RESEARCH ARTICLE

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Comparison and Assessment of Different Small Volume Radiation Detectors for Small Field Dosimetry in Stereotactic Radiotherapy

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Abstract

Objective: The small fields are used in the treatment of stereotactic radiosurgery (SRS), stereotactic radiotherapy (SRT), and stereotactic body radiation therapy (SBRT). The aim of this study is to compare and assess various small-volume radiation detectors for small-field dosimetry. **Methods:** The small field dosimetry was performed with the High Definition Versa Linear Accelerator (HD-LINAC) from Elekta. The 6MV flattening filter (FF) and 6MV flattening filter free (FFF) radiation energies were chosen for the measurement. The field sizes of 2x2cm^2, 4x4cm^2, 5x5cm^2, 7x7cm^2, 8x8cm^2, and 10x10cm^2 were selected. The quality assurance (QA) included percentage depth dose (PDD), dose profile measurement, and output factor (OF) measurement. The three radiation detectors, pinpoint ionization chamber type 31014, microDiamond detector type 60019, and Dosimetry diode SRS detector type 60018, from PTW-Freiburg, Germany, were utilized for the dosimetry. The measurements were performed with a radiation field analyzer (RFA) water phantom from PTW Freiburg. **Result:** PDD values for all the detectors were similar except for Ds, which increased with the increase in field size in all detectors for the 6MV FF and 6MV FFF beams. Beam profile data gave similar results in all the detectors, with penumbra width having statistically significant differences in the 6MV FF beam between the three detectors. Penumbra width was found lower in pinpoint and microDiamond detectors for both energies compared to the SRS dosimetry diode. **Conclusion:** The performance of all the detectors used in this study was similar with less noticeable differences between each other. As there was no great difference found in the results between the detectors, it can be concluded from this study that all three radiation detectors are suitable for the small field dosimetry performed for SRS and SBRT treatments.

Keywords: Percentage depth dose- radiation beam profile- pinpoint ion chamber- microDiamond detector

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Introduction

There has been notable growth in the use of small-field dosimetry in the past five years in various treatment units to deliver stereotactic radiotherapy (SRT) treatments successfully [1]. In general, a field size lesser than 4x4cm^2 is considered the nonconventional field for most clinical treatments, and hence, it is considered to be a small field [1, 2]. The definition for the small field has been provided by the Institute of Physics and Engineering in Medicine (IPEM) as "small field is the field having dimensions smaller than the lateral range of charged particles, that contribute to the dose deposition at a point of measurement along the central axis." As per the code of practice given by technical report series 483 (TRS 483), a field of photon beam can be considered small if the detector's size is greater than or equal to the beam dimension, there is partial occlusion of the primary photon beam on the beam axis, and there is loss of charge particle equilibrium on the radiation beam's axis [3].

The need for small-field dosimetry is increased as SRT, intensity-modulated radiation therapy (IMRT), and volumetric-modulated arc therapy (VMAT) technologies for radiation delivery are routinely used [4]. The major requirement of SRT is the accuracy in the patient positioning and radiation dose delivery which results

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in the minimum to less damage to the critical organs close to the treatment site [5]. Advances in stereotactic radiosurgery (SRS), SRT, and stereotactic body radiation therapy (SBRT) have made the use of small fields of less than 3cm, which have created innovations in the treatment machines with various widths of multileaf collimators from 10mm to 2.5mm which is known as micro-multi leaf collimator [6]. Since the stereotactic treatment in the form of IMRT and VMAT for small tumors of less than 2mm are also regularly delivered, the establishment of accurate dosimetry for the field of 1 to 3 mm is important for the safe administration of large doses of radiation in one or fewer number fractions [7].

The quality assurance (QA) tests should be made stringent to reduce the treatment error to be less than the minimum. QA, such as output factor (OF), percentage depth dose (PDD), and beam profile measurements, are frequently used for dosimetry [8]. However, it is highly difficult to achieve accuracy in the dose distribution due to various factors such as lateral charge particle disequilibrium, perturbation factor, and volume averaging effect. Various detectors are available globally, that includes diodes, diamond detectors, and other small volume ion chambers, which have minimized these effects. Due to their small sensitive volumes, the volume averaging effects are successfully reduced [4].

In the dosimetry of the small fields, the dose measurements are always influenced by the direction and the detector's energy response. Also, perturbation and volume averaging, which is the source of the limited dimension of the active volume of the detector, contribute to the overall measurements [9]. The ion chambers offer many benefits in the dose measurements due to their robustness, high stability, optimum tissue equivalence at the range of therapy energies, and minimum recombination at the therapy range dose rates. Small-volume ion chambers and solid-state detectors used earlier in radiotherapy offered errors in the accuracy of the field area. Also, solid-state detectors provided inconsistency in the results compared with the similar products from the different manufacturers [10]. It has been found by several studies that there is a difference in the OFs determined using ionization chambers and diodes for the field size lesser than 3x3cm^2 due to the lack of lateral electronic equilibrium [4, 5]. However, every detector has its characteristics which makes them fit into small field dosimetry [10].

If the dosimetry with a small field is performed accurately with high precision, it is possible to make advanced radiotherapy techniques clinically advantageous and beneficial [1]. An ideal detector must have a small sensitive volume, which makes it possible to attain high accuracy in the positioning of the detector. It should be independent of the dose rate, beam direction, and energy used [9]. A single detector cannot fulfill all the characteristics of an ideal detector, as every detector has its limitations. So, investigations have been performed with a variety of radiation detectors such as air and liquid ionization chambers, radiographic and gafchromic films, diamond detectors, plastic scintillators, TLDs, MOSFETs, radiophotoluminescence glass plates, polymer gels, and silicon diodes for measuring small field profiles to analyze the advantages and disadvantages of each dosimeter [11].

Flattening filter free (FFF) photon beams are extensively employed in treating SRT due to their high dose rate, significantly reducing the treatment duration. Because of this, in order to measure the dose accurately, the dose rate response of the detector must be computed [1, 12]. FFF beam delivery with a conventional linear accelerator (linac) will have a flattening filter replaced by a thin foil, and when it comes to dose profiles, it will differ greatly from flattening filter (FF) beams. The FFF beam profiles will always have an unflattened forward peak in the central axis of the beam. This kind of beam is available in most of the linacs to deliver clinically advantageous hypofractionated radiotherapy. The nominal dose rate for the 6MV FF beam is 600MU/Min, whereas for the 6MV FFF beam, it is 1400MU/Min [13].

QA in beam dosimetry for FFF beams is still in need as they are mostly used in hypofractionated radiotherapies [13]. In this study, we have performed dosimetric measurements using three small sensitive volume detectors, Pinpoint Chamber (Type 31014), microDiamond (Type 60019), and Dosimetry Diode SRS (Type 60018) detectors purchased from a single vendor that is used especially in small field dosimetry. The radiation OF, PDD, and dose profile measurements were evaluated for the 6MV FF and FFF energies, and the performance of the detectors was evaluated and compared.

Materials and Methods

Radiation Detectors

The pinpoint ionization chamber is a vented and watertight chamber utilized in high-energy photon beam dosimetry. The absorbed dose to water, air kerma, or exposure is used to quantify dose or dose rates. Since the sensitive volume of this ion chamber is relatively small (0.015cc), it is best suitable for measuring beam profiles in water phantoms. The minimum to maximum field sizes used in the dosimetry are 2x2cm^2 to 30x30cm^2, respectively. The photon beam energies of Cobalt 60 to 50MV can be used with this chamber [14].

MicroDiamond type 60019 is a synthetic single-crystal diamond detector (SCDD) used in measurements involving ionizing radiation. This water-resistant detector works in solid-state phantoms, air, and water. High spatial resolution is offered by this detector and it can be widely employed for dose measurements in electron and photon fields wherein IMRT and stereotactic beams are used. Its excellent spatial resolution makes its use in the precise radiation beam profile measurements for small fields, including the penumbra region. This detector measures the dose and dose rate in relative dosimetry applications. Moreover, it can be applied to the precise dosimetry of electron and photon beams. It can also be used for the absolute dosimetry of photon and electron beams, provided its calibration with ionization chambers must be performed. The minimum to maximum field sizes used in the dosimetry are 1x1cm^2 to 40x40cm^2, respectively. The photon beam energies from 100KeV to 50MV and electron energies from 6MeV to 25MeV can be used with this detector [12]. This detector exhibits dose rate independence in circular and square fields of less than 20mm [15].

The Dosimetry Diode SRS is a waterproof detector that provides high spatial resolution and can be used in the photon field relative dosimetry. The high response of this detector makes its best use in the beam profile measurements, delivering extremely high resolution in a brief measurement period. It is typically used in the measurement of beam profile. The minimum to maximum field sizes in photon dosimetry are 1x1cm^2 to 10x10cm^2, respectively. The photon beam energies of Cobalt 60 to 6MV can be used with this detector [16]. The technical details of all three detectors are mentioned in Table 1. This stereotactic detector is the most preferred choice for measuring output factor and beam profiles in small fields. it is a great option for commissioning small circular cones for SRS because it provides good spatial resolution and reduced detector volume averaging impact [15].

Radiation Dosimetry of Small Fields

The dosimetry was carried out with the High Definition Versa Linear Accelerator (HD-LINAC) from Elekta. The 6MV and 6MV FFF radiation energies were chosen for the measurement purpose. Since the SRS/SRT/SBRT is performed for small fields, the field sizes of 2x2cm^2, 4x4cm^2, 5x5cm^2, 7x7cm^2, 8x8cm^2, and 10x10cm^2 were chosen to measure PDD, dose profile measurement, and OF. Three radiation detectors, pinpoint ionization chamber type 31014, microDiamond type 60019, and Dosimetry diode SRS type 60018, from PTW-Freiburg, Germany, were used for the dosimetry [17]. The measurements were performed with a radiation field analyzer (RFA) water phantom from PTW Freiburg. The source-to-surface distance (SSD) was kept at 100cm. It is important to observe the detector orientation carefully such that the smallest dimension of the sensitive volume of the detector is perpendicular to the scan direction [3]. The detector and phantom setup were made following the guidelines given by TG 106 [18].

The measurements in the pinpoint ionization chamber were performed with the chamber irradiated in the radial direction, and the measurements in microDiamond and Dosimetry Diode SRS were carried out with the radiation directed at the front of the detectors, i.e., the center of the beam parallel to the detector axis. The PDD and beam profiles were measured at a depth of 1.5cm (Dmax) and 10cm using all three radiation detectors. The dose curves were generated using Maphysto relative dosimetry software. The OF was measured with the chambers connecting to a PTW Unidose Electrometer for all the mentioned field sizes, with a 10x10cm^2 field kept as the standard to calculate the output factor. The chamber was placed at a depth of 10cm in the water, and the SSD was maintained at 100cm [12,15].

Statistical Analysis

Descriptive statistics was used to describe the data using Jamovi 2.3.26 statistical analysis software. The data's normality was determined using the Shapiro-Wilk test. Since the data were found to be normally distributed, the mean and standard deviation were recorded for the continuous variables. A mixed linear model was used to predict the significant difference of various parameters in PDD and profile between three detectors. A statistically significant difference between the variables was defined as $p<0.05$.

Results

Percentage depth dose measurement

The PDD results of 6MV photon beams were compared between the three radiation detectors, pinpoint ionization chamber type 31014, microDiamond type 60019, and Dosimetry diode SRS type 60018. The parameters used to compare the PDD for the field sizes 2x2cm^2, 4x4cm^2, 5x5cm^2, 7x7cm^2, 8x8cm^2, and 10x10cm^2 were R100, Ds, D100, D200, and Qi. R100 is the depth of maximum dose value (mm), Ds is the dose value at the surface at a depth of 0.05mm (%), D100 is the dose value at 100mm depth (%), D200 is the dose value at 200mm depth (%) and Qi is the quality index. The compared results between the chambers are mentioned in Table 2 as mean and standard deviation.

It was found that among the dependent variables, R100 and Qi showed no statistically significant difference, but

Table 1. Technical Specification of the Radiation Detectors

Detector	Type	Nominal sensitive volume	Dimensions of the sensitive volume	Wall of sensitive volume	Area Density
Pinpoint Chamber Type 31014	Vented Thimble ionization chamber	0.015 cm^3	radius 1.45 mm length 5 mm	0.57 mm PMMA, 1.19 g/cm^3 0.09 mm graphite, 1.85 g/cm^3	84.4mg/cm^2
microDiamond Type 60019	Solid State Detector(Diamond)	0.004 mm^3 (circular)	radius 1.1 mm, circular, thickness 1 µm	Chamber wall/Entrance Window: 0.3 mm RW3 0.6 mm Epoxy 0.01 mm Al 99.5 0.03mm in air	0.1g/cm^2
Dosimetry Diode SRS Type 60018	p-type silicon	0.3 mm^3	1 mm^2 circular 250 µm thick	Entrance Window: 0.3 mm RW3, 0.27 mm epoxy	0.14g/cm^2

The detector manufacturer: PTW-Freiburg, Germany [17]

Table 2. Comparison of Pooled PDD between the Three Detectors for 6MV and 6MV FFF Photon Beam Energy for Different Field Sizes

Field Size cm^2	R100 [mm]		Ds [%]		D100 [%]		D200 [%]		Qi	
	6MV FF	6MV FFF	6MV FF	6MV FFF	6MV FF	6MV FFF	6MV FF	6MV FFF	6MV FF	6MV FFF
2x2	16±0.66	17±0.1	42±5.34	44.5± 4.16	60.6±0.07	60.8± 0.29	33±0.04	33± 0.28	0.63±0.001	0.629± 0.003
4x4	15.9±0.05	17.8±0.20	43.6±4.83	46.1± 4.18	63.1±0.26	63.4± 0.08	34.8±0.12	34.9± 0.12	0.63±0.001	0.638± 0.002
5x5	15.5±0.57	18±0.26	44.4±4.51	46.5± 4.1	64.3±0.08	64.4± 0.13	35.8±0.14	35.8± 0.07	0.64±0.001	0.645± 0.001
7x7	16.1±0.26	18.1±0.40	45.8±4.53	47.7± 3.73	66.1±0.15	66± 0.06	37.6±0.18	37.4± 0.10	0.66±0.002	0.659± 0.002
8x8	15.5±0.61	17.6±0.23	46.8±4.48	48.4± 3.17	66.8±0.22	66.6± 0.09	38.4±0.27	38.1± 0.08	0.67±0.002	0.665± 0.002
10x10	15.4±0.20	17.7±0.87	48.6±4.04	49.6± 3.15	67.9±0.40	67.7± 0.30	39.8±0.33	39.2± 0.17	0.682±0.0017	0.674± 0.001
p-value	0.277	0.088	<0.001	<0 .001	0.027	0.837	0.004	0.315	0.277	0.083

Note: The data mentioned here is in the form of mean and standard deviation. R100 is the depth of maximum dose value, Ds is the dose value at the surface at a depth of 0.05mm, D100 is the dose value at 100mm depth, D200 is the dose value at 200mm depth and Qi is the quality index.

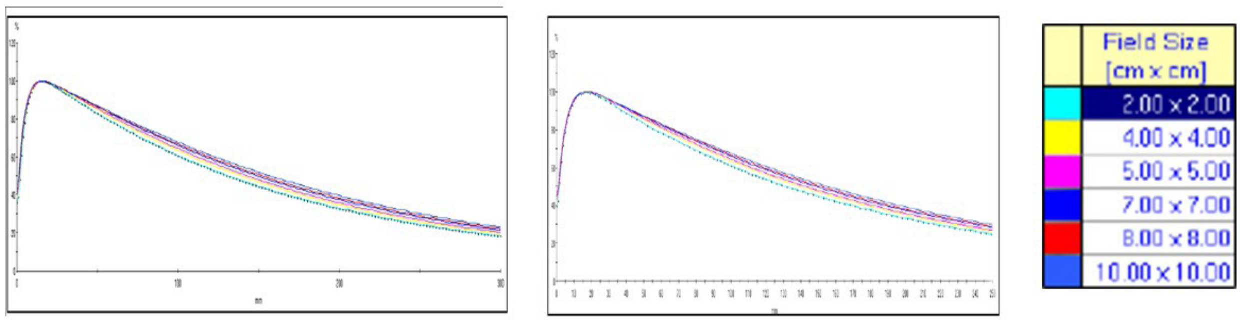

Figure 1. Graph of PDD Representing Pinpoint Ion Chamber for 6MV (left) and 6FFF (right) beam Energy

D100, D200, and Ds displayed data that were statistically significant, with p-value <0.05. The three radiation detectors were used for the measurement with various field sizes mentioned in the methodology section. It was found in Pillai's Trace test that there was a significant difference between the three radiation detectors, as the p-value is 0.018. With respect to the PDD data, the surface dose (Ds) variable among the many dependent variables, showed highly significant differences between the three detectors, resulting in an ICC (interclass correlation coefficient) value to be 0.907, which is equivalent to 1.

Similar results were found with 6FFF beam energy (Table 2). Here it was found in Pillai's Trace test that there was a significant difference between the three radiation detectors, as the p-value is 0.025. Here the Ds shows a significant difference between the detectors with p<0.001 with ICC=0.89.

The PDD graphs for the pinpoint ion chamber, micro diamond detector, and SRS diode measured using 6MV and 6FFF energies are mentioned in Figures 1, 2, and 3. The graphs obtained for PDD are in such a way that percentage is on the y-axis and depth is on the x-axis.

Profile measurement

For particular beam energy, beam profiles and diagonal profiles were determined for pinpoint, micro diamond, and Dosimetry diode SRS. Inline and crossline beam profiles were measured for every field sizes 2x2, 4x4, 5x5, 7x7, 8x8 and 10x10 cm^2. "Field size is defined as the distance between the two isodose points on the left and right side of the beam profile, referred to as the central axis." Penumbra left and right are the distance between the two isodose points at the left/right field boundary, expressed as a percentage of the central axis dose. Flatness is the indicator for the flatness of the profile or an area. the homogeneity of the profile is determined within the flattened region. This is usually calculated as the percentage dose ratio, which is (Dmax/Dmin)x100%. The percentage dose difference can be calculated as [(Dmax-Dmin)/(Dmax+Dmin)]100%. Here Dmax and Dmin are the maximum and minimum dose in the region. Symmetry is the indicator of the symmetry of the profile. It is determined within the field region. It can be calculated as the maximum dose ratio, which is [D(x)/D(-x)]x100%. The area ratio can be calculated as |(a-b)/(a+b)|x200%

Table 3. Mean Value of Flatness and Symmetry Measured for Profiles at a Depth of 1.5cm and 10cm for 2x2, 4x4, 5x5, 7x7, 8x8, and 10x10cm^2 Field Sizes 6MV Beam

	Flatness (%)	p value	Symmetry (%)	p-value
Beam profile at 1.5cm depth	101.19±0.29	0.39	100.72±0.17	0.311
Diagonal profile at 1.5cm depth	101.08±0.25	<.001	100.83±0.25	0.005
Beam profile at 10cm depth	102.41±0.46	<.001	100.58±0.15	0.619
Diagonal profile at 10cm depth	102.16±0.27	0.037	100.91±0.25	0.054

Note: The data mentioned here is in the form of mean and standard deviation.

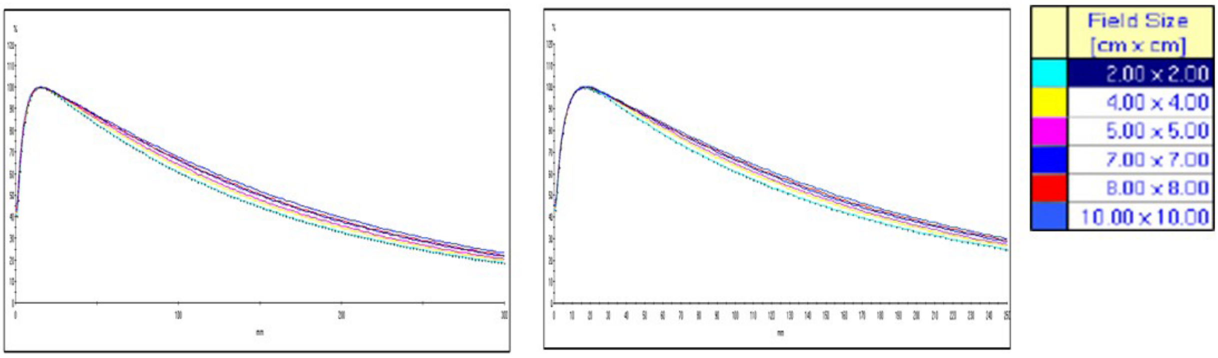

Figure 2. Graph of PDD Representing MicroDiamond Detector for 6MV (left) and 6FFF (right) Beam Energy

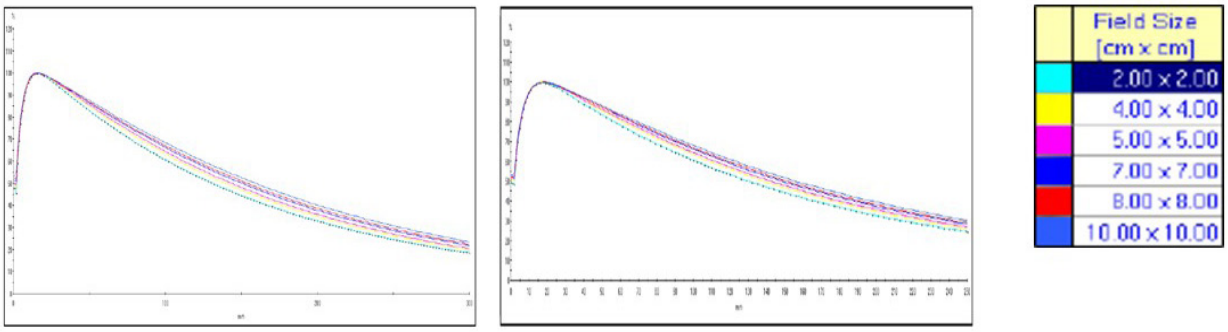

Figure 3. Graph of PDD Representing SRS Diode for 6MV (left) and 6FFF (right) Beam Energy

Table 4. Mean Value of Symmetry Measured for Profiles at a Depth of 1.5cm and 10cm for 2x2, 4x4, 5x5, 7x7, 8x8, and 10x10cm² field sizes for 6MV FFF beam.

	Symmetry (%)	p-value
Beam profile at 1.5cm depth	103.2±3.16	0.648
Diagonal profile at 1.5cm depth	103.1±2.76	0.561
Beam profile at 10cm depth	103.91±1.02	0.107
Diagonal profile at 10cm depth	103.83±0.99	0.225

Note: The data mentioned here is in the form of mean and standard deviation.

where a and b are the integral over the left and right half of the profile, respectively. It is calculated from the central axis to the 50% field size.

The Profiles measured at 1.5cm depth showed that among all the dependent variables, penumbra left showed a significant difference between the three detectors. Flatness and Symmetry results were comparable in the profiles measured at 1.5cm depth for a 6MV photon beam. The profile results measured at a depth of 10cm showed a statistically significant difference in the penumbra

Table 5. Comparison of Output Factor for the Three Detectors for 6MV and 6MV FFF Beam Energies

Detectors		Mean Difference	SE	ptukey
microDiamond 6MV	Micro6FFF	-0.02	0.00395	0.055
	Pin6MV	0.04	0.00248	0.466
	Pin6FFF	-0.014	0.00349	0.049
	Srs6MV	0.00932	0.00294	0.14
	SRS6FFF	-0.01615	0.00395	0.059
microDiamond 6FFF	Pin6MV	0.02128	0.00585	0.09
	Pin6FFF	0.00147	0.00113	0.777
	Srs6MV	0.02575	0.00663	0.071
	SRS6FFF	0.0002	0.00162	1
pinpoint 6MV	Pin6FFF	-0.01982	0.00546	0.09
	Srs6MV	0.00447	0.00114	0.069
	SRS6FFF	-0.021	0.00602	0.103
pinpoint 6FFF	Srs6MV	0.02428	0.00624	0.07
	SRS6FFF	-0.00118	0.0018	0.98
SRS diode 6MV	SRS6FFF	-0.02547	0.00672	0.077

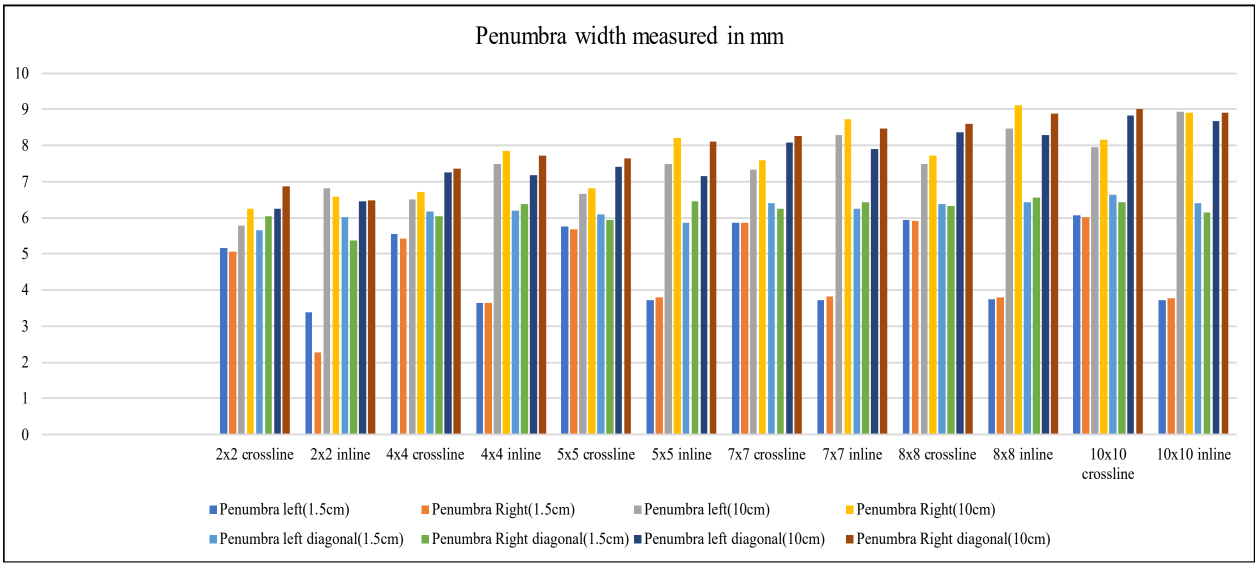

Figure 4. Penumbra Width (mm) between the Three Detectors for 6MV Photon Beam Energy for 1.5cm and 10cm Depth

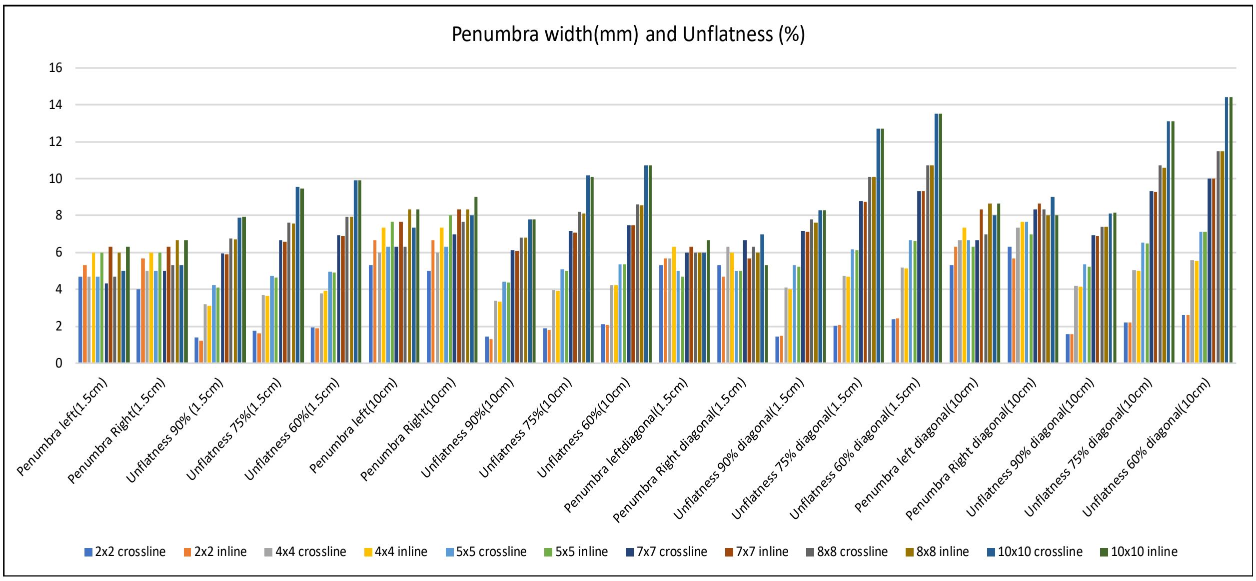

Figure 5. Penumbra Width (mm) and Unflatness (90%, 75%, 60%) between the Three Detectors for 6MV FFF Photon Beam Energy at the Depth of 1.5cm 10cm

right, penumbra left, and beam flatness between the three detectors, whereas the symmetry results were similar. The diagonal profile results measured at a depth of 1.5cm showed a statistically significant difference in the penumbra right, penumbra left, and beam flatness between the three detectors, whereas the symmetry results were similar. The diagonal profile results measured at a depth of 10cm showed a statistically significant difference in the penumbra right, penumbra left, and beam flatness between the three detectors, whereas the symmetry results were similar (Table 3, Figure 4).

The profile results of the 6MV FFF photon beam measured at a depth of 1.5cm and 10cm showed no statistically significant difference in the variables tabulated. It shows that the results are comparable. The diagonal profile results measured at a depth of 1.5cm showed a statistically significant difference in the penumbra left, penumbra right, and unflatness 90% with $p<0.05$. rest all parameters were comparable between the three detectors. The diagonal profile results measured at a depth of 10cm showed a statistically significant difference in the penumbra left, penumbra right, and unflatness 90% with $p<0.05$. Rest all parameters were comparable between the three detectors (Table 4, Figure 5).

Output Factor Measurement

The OF was determined as the ratio of the corrected dosimeter reading under the given set of reference conditions to that measured under the reference condition. These measurements are performed at the reference depth. The OF was measured for 6MV FF and 6MV FFF beam energies for the field sizes 2x2cm^2, 4x4cm^2, 5x5cm^2, 7x7cm^2, 8x8cm^2, and 10x10cm^2. The reference standard field size was considered to be 10x10cm^2. The SSD was kept at 100cm, and the measurement was performed with all the chambers at a depth of 10cm. The resultant data was compared between the 6MV FF and 6FFF beam energies. The data was analyzed using repeated measures of ANOVA. It was found that there was a statistically significant difference between the three detectors as the p-value was less than 0.05, and the effect size was 0.734. The Bonferroni test was performed to check the significance of the results. It was found that statistically significant results were found between microDiamond and pinpoint radiation detectors with 6MV and 6FFF beam energies with p values less than 0.05. These results show that the performance of the detractors in the measurement of the OF is similar with very slight difference between microDiamond and pinpoint radiation detectors in the field sizes mentioned above as the p-value was close to 0.05 (Table 5).

Discussion

In our study, the response of the three distinct detectors was observed by performing small-field dosimetry. the PDD, profile, and OF were determined using a pinpoint ion chamber, microDiamond detector, and SRS diode for the field sizes from 2x2cm^2 to 10x10cm^2. These measurements were carried out with RFA (PTW, Freiburg). It was found that the responses of all three detectors were similar for all three QAs. We found good agreement in the response of the three detectors with respect to all the measurements performed. Since the data was normally distributed in this study, the readings were tabulated in the form of mean and standard deviation. The three radiation detectors were used for the measurement of various field sizes mentioned in the methodology section.

Diodes and microDiamonds are suitable for profile measurements with the scanning system as they have small sensitive volumes [3]. Detectors with small volumes are appropriate for small-field dosimetry. Ciancaglioni et al. [19] performed a study that characterized a single-crystal diamond detector. The SCDD was compared against the pinpoint ion chamber for various quality assurance such as temporal behaviour and time stability, the dose and dose rate dependence of the detector, OF, PDD, and Profile measurement. Here, the PDD and profiles were measured for the 10MV photon beam for the field sizes 1x1, 2x2, 3x3, 4x4, 5x5, and 10x10cm^2 at the Dmax 2.4cm. The results of both detectors were in good agreement with each other, with a deviation within 1%. This indicated a very similar spatial response of the detectors. Here, the pinpoint ion chamber was vertically oriented, with its axis parallel to the beam's central axis, with the measurement point in the chamber considered 2mm below the tip of the chamber [19].

Small-size vented pinpoint ion chamber has a sensitive volume of 0.015 cm^3. This chamber can typically be employed for measuring radiation dose measurements less than 2x2cm^2. Since this chamber has a very small volume, they are basically designed to measure relative beam profiles. They do not offer any stem and polarity effect due to their small sensitive volume [20]. Caution is necessary while using these chambers in the large fields where the stem and cable effects become more significant. It should be noted that there is no steel electrode in the chamber that is being used. Diamond detectors are solid-state detectors that combine small size with high response per volume. In addition, their response is almost independent of energy, i.e., they are very much water equivalent. They also feature a very good directional response [19, 21].

In the measurement of PDD, the Ds, which is the dose value at the surface at a depth of 0.05mm, as explained earlier, is measured in percentage. Ds had a statistically significant difference across the field sizes and across the different detectors. It was found that the Ds values continuously increased as the field size increased from 2x2 to 10x10cm^2. A similar study was performed by Henry Finlay Godson et al., where the PDD and profile measurements were obtained with IBA photon field diode (PFD) and electron field diode (EFD), Nordic Association of Clinical Physicists (NACP) parallel plate, and RK cylindrical ion chamber. It was found that the variation in the PDD values for various detectors was within a deviation of 1%, with the Parallel plate chamber giving a little more variation of up to 1.9% for 2x2cm^2 field size. They observed similar findings of the large variation in the relative Ds values across the various detectors for different field sizes and the increase of Ds values with an increase in the field size [22].

Marziyeh Tahmasbi et al. also found the PDD and profiles that used a pinpoint ion chamber for field sizes less than 3x3cm^2. For the filed sizes greater than 3x3cm^2, they used an SNC125c ion chamber. However, the results were similar to the results obtained in this study. The output factor was measured for the 1x1 to 40x40cm^2 field sizes using PTW 60019 microDiamond, PTW 31016 PinPoint 3D, SNC Edge, and PTW 60018 SRS Diode detectors. The study's results were comparable with those found in our study, wherein the same detectors were included. Additionally, the edge detector showed increased readings compared to the pinpoint chamber [23].

Out of all the popular types of detectors, silicon diode detectors have the highest response per volume. Because of this, their sensitivity volume is often modest enough to prevent dose-volume effects in fields that are extremely small. The density perturbation effect is still evident, though. Silicon diodes' directional response and reaction to low-energy scattered photons are not optimal. Diodes are available in a shielded configuration, where the shield attenuates the signals from these photons to lessen the latter effect. The low energy scatter contribution is negligible in tiny fields. therefore, unshielded diodes are advised for tiny fields, and diode shielding is not necessary [3].

The distance between the 80% and 20% isoline from the central axis of a beam profile is known as penumbra. In this region, as the dose gradient is high enough, it is critical to analyze the measured dose flawlessly. So, to achieve a precise beam profile in the high dose gradient region, a radiation detector with high spatial resolution is necessary, especially in the small fields [20]. Penumbra width in the profile measurement was investigated by E. Pappas et al., which showed that the pinpoint ion chamber had a broadened penumbra width compared to the diamond detector. This result was similar to the results found in our study for the beam profile measured at 1.5cm depth for 6MV FF and FFF beams. One possible explanation for this could be the pinpoint detector's limited size. Also, it was noted that the orientation of the detector does not offer much variation in the penumbra width. In our study, the orientation of the detector was made in such a way that the central axis of the detector was perpendicular to the central axis of the beam. For the 10cm depth beam profile and for the 1.5cm and 10cm depth diagonal profiles, the penumbra width was broad in the SRS diode compared to the other two detectors [11]. However, a statistically significant difference was found in the width of the penumbra region between all the detectors

The parameter beam unflatness, which is basically determined in FFF beams, is the ratio of the dose level at the central axis of the beam to the dose level at the predefined distance from the central axis [13]. The unflatness measured for all the detectors was comparable with each other, having no statistically significant difference between the detectors. Yuichi Akino et al., performed small field dosimetry using FF and FFF beams with various detectors such as edge, dosimetry diode SRS, dosimetry diode E, pinpoint ion chamber, synthetic diamond detector, SFD, and CC01 ion chamber. Here the beam data was taken from 12 different LINACs. They found that for the field size of 5x5mm2, the CC01 ion chamber showed more deviation for 6MV energy, whereas for the 10MV beam, the difference in the measured data was greater with CC04, diode E, and Edge detector. The penumbra width was found to be more in CC01 and Diode E compared to the Edge and microDiamond detector. Also, the measured OFs showed more deviation in the edge detector compared to all the detectors. Overall, if all the beam data was compared with all the used detectors, the microDiamond, pinpoint, and the SRS diode showed comparable results. These results were similar to the findings observed in our study, which indicates that the application of these three detectors in the small field dosimetry will give similar comparable results [24].

Lack of charged particle equilibrium is prominent in the small field dosimetry as the lateral range of the charged particles will always be greater than the field size, which may increase the penumbra region and cause under dosage of the PTV due to heterogeneity of the body tissues. This can be, to some extent, eliminated by carefully choosing the optimum radiation detector for small field dosimetry that has high spatial resolution and signal, low energy and directional dependence, water equivalent, highly stable, and easy to use clinically. However, there is no single detector available that meets all the properties to make it suitable for small-field dosimetry. Therefore, it is logical to use several detectors for data acceptance and periodic quality assurance. The lateral range of the electrons is usually greater than the field size in the small fields. Because the PTV must be covered with the optimal isodose, the absence of lateral CPE is crucial, particularly when heterogeneity is present. In SBRT, it must be considered the dose perturbations in and beyond air cavities, lung tissues, and bone. Ignoring the tissue inhomogeneity in dose computation might result in errors and lower the tumor control probability [20].

The small field dosimetry performed with, pinpoint ionization chamber type 31014, micro Diamond type 60019, and Dosimetry diode SRS type 60018 for the 6MV and 6MV FFF photon beam energies for the filed sizes of 2x2cm^2, 4x4cm^2, 5x5cm^2, 7x7cm^2, 8x8cm^2, and 10x10cm^2 gave comparable results for PDD, OF and profile measurements. PDD values for all the detectors were similar except for Ds, which increased as the field size increased in all detectors for the 6MV FF and 6MV FFF beams. Beam profile data gave similar results in all the detectors, with penumbra width having statistically significant differences in the 6MV FF beam between the three detectors. Penumbra width was found lower in pinpoint and microDiamond detectors for 6MV FF and 6MV FFF beams compared to the SRS dosimetry diode. The performance of all the detectors used in this study was similar with less noticeable differences between each other. As there was no great difference found in the results between the chambers, it can be concluded from this study that all three radiation detectors are suitable for the small field dosimetry performed for SRS and SBRT treatments.

Author Contribution Statement

Ms. Rechal Nisha Dsouza- Data collection, data analysis, data interpretation, article drafting. Dr. Krishna Sharan- Concept and Design of the work. Dr. Suresh Sukumar-Concept and Design of the work. Mr. Srinidhi G Chandraguthi-Critical revision of the article. Dr. Shreekripa Rao-Critical revision of the article. Dr. Shirley Lewis-Critical revision of the article. Dr. Senthil Manikandan-Concept and Design of the work

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General

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Study Registration

The study is registered under Clinical Trials Registry, India; registration number CTRI/2021/11/037842, on 8th November 2021.

Availability of the Data

Data can be provided by the author at the request of the reader.

Ethical Declaration:

The study is approved by the Institutional Ethics Committee, Kasturba Medical College and Kasturba Hospital, Manipal Academy of Higher Education Manipal (IEC427-2021) on 8th August 2021

Conflict of interest

The authors declare that there is no competing interest involved in this research work.

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