EVALUATION OF SMALL-FIELD DOSE MEASUREMENTS USING ULTRA-SMALL VOLUME IONIZATION CHAMBER (0.01 CC) AND DIODE DETECTOR SYSTEMS

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Abstract— **The aim of the study to evaluate the performance of a 0.01 cc ionization chamber and a diode detector for small-field dosimetry on a True Beam linear accelerator (LINAC). Small radiation fields are integral to modern radiotherapy techniques, including dynamic IMRT, VMAT, and stereotactic treatments. Materials and Methods: Experimental data were acquired using a 0.01 cc Razor ionization chamber and a Photon Field Detector (PFD) diode detector, mounted in a Blue Phantom² water tank (IBA, Germany) and myQA Accept software. The percentage depth dose (PDD), surface dose, beam profiles, field width, and output factors for field sizes of 1×1, 2×2, 3×3, 4×4, and 10×10 cm² were assessed. Results: The PFD measured sharper penumbra and more accurate field widths in small fields, whereas the Razor chamber showed slight penumbra broadening due to volume-averaging effects. Flatness and symmetry remained within clinical tolerance for both detectors, with symmetry maintained within ~0–1% and flatness increasing marginally with field size. Percentage depth dose (PDD) measurements showed deeper D_{max} and higher PDD values with increasing field size for both detectors; however, the PFD reported shallower D_{max} and slightly lower PDD in very small fields due to higher spatial resolution. Output factor comparison revealed the largest deviation at 1×1 cm², with the PFD recording 0.7641 and the Razor chamber 0.6994, while agreement improved with increasing field size, converging at unity for 10×10 cm². Conclusion: The Razor ionization chamber and diode detector exhibited variations in dosimetric response for small fields, particularly in beam profile assessment. Based on these results, the diode detector is considered more suitable for small-field measurements, whereas the 0.01 cc Razor chamber may introduce uncertainty when used for fields smaller than 4 cm ×4 cm.**
Keywords: Small field dosimetry, diode detector, ionization chamber.

I. INTRODUCTION

In radiation therapy, the dose given to the patient must be precise so that patient receives the correct dose of radiation that will kill cancer cells without damaging the normal tissue[1,2]. Over the last few years, several radiation therapy techniques such as, intensity modulated radiation therapy (IMRT), Stereotactic radiosurgery (SRS), have been widely used for this purpose[3]. Small fields are usually imputable to therapeutic field size between 4×4 cm^2 and 0.3×0.3 cm^2 [4]. Rather it be dynamic IMRT, VMAT or stereotactic treatments, the small fields play a role in ensuring dose conformity and minimizing normal tissue toxicity. Therefore, the significance of commissioning small beams has been increased. Furthermore, the impact of scatter radiation from collimators are important in small fields [5].

In spite of that, when using standard detectors, it is difficult to commission small beams with a high dose gradient region as it widens the penumbra area. In ionization chamber, the absorbed dose to medium is evaluated in accordance with cavity theory[6]. However, in small fields, the cavity theory breaks down and in consequence with charge particle equilibrium condition will not be fulfilled. For the electronic equilibrium, the cavity size must be smaller than the range of secondary charge particle passing through it [7].

Besides, partial occlusion of the primary photon source by the collimating devices on the beam axis and volume averaging effect are also challenging in small field dosimetry. Thus, dosimetry in small fields is influenced by design and type of detectors. Generally, detectors with large active volume broaden the penumbra region, while detectors with small active volume create noisier signals. Thus, evaluation of the characteristics of different detectors for small fields is an essential requirement.

A dosimetric study was conducted by Bucciolini *et al.* (2003) for the comparison of diamond detector, silicon diode and ionization chamber in photon beams of different energy and field sizes. Due to the high resolution, the diamond detector was confirmed as suitable for accurate dosimetric measurements as compared to silicon diode and ion chamber [8]. A study was carried out by Stasi et al. for the comparison of micro-ionization chamber with a diamond detector when used for IMRT dosimetry. The results show that, both detectors showed good agreement for a 1×1 cm^2 field [9].

The current study aimed to evaluate the dosimetric capability of 0.01 cc ion chamber and diode detector in small fields of TrueBeam linear accelerator. The dosimetric parameters, including the percentage depth dose, percentage surface dose, beam profiles, field width and output factors for the field size of 10×10 cm^2 as the reference field and small fields of 4×4, 3×3, 2×2 and 1×1 cm^2 were evaluated for both dosimeters.

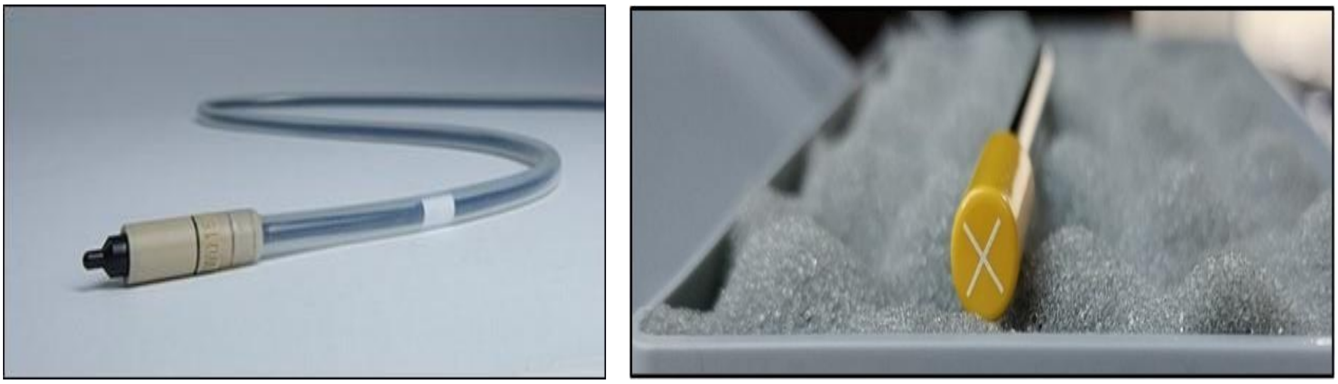
II. MATERIALS AND METHODS

Detector Specifications

The ionization chamber (razor chamber) (Figure 1a) and diode detector (PFD - photon field detector) chosen for this study was manufactured by IBA, Germany. The razor chamber was intended for relative or absolute dose determination, depth dose measurements, and field profile analysis in a water phantom or in free air, for photon and electron. The razor chamber is a high spatial resolution, small volume chamber. The cavity volume is 0.01 cm^3. It is waterproof and vented through a waterproof sleeve. The outer and inner electrode material is shonka (C552) and graphite. The reference point is on the chamber axis, 2.3 mm from the distal end of the chamber thimble. The chamber is designed for positioning with its long axis perpendicular to the beam.

The photon field detector (PFD) (Figure 1b) is based on the third generation of p-type silicon semiconductor. The highly doped p-type silicon detector chips, specially designed for radiotherapy applications, have been natural choice of measurements where high spatial resolution is required. The PFD has an integrated energy filter that effectively reduce the overcompensation of signal in situations with a large portion of scattered low-energy radiation, such as medium sized photon fields and at large depths.

All measurements with PFD were made by irradiating the detector from the top, i.e. parallel to the detector axis. The effective point of measurement is located 1.2 ± 0.2 from the surface. The details of detectors are shown in Table 1.



a) b)

Figure 1: Devices used in this study (a) ionization chamber (Razor chamber) and (b) photon field detector

Table 1: Details of Detectors

Detector	Sensitive material	Inner electrode	Sensitive Volume (cm^3)	Dimension
Razor chamber (IBA)	Air	Graphite	0.01	0.55 mm diameter, 2.8 mm length
PFD (IBA)	Silicon	-	0.0017	1.6 mm diameter, 0.08 mm thickness

Experimental Setup

All the measurements for photon energy 6 MV was analyzed while taking beam data in Varian TrueBeam linear accelerator. We used automatic water scanning phantom, Blue Phantom[2] (IBA, Germany), controlled by myQA Accept software. It consists of a three - dimensional servo, a control unit with integrated two channel electrometer (CCU), and two signal detectors. The scanning volume of water phantom is 480 mm × 480 mm × 410 mm. As per the manufacturer, the position accuracy is ±0.1 mm. The placement of the water phantom is shown in Figure 2a.

The gantry and collimator were set to 0º angle. The source-to-surface distance (SSD) was kept at 100 cm. The orientation of razor chamber and diode detector were kept in perpendicular and parallel with respect to central axis. The orientation of the detector axis relative to the beam axis affects the shape of the measured profile or field output factor. A general rule is to orient the detector's sensitive volume so that the smallest dimension is perpendicular to the scan direction whenever possible[10]. The orientation of the 0.01 cc razor chamber and PFD are shown in Figure 2b and 2c respectively. The high voltage bias of +300 V was applied to razor chamber and 0 V was applied to diode detector.

Beam profiles:

The beam profiles were measured in orthogonal directions (in-plane and cross-plane), for both ion chamber and diode detector for square field sizes of 1×1, 2×2, 3×3, 4×4 and 10×10 cm^2 at water depths of 10 cm for 6 MV energy and dose rate 500 MU/min. For beam profiles measurement, the step-by-step measurement mode was chosen. The measurement time was 2 seconds; positioning and scanning speed were 1 cm/s, and medium sensitivity was selected. The step size was chosen 1 mm and absolute penumbra margin was given 5 cm. Background measurement was repeated at regular interval. To compare the effectiveness of razor chamber and diode detector, we analyzed the penumbra widths and FWHM for various field sizes. From the measured beam profiles, the mean values of the right and left side of the penumbra were calculated.

Percentage Depth Dose (PDD):

The PDD was measured for 1×1, 2×2, 3×3, 4×4 and 10×10 cm^2 square fields for 6 MV energy and dose rate 500 MU/min. It was measured in continuous mode of measurement for depth from 30 to -0.05 cm. To avoid surface tension, detectors were moved vertically along the beam axis from the bottom to top of the water tank.

Output factors:

The field Output was measured for all the field sizes and at reference depth of measurement, $Zref$ was 5 g/cm^2 using both detectors and DOSE1 electrometer (IBA, Germany) by delivering 100 MU. The field output factors were measured for the field size of 10×10 cm^2 as the reference field and for the small field sizes 4×4, 3×3, 2×2 and 1×1 cm^2. The measurement was repeated for 3 times for accuracy and precision of output.

III. RESULTS

Beam Profile

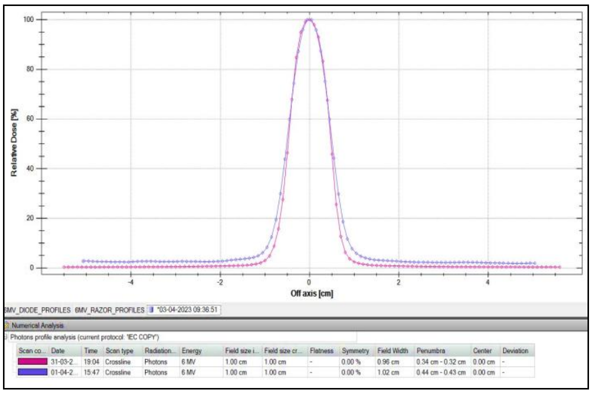
Flatness and symmetry values for 6 MV photons were evaluated using PFD and Razor chamber detectors for field sizes from 1×1 cm² to 10×10 cm² in both inline and crossline directions. For 1×1 cm² fields, flatness values were not reported due to the extremely small field size; however, symmetry remained ideal at 0.00% for both detectors as shown in table 2 respectively.

For 2×2 cm² fields, flatness values were close to unity for both detectors (≈100.05%–100.08%), and symmetry remained near 100%, indicating minimal dose variation across the field. As field size increased, flatness values increased progressively, reaching a maximum of 104.94% (PFD) and 105.76% (Razor) for the inline 10×10 cm² field. Symmetry remained within 100.00%–101.05% for all field sizes and detectors, indicating stable and well-balanced dose profiles across both axes as shown in table 2 respectively. Penumbra and field-width measurements for 6 MV beams using the PFD and Razor chamber demonstrated close agreement across all field sizes. The PFD consistently measured smaller penumbra values compared to the Razor chamber, particularly for small fields (1×1 cm² and 2×2 cm²).

In the 1×1 cm² beam profile scan (Inline and Crossline), the penumbra recorded by the PFD was 0.34 – 0.51 cm, whereas the Razor chamber measured 0.46-0.74 cm as shown in table 3 respectively. Field-width assessment showed that both detectors produced values close to the nominal field size; however, the Razor chamber demonstrated slightly higher readings in smaller fields due to partial-volume effects. With increasing field size (e.g., 10×10 cm²), the differences between the detectors reduced, with the PFD and Razor chamber measuring 10.83–10.95 cm and 10.87–10.98 cm, as shown in table 3 Respectively. The graphical demonstration of beam profiles (crossline) for 1×1 to 4×4 cm^2 field sizes with a 6 MV photon beam at a 5-cm water depth with two dosimeters. Penumbra of the dose profiles showed considerable dependence on the chamber design and volume as shown in Figure 3a, 3b, 3c, and 3d respectively.

Table 2: Comparison of Beam Flatness and Symmetry for 6 MV Photon Beams Using PFD and Razor Chamber Detectors

Scan Type	Field Size (cm^2)	Flatness (PFD) %	Flatness (Razor Chamber) %	Symmetry (PFD) %	Symmetry (Razor Chamber) %
Inline	1×1	-	-	0.00	0.00
Crossline	1×1	-	-	0.00	0.00
Inline	2×2	100.05	100.08	100.02	100.08
Crossline	2×2	100.05	100.05	100.00	100.03
Inline	3×3	100.61	100.89	100.31	100.26
Crossline	3×3	100.37	100.59	100.12	100.21
Inline	4×4	101.16	101.55	100.46	100.52
Crossline	4×4	100.82	101.29	100.18	100.08
Inline	10×10	104.94	105.76	100.97	101.05
Crossline	10×10	104.26	104.69	100.33	100.27



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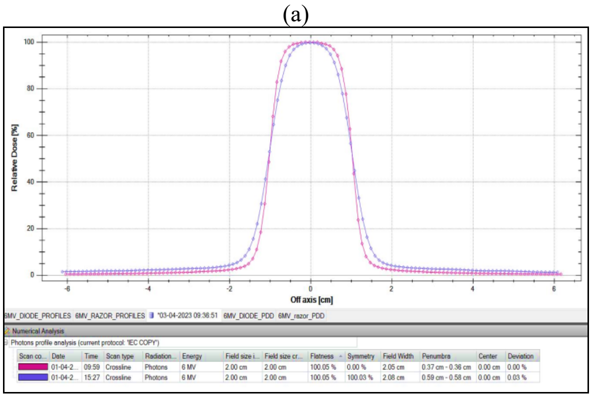

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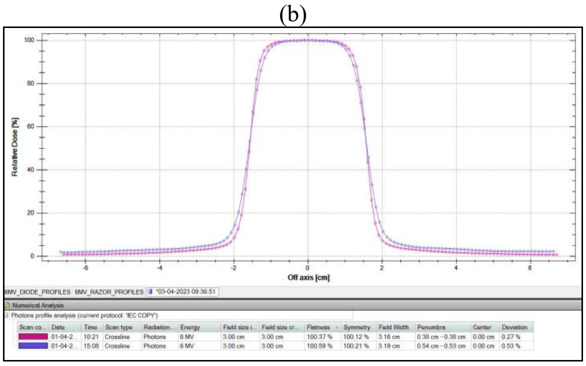

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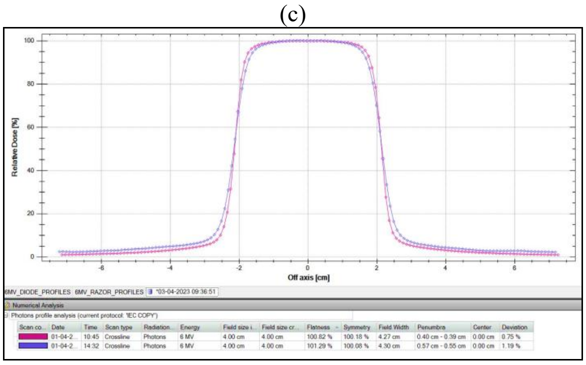


(d)

Fig. 3: Beam profiles (crossline) for 1×1 to 4×4 cm^2 field sizes with a 6 MV photon beam at a 5-cm water depth with two dosimeters. Penumbra of the dose profiles showed considerable dependence on the chamber design and volume. Field sizes: (a) 1×1 cm^2, (b) 2×2 cm^2, (c) 3×3 cm^2, and (d) 4×4 cm^2

Table 3: Comparison of Penumbra and Field Width for 6 MV Photon Beams Using PFD and Razor Chamber Detectors

Scan Type	Field Size (cm^2)	Penumbra (PFD) cm	Penumbra (Razor Chamber) cm	Field Width (PFD) cm	Field Width (Razor Chamber) cm
Inline	1×1	0.34 – 0.34	0.46 – 0.46	0.95	1.04
Crossline	1×1	0.34 – 0.32	0.44 – 0.43	0.96	1.02
Inline	2×2	0.38 – 0.38	0.55– 0.54	2.03	2.07
Crossline	2×2	0.37 – 0.36	0.59 – 0.58	2.05	2.08
Inline	3×3	0.40 – 0.40	0.57 – 0.57	3.12	3.06
Crossline	3×3	0.38 – 0.38	0.54 – 0.53	3.16	3.19
Inline	4×4	0.43 – 0.42	0.60 – 0.60	4.24	4.26
Crossline	4×4	0.40 – 0.39	0.57 – 0.55	427	4.30
Inline	10×10	0.51 – 0.51	0.74 – 0.74	10.83	10.87
Crossline	10×10	0.48 – 0.47	0.70 – 0.68	10.95	10.98

Percentage Depth Dose

Depth of maximum dose (D_{max}) and (PDD) values were measured using the PFD and Razor chamber for field sizes ranging from 1×1 cm² to 10×10 cm². For the smallest field (1×1 cm²), the PFD recorded a shallower D_{max} (1.15 cm) compared to the Razor chamber (1.26 cm), along with slightly lower PDD values (56.68% vs. 57.23%). As field size increased, D_{max} values gradually shifted deeper for both detectors, stabilizing around 1.38–1.51 cm. Similarly, PDD values increased with field size, reaching 66.82% (PFD) and 66.99% (Razor chamber) for the 10×10 cm² field. Agreement between the detectors improved with increasing field size. Table 4 shows the Comparison of PDD and for 6 MV Photon Beams Using PFD and Razor Chamber Detectors for all field sizes. Depth of maximum dose (D_{max}) and percentage depth dose (PDD) values were measured using the PFD and Razor chamber for field sizes ranging from 1×1 cm² to 10×10 cm². For the smallest field (1×1 cm²), the PFD recorded a shallower D_{max} (1.15 cm) compared to the Razor chamber (1.26 cm), along with slightly lower PDD values (56.68% vs. 57.23%). As field size increased, D_{max} values gradually shifted deeper for both detectors, stabilizing around 1.38–1.51 cm. Similarly, PDD values increased with field size, reaching 66.82% (PFD) and 66.99% (Razor chamber) for the 10×10 cm² field. Agreement between the detectors improved with increasing field size.

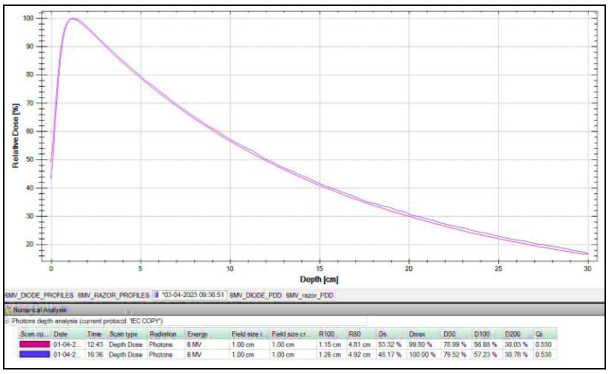
Table 4: Comparison of PDD and for 6 MV Photon Beams Using PFD and Razor Chamber Detectors

Field Size (cm^2)	PFD							Razor Chamber						
	R100 (cm)	R80 (cm)	Ds (%)	D_{max} (%)	D50 (%)	D100 (%)	Qi	R100 (cm)	R80 (cm)	Ds (%)	D_{max} (%)	D50 (%)	D100 (%)	Qi
1×1	1.15	4.81	53.32	99.80	78.99	56.68	0.530	1.26	4.92	48.17	100.00	79.52	57.23	0.538
2×2	1.39	5.25	50.56	99.74	81.29	58.91	0.536	1.40	5.32	44.08	100.00	81.55	58.97	0.540
3×3	1.39	5.51	50.96	99.65	82.70	60.53	0.538	1.51	5.56	43.92	100.00	82.80	60.82	0.543
4×4	1.38	5.74	51.25	99.72	83.56	61.64	0.545	1.51	5.81	44.67	100.00	83.97	62.25	0.548
10×10	1.46	6.55	58.29	99.59	86.55	66.82	0.576	1.51	6.62	49.61	100.00	86.42	66.99	0.582

For the Razor ionization chamber, the depth of maximum dose (R100) also increased with field size, from 1.26 cm at 1×1 cm² to 1.51 cm at 10×10 cm². The R80 value similarly increased from 4.92 cm to 6.62 cm with increasing field size. Surface dose values ranged from 48.17% for the smallest field to 49.61% for the 10×10 cm² field, which were consistently lower than the diode readings. The quality index increased from 0.538 for 1×1 cm² to 0.582 for 10×10 cm², again reflecting increasing beam quality with larger field dimensions. The graphical demonstration of PDD for 6 MV photon beam for a different field size for both detectors. Field sizes: (a) 1×1 cm^2, (b) 2×2 cm^2, (c) 3×3 cm^2, and (d) 4×4 cm^2 figure 4a, 4b, 4c, and 4d respectively.

Output Factors

The measured output factors were normalized to 1 for a field size of 10×10 cm^2. Output factor measured by both detectors vary by around 8% for 1×1 cm^2 field size but, in larger field size differences was around 5%. The measured output factors for small fields demonstrated notable differences between the PFD detector and the Razor chamber. For the 1×1 cm² field, the output factor obtained using the PFD was 0.7641, whereas the Razor chamber recorded a lower value of 0.6994, indicating a significant under-response of the ionization chamber in the smallest field size. At 2×2 cm², the PFD measured an output factor of 0.8066, compared to 0.8422 with the Razor chamber. A gradual reduction in discrepancy was observed with increasing field size. For the 3×3 cm² field, the output factors were 0.8312 (PFD) and 0.8787 (Razor chamber), while for 4×4 cm², the values were 0.8570 and 0.9069, respectively.



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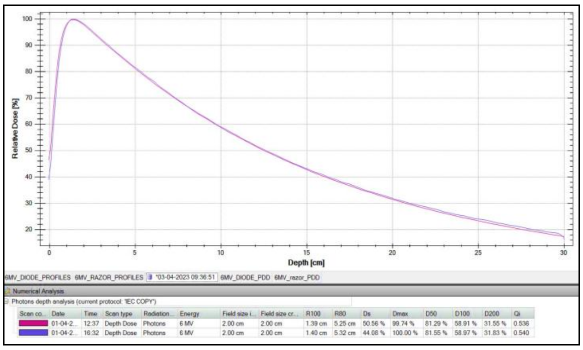

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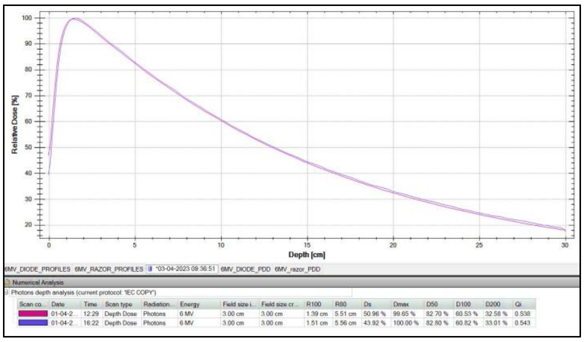

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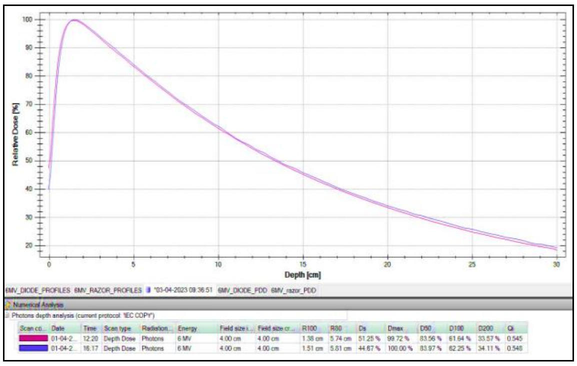

(d)

Fig. 4: PDD for 6 MV photon beam for a different field size for both detectors. Field sizes: (a) 1×1 cm^2, (b) 2×2 cm^2, (c) 3×3 cm^2, and (d) 4×4 cm^2

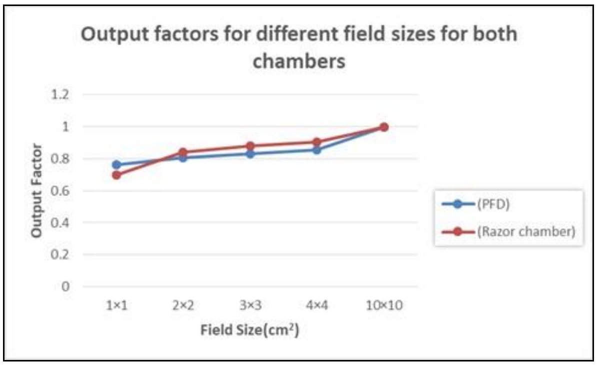

Fig. 5: Plot of measured output factors with respect to field sizes for both detectors

For the reference 10×10 cm² field, both detectors recorded an output factor of 1.000, validating normalization. Overall, the PFD demonstrated superior consistency in the smallest field, while the Razor chamber showed comparatively higher output factors for field sizes ≥2×2 cm² which is shown in Figure 5.

IV. DISCUSSION

To determine an accurate dose in a small photon beam is an important and difficult task. In this work, we evaluated the performance of Razor chamber and diode detector in small field. The ion chambers are broadly use in radiotherapy due to low directional dependence, dose rate independence and better dose response. Instead, its application in small field dosimetry is limited when the dimension of the dosimeter is large compared to the size of the irradiation field (volume averaging effect). On the other hand, due high spatial resolution, the diode detectors can be produced at a small size and so far, they have been utilized in small field dosimetry by virtue of high sensitivity per volume, small size and real-time readout [11].

The results demonstrate that both detectors exhibit consistent trends, with D_{max} moving deeper and PDD increasing as field size increases, reflecting enhanced contribution of scatter radiation in larger fields. The PFD consistently measured slightly shallower D_{max} and marginally lower PDD values compared to the Razor chamber, especially in small fields, due to its smaller active volume and higher spatial resolution

The Razor chamber exhibited minor over-response in small fields, likely from volume-averaging effects and reduced resolution in steep dose gradients. The convergence of readings at larger fields confirms that both detectors are reliable for conventional field dosimetry, while the PFD provides improved accuracy in small-field depth-dose measurements relevant for stereotactic applications.

As shown in Table 3 and Fig. 3a, 3b, 3c, and 3d, we observed some variation in penumbra region and FWHMs of the beam profile. The range of electron is higher in air than that of water, as a result penumbra broadening is observed in ion chamber. However, the semiconductor detector based on silicon shows narrow penumbra as a result of electron transport in silicon to water is quite less [12].

As shown in Fig. 4, both detectors showed an increase in R100, R80, and Qi values with increasing field size. However, the PFD diode reported higher surface dose values compared to the Razor ion chamber for all field sizes, consistent with the known over-response of diodes in the buildup region. Conversely, the ionization chamber demonstrated slightly deeper R100 for very small field sizes and a comparatively lower surface dose, attributable to its air-filled design and reduced sensitivity to low-energy scattered electrons. Overall, both detectors showed consistent depth-dose trends, with expected differences arising from their detector characteristics.

The results indicate that both the PFD and Razor chamber accurately measure field widths in small and standard photon fields. Slight over-measurement was observed in smaller fields with the Razor chamber, likely due to its larger sensitive volume and volume-averaging effect, making the PFD more suitable for precise small-field dosimetry. In larger fields, both detectors produced closely matched readings, confirming their reliability.

Overall, the PFD demonstrated superior accuracy in small fields, while both detectors provided consistent results in larger fields, supporting their suitability for clinical use in advanced radiotherapy techniques.

As the field size increased, the discrepancy between the two detectors decreased, demonstrating that both detectors are reliable for conventional field sizes. These results reinforce the importance of detector selection in small-field dosimetry, with PFD being more suitable for stereotactic and advanced radiotherapy.

Percentage surface dose measured by diode detector is over estimated relative to ion chamber as a result of semiconductor detector based on silicon gives a signal which is high compared to the signal from an air-filled ionization chamber. This is due to two parameters. The energy required to create an electron-hole pair in silicon detector is about 3.6 eV and the corresponding energy required in an air-filled ion chamber is about 33 eV. Additionally, the density for silicon is about 2000 times higher than that for air. These two parameters result in a signal which is about more than 17,000 times higher for pure silicon.

Due to finite size of detector volume, the ion chamber is unsuitable in measuring output factors as the air cavity size plays an important role in electronic equilibrium and output factor estimation. The water equivalency and active volume of the detector become important as the lateral electronic equilibrium breaks down with decreasing field size [7].

Noteworthy, setup errors may affect small-field- dosimetry. Therefore, uncertainty related to setup should be minimize.

V. CONCLUSION

The results demonstrated that both detectors produced consistent depth-dose and beam profile trends across increasing field sizes. However, significant performance differences were noted in the small-field regime. The PFD diode exhibited superior spatial resolution and minimized volume-averaging effects, leading to more accurate measurements of output factors, penumbra, and depth-dose parameters in fields below 3 × 3 cm². In contrast, the Razor ion chamber showed slight over-response and broadening in penumbra regions due to its larger sensitive volume and limitations in steep dose-gradient regions.

The diode detector consistently reported higher surface doses, as expected, due to its high density and sensitivity compared to the air-filled ion chamber. Conversely, the ion chamber provided reliable results in larger fields but demonstrated limitations in conditions of lateral electronic disequilibrium. The PFD diode is more appropriate for stereotactic and advanced radiotherapy applications requiring high spatial resolution and precision, whereas the ion chamber remains a robust option for standard clinical fields. Careful setup and minimized positioning uncertainties are essential for accurate small-field dose measurements.

ACKNOWLEDGMENT

This work is a part of M.Sc. thesis at The Gujarat Cancer & Research Institute, Ahmedabad, India.

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