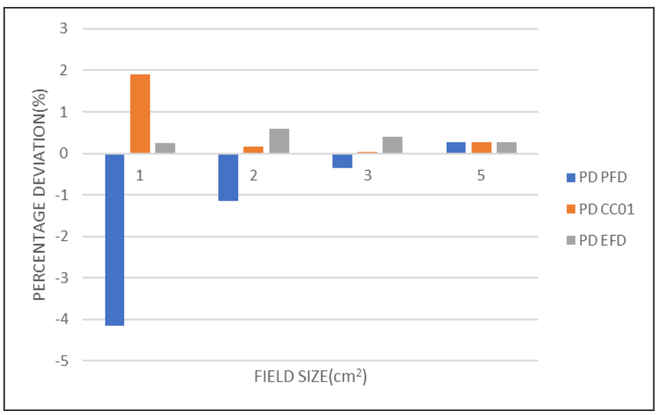

Figure 5: Percentage deviation of OFs for the 6 Mega Volt Flattening Filter Free beam for different detectors from reference data. PD : Percentage deviation, PFD : Photon field detector, EFD : Electron field detector

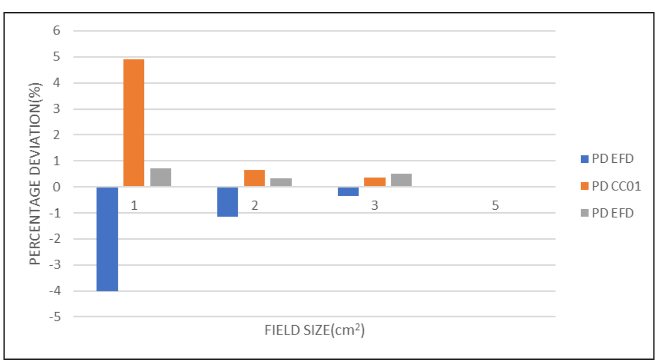

Figure 6: Percentage deviation of OFs for the 6 MV-FF beam for different detectors from reference data. PFD : Photon field detector, EFD : Electron field detector, MV-FFF : Mega volt flattening filter free.

Table 3: Percentage variation of output factors for the three detectors in comparison to output factors measured using Gafchromic films for the 6 MV-FF beam,

Side of square field (cm)	PFD	CC01	EFD
0.8	-5.883197546	1.41538339	-4.969646127
1	-4.647910521	-1.291663341	-4.34491355
2	1.578458951	1.267463575	0.285920157
3	-1.419277387	-1.905927536	-2.588373601
4	5.35100122	5.653521209	5.35100122

PFD : Photon field detector, EFD : Electron field detector

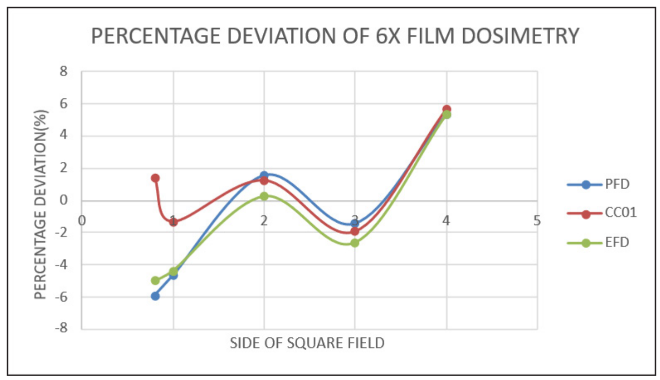

Figure 7: Percentage variation of output factors for the three detectors in comparison to output factors measured using Gafchromic films for a 6 MV-FF beam. PFD : Photon field detector, EFD : Electron field detector, MV-FFF : Mega volt flattening filter free.

Table 4: Percentage variation of output factors for the three detectors in comparison to output factors measured using Gafchromic films for the 6 MV-FFF beam,

Side of square field (cm)	PFD	CC01	EFD
0.8	-8.18421	0.466369	-2.87048
1	-0.25644	5.572444	3.978324
2	-0.212	1.085464	1.519501
3	-3.16107	-2.75561	-2.38256
4	5.069477	5.069477	5.069477

PFD : Photon field detector, EFD: Electron field detector

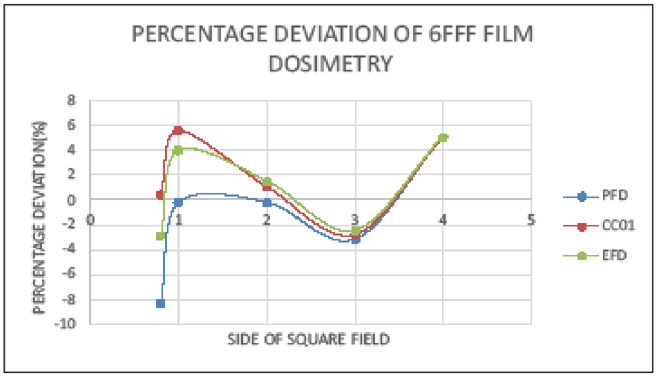

Figure 8: Percentage variation of output factors for the three detectors in comparison to output factors measured using Gafchromic films for a 6 MV-FFF beam. PFD : Photon field detector, EFD : Electron field detector, MV-FFF : Mega volt flattening filter free.

The output factors of 6 MV-FF and 6 MV-FFF beams with different dosimeters like EFD, PFD, and CC01 were measured with field sizes from 0.8 x 0.8 cm^2 to 4 x 4 cm^2 Those values were compared with the output factors measured using Gafchromic films [Table 3 and 4].[19] The results using Gafchromic films are independent of the source occlusion effect and the volume averaging effect. As with the results of the percentage deviation of the measured output factor with the reference data, the percentage deviation of the output factors using various detectors as compared to that measured using Gafchromic films is greater for smaller fields, as compared to the field size of 2 x 2 cm^2 and above. Figure 5 shows the percentage deviation of the output factors measured using the three detectors with regard to those measured using Gafchromic films. From the results, it is evident that the percentage deviation for all measurements is less than 10 per cent. Deviation is relatively higher for fields less than 1 x 1 cm^2 and also for 4 x 4 cm^2. For the 6 MV-FF beam, CC01 is more consistent. Figure 6 shows that for 6 MV-FFF, the EFD detector is more suitable for measuring output from 1 x 1 cm^2 to 3 x 3 cm^2.

DISCUSSION

The present study compared the output factors, measured using different detectors for small field sizes ranging from 1x1 cm2 to 5x5 cm2 with standardized reference data. Since the Kclin correction factor, was not used by published reference data, we used the output factors without this correction factor to compare with the standard. From this study it is found that the detectors like PFD and CCO1 showed percentage deviation greater than 1% for both 6MV-FF and 6MV-FFF beams where as EPD showed variation less than 1% for all field sizes . Additionally, the output factors measured using different detectors for the field sizes from 0.8 x 0.8 cm2 to 4 x 4 cm2 were compared with Gafchromic film data which is not influenced by of source occlusion effect and volume averaging effect. It was found that the percentage deviation of output factors was highest for small field sizes less than 2x2cm2. From table 4 and figures 7, 8 it is evident that the detector CC01 is most suitable for small field sizes for both 6MV- FF and 6MV-FFF beams.

CONCLUSION

In this study, we compared the output factors for small fields of True Beam STX linear accelerator using EFD and PFD detectors,and also CCO1 ionization chambers, with the output factors measured using Gafchromic films. From the comparison, keeping Gafchromic film data as the standard, it was seen that CC01 is more suitable for 6 MV-FF beam measurement, whereas EPD gives the least percentage deviation for the output factors of 6 MV-FFF beams. Hence, the data generated using these detectors for the respective energies can be used for beam modelling in the treatment planning system.

Author contributions: SP, SJ, RB, AC, KP: Created data collection and analysis; SP, SJ: Drafted the manuscript ,images and tables; AT: Manuscript review and editing.

Ethical Approval: The research/study approved by the Institutional Review Board at Govt. Medical College, Kozhikode, number IRC/2024/Protocol/325, dated 1st October, 2024.

Declaration of patient consent: Patient's consent not required as there are no patients in this study.

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Conflicts of interest: There are no conflicts of interest.

Use of artificial intelligence (AI)-assisted technology for manuscript preparation: The authors confirm that there was no use of artificial intelligence (AI)-assisted technology for assisting in the writing or editing of the manuscript and no images were manipulated using AI.

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