Dosimetric Characteristics of Edge Detector™ in Small Beam Dosimetry

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In this study, we evaluated an edge detector for small-beam dosimetry. We measured the dose linearity, dose rate dependence, output factor, beam profiles, and percentage depth dose using an edge detector (Model 1118 Edge) for 6-MV photon beams at different field sizes and depths. The obtained values were compared with those obtained using a standard volume ionization chamber (CC13) and photon diode detector (PFD). The dose linearity results for the three detectors showed good agreement within 1%. The edge detector had the best linearity of ±0.08%. The edge detector and PFD showed little dose rate dependency throughout the range of 100～600 MU/min, while CC13 showed a significant discrepancy of approximately −5% at 100 MU/min. The output factors of the three detectors showed good agreement within 1% for the tested field sizes. However, the output factor of CC13 compared to the other two detectors had a maximum difference of 21% for small field sizes (～4×4 cm^2). When analyzing the 20～80% penumbra, the penumbra measured using CC13 was approximately two times wider than that using the edge detector for all field sizes. The width measured using PFD was approximately 30% wider for all field sizes. Compared to the edge detector, the 10～90% penumbras measured using the CC13 and PFD were approximately 55% and 19% wider, respectively. The full width at half maximum (FWHM) of the edge detector was close to the real field size, while the other two detectors measured values that were 8～10% greater for all field sizes. Percentage depth doses measured by the three detectors corresponded to each other for small beams. Based on the results, we consider the edge detector as an appropriate small-beam detector, while CC13 and PFD can lead to some errors when used for small beam fields under 4×4 cm^2.

Key Words: Edge detector, Small beam, Penumbra

INTRODUCTION

The purpose of radiation therapy is to provide a high dose to the target volume while minimizing the damage to normal tissue.[1] In recent years, intensity modulated radiation therapy (IMRT), intensity modulated radiosurgery (IMRS), and stereotactic radiosurgery (SRS) have been extensively used for this purpose. Thus, the importance of commissioning small beams has increased. However, it is difficult to measure and commission small beams with a steep dose gradient region when using standard detectors, which broaden the penumbra area. In general, bigger detectors widen the penumbra region, while smaller detectors produce noisier signals. Therefore, it is very important to analyze the characteristics of various detectors by comparing their dosimetric properties for small beams.

Small beam dosimetry requires a small active volume and high resolution because the large active volume of the detector could take inaccurate measurements, which would hinder the planning for precision therapy such as IMRT and IMRS. In recent years, many studies have attempted to verify the dosimetry of small fields. Several researchers have applied the Monte Carlo simulation method, which agrees well with the measured data for small IMRT segments, i.e., output factors,

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percentage depth dose (PDD), beam profiles, and dose rate dependence.

Bucciolini et al. compared a diamond detector, silicon diode-type detector, and ion chamber in terms of the photon beam and for different field sizes. The diamond detector was confirmed as suitable for accurate dosimetric measurements due to its high resolution compared to silicon diode and ion chamber system.[2] Aaki et al. showed that a glass plate dosimeter (GPD) has a slightly narrower penumbra than the Monte Carlo simulation for 4 and 10 MV photon beams and that GPD had nearly no difference compared with simulations.[3] Laub et al. measured the volume effect of various detectors for small field dosimetry in IMRT. The results were suitable for output test measurements due to the high resolution of the diamond detector.[4] Stasi et al. performed an experiment that compared a micro-ionization chamber with a diamond detector when used for IMRT dosimetry. In their results, the two detectors showed good agreement for a 1×1 cm^2 field.[5] As mentioned earlier, other researchers carried out experiments where a significant difference was recognized in the small field used for IMRT and IMRS with detectors of different active volume. However, so far, there has not been as much research on edge detectors, which are dedicated to small beam dosimetry with a steep gradient region.

This work aims to evaluate the edge detector for small beam dosimetry in terms of basic dosimetric parameters such as dose linearity, dose rate dependence, output factor, beam profiles, and PDD. The edge detector was compared with a standard volume ionization chamber and a photon diode detector, which are the most commonly used detectors for beam data commissioning of medical linear accelerators.

MATERIALS AND METHODS

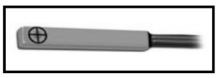
1. Detector specifications

An edge detector, standard volume ionization chamber, and photon diode detector were evaluated in this study. Their geometrical properties are shown in Table 1.

The edge detector (Model 1,118 Edge, Sun Nuclear Corporation, Melbourne, USA) was especially designed as a scanning system for water phantoms; it measures small beam data and is an *n*-type silicon diode detector. Its active detection area and sensitivity are 0.8 mm^2 and 32 nC/Gy, respectively. The diode die is located 0.3 mm from the top, 4.3 mm from the end, and 2.7 mm from the side, with the cross marked on the top surface. The water equivalent depth is 0.5 mm. The detector housing wall thickness is 0.13 mm, and the wall material is brass. A zero voltage bias was applied to the electrometer. The detector is waterproof.

The compact chamber (CC13, S/N-6003, Scanditronix-Wellhofer, IBA, Germany) is a standard ionization chamber that is designed for conducting measurements in air, solid, and water phantoms with high reproducibility. It is suitable for clinical use with water phantoms and measuring output factors. The cavity volume is 0.13 cm^3. The wall and central electrode material is C552, and the wall thickness is 0.070 g/cm^2. Unlike the edge detector, a 300 V bias was applied to the electrometer. The photon field detector (PFD, S/N: DEB012-3438, Scanditronix-Wellhofer, IBA, Uppsala, Sweden) is a highly doped *p*-type silicon detector with a diameter of 2 mm and

Table 1. Specifications for the three dosimeters applied.

Dosimeters	Sensitive volume	Wall thickness and material	Miscellaneous properties
Edge detector 	0.8 mm×0.8 mm×2.5 μm	0.13 mm, Brass	*n*-type silicon diode
CC13 	0.13 cm^3	0.7 mm, C552	Central electrode material, C552
PFD 	2×2×0.06 mm	0.5 mm, unknown	*p*-type silicon diode

thickness of 0.06 mm for the active area, which forms a circle. It is specially designed for measuring small photon beams. Its effective measurement point is located 0.5±0.15 mm below the surface of the detector.

2. Experimental setup

We used linear accelerators (CL 21EX, Varian Medical System, Palo Alto, CA, USA) to produce a 6 MV photon beam during all measurements. The source-to-surface distance (SSD) was set to 100 cm at all times. All measurements were performed in an automatic water scanning phantom (Blue phantom, Scanditronix-Wellhofer, IBA, Germany) with a volume of 48×48×48 cm^3. The gantry and collimator angle was set to 0^o. The stem of the ionization chamber and edge detector were located perpendicular to the beam central axis, and the diode detector stem was parallel to the central axis. The three detectors were connected to an electrometer (Dose 1, Scanditronix-Wellhofer, IBA, Germany) to collect a charge. The detectors were calibrated to a standard temperature and pressure before the measurements. A high voltage bias of +300 V was applied to the ionization chamber, while 0 V was applied to the chambers of the diode-type detectors; the voltage biases were transmitted through a triaxial cable. When a diode-type detector was being used as the scanning (or field) detector, the reference field detector (RFD, Scanditronix-Wellhofer, IBA, Germany) acted as the reference detector and was fixed in the field. The reference detector was used to eliminate fluctuations or drift in the photon beam.[6)] The gain was automatically adjusted to produce identical reading values at the reference point before measurements.[6)] In all measurements, the length of irradiated cable was minimized.[7)]

3. Measurement contents

1) Dose linearity: For the three detectors, dose linearity was measured to see if the detector signal was linearly proportional to the dose. The test was carried out for a field size of 10×10 cm^2 at a depth of 5 cm in the water phantom. Measurements were conducted by delivering 10, 50, 100, 200, 400, and 600 monitor units (MU) for a 6 MV photon beam. The response signal was converted to dose (cGy) using the PDD value at the depth of 5 cm. The linear fit function was used to evaluate the linearity.

2) Dose rate dependency: Similar to the dose linearity test setup, the dose rate dependency was measured for each detector by delivering 200, 300, 400, 500 and 600 MU/min for a 6 MV photon beam. The reading values were normalized so that 300 MU/min corresponded.

3) Output factor: The output factor were measured by delivering 300 MU at 1.5 cm depth in the water phantom. This test was to measure the dependence on the field size and collecting volume for the different detector systems. The measurements were carried out for 1×1, 2×2, 4×4, 6×6, 8×8, and 10×10 cm^2 field sizes; these were combined with multileaf collimator (MLC) square fields with square independent jaws. All output factors were measured in square fields where the MLC size was smaller than or equal to the independent jaw setting. The data were normalized to 1 for a field size of 10×10 cm^2.

4) Beam dose profiles: The beam dose profiles were measured in orthogonal directions (in-plane and cross-plane) for all detectors using square field sizes of 1×1, 2×2, 4×4, 6×6, 8×8, and 10×10 cm^2 at water depths of 0.5, 1.5, 5, 10, 20, and 30 cm. Transverse profiles were measured with an offset of half the leaf thickness to avoid interleaf gap. To compare the effectiveness of the edge detector against other detector systems for small beam measurements, we analyzed the penumbra widths (10∼90% and 20∼80%) and full width at half-maximum (FWHM) for various field sizes. The mean values of the left and right sides of the penumbra widths were calculated from the beam profiles measured with different detectors at a depth of 10 cm.

5) Percentage depth dose (PDD): The percentage depth dose was measured for 1×1, 2×2, 4×4, 6×6, 8×8, and 10×10 cm^2 square fields in water depths of 0.5 to 30 cm. Detectors were moved vertically along the beam axis from the bottom of the water tank to avoid surface tension.

RESULTS

1. Dose linearity

As shown in Fig. 1, the response proportionally increased with MU for all detectors. The linear fit function results all showed excellent linearity, with the discrepancy within 1% for all three detectors; the best results were produced by the edge detector, which ranged within ±0.08% (not shown).

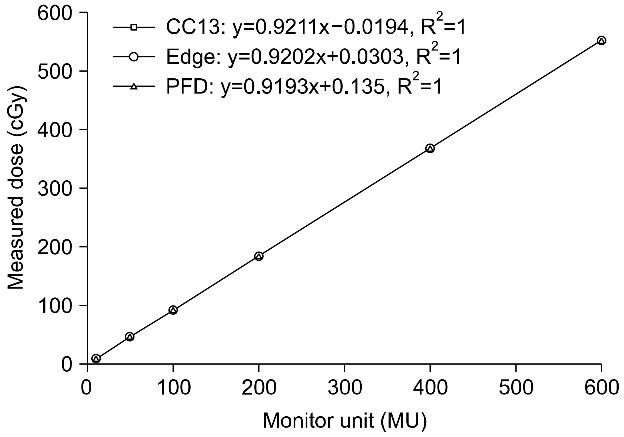


Fig. 1. comparison of dose linearity range from 10 to 600 mu for a 6 mv x-ray beam. response was shown as a function of the monitor unit (mu).

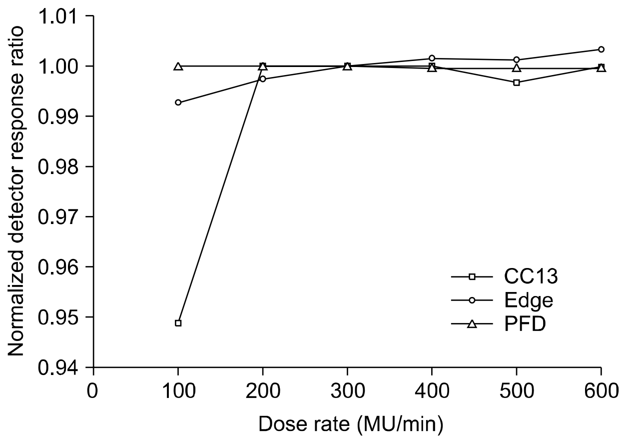


Fig. 2. Dose rate dependence ranging from 100 to 600 MU/min for a 6 MV photon beam. Dose rate was normalized to 1 for 300 MU/min.

2. Dose rate dependency

Fig. 2 shows the results for each of the detectors; the responses were normalized to 1 at 300 MU/min. The ion chamber had a slight lower value than the other detectors at 100 MU/min, and the discrepancy was approximately 5%. Both diode-type detectors produced similar responses for all exposure ranges. The edge detector had a slightly increased response with increasing dose rate, while the PFD was nearly constant.

3. Output factors

Fig. 3 shows the measured output factors for all field sizes.

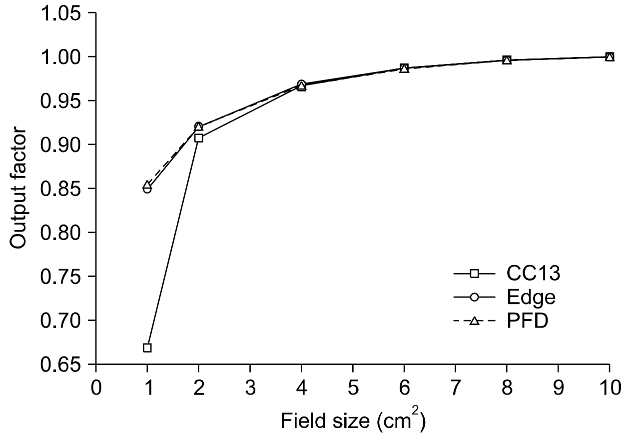


Fig. 3. Output factor for different field sizes ranging from 1×1 cm^2 to 10×10 cm^2. Field sizes and sensitive volume dependence of output factor for a 6 MV photon beam. Output factor was normalized to 1 for a field size of 10×10 cm^2.

The measured output factors were normalized to 1 for a field size of 10×10 cm^2, which is a combined MLC with jaw. The data of the three detectors for field sizes of 4×4 to 10×10 cm^2 had good agreement. However, for small fields-in particular, 1×1 cm^2-the output factors for the ion chamber and two detectors showed significant differences (maximum difference of 21%). The difference between the diode-type detectors was within 1% for the smallest field (1×1 cm^2).

4. Beam dose profiles

Fig. 4 shows a comparison of dose profiles for field sizes of 1×1 to 6×6 cm^2 size with a 6 MV photon beam at a water depth of 10 cm. The penumbra widths for the three detectors are summarized in Table 2. As shown in Fig. 4, the penumbras of the profiles were significantly dependent upon the chamber type and sensitive volume. As expected, the edge detector measured a narrower penumbra width than the other detectors for all field sizes. For the 20～80% penumbra, the penumbra width measured with the ion chamber was approximately two times wider than the penumbra measured with the edge detector in all cases. The PFD measured a penumbra width that was 30% wider for all field sizes. On average, when compared to the edge detector, the ion chamber and PFD measured 10～90% penumbras that were approximately 55% and 19% wider, respectively. We confirmed that as the 20～80% penumbra width stayed constant, while the 10～90%

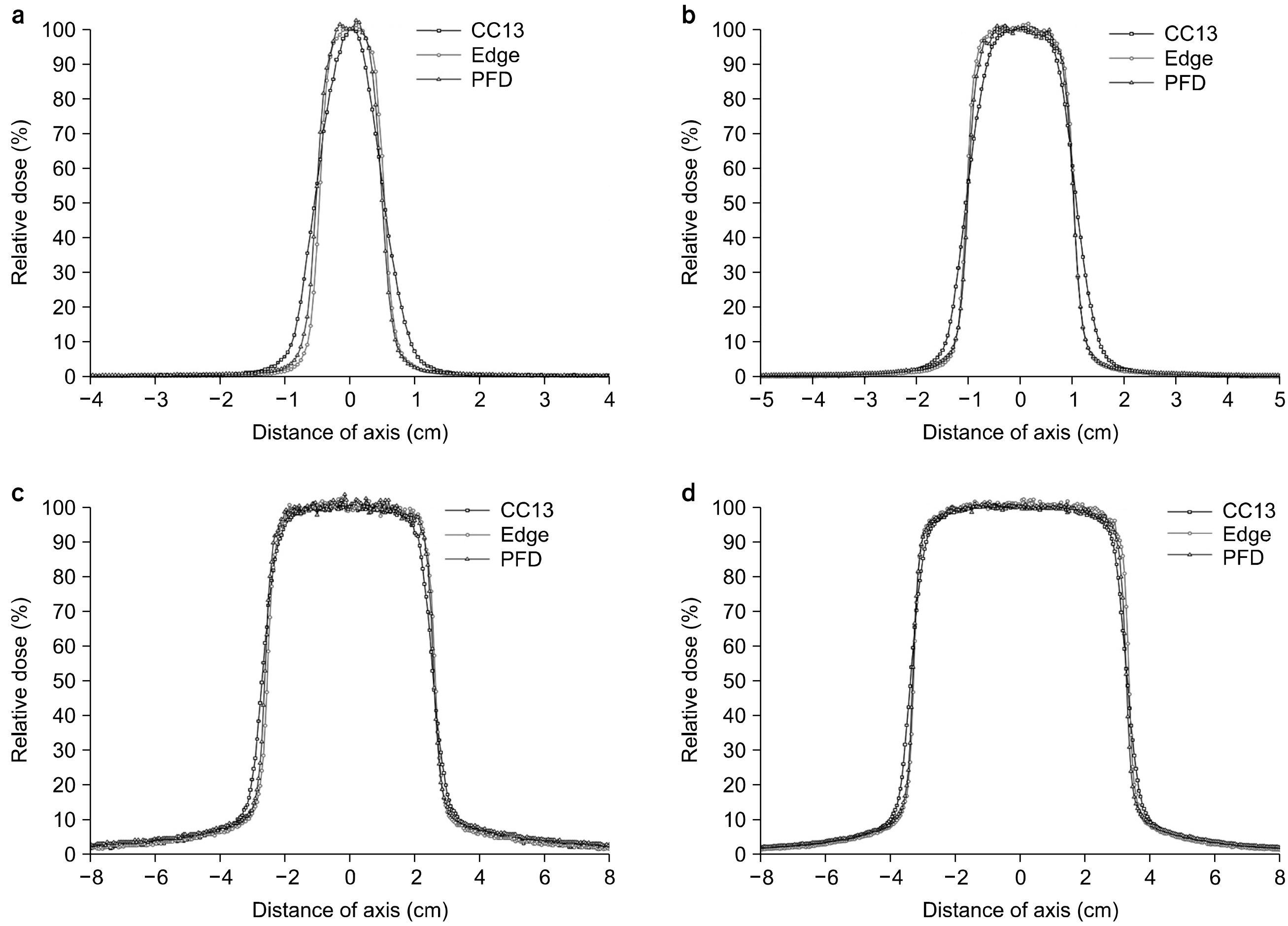


Fig. 4. Dose profiles for 1×1 to 6×6 cm^2 field sizes with a 6 MV photon beam at a 10-cm water depth with three dosimeters. Penumbras of the dose profiles showed considerable dependence on the chamber design and volume. Field sizes: (a) 1×1, (b) 2×2, (c) 4×4, and (d) 6×6 cm^2.

penumbra width tended to increase with field size. As shown in Table 2, the FWHM of the edge detector was close to the real field, while the ionization chamber and PFD showed wider FWHMs in all cases. On average, when the real field size was normalized to 1, the discrepancy of the three detectors was within 8～10% for all field sizes. The FWHM measured with the ion chamber had the largest difference of 15% for the smallest field size (1×1 cm^2). The minimum difference between the real field size and FWHM as measured with the edge detector was 2% for the 1×1 cm^2 field. This contrast between detector systems can be attributed to the broader collecting volume of the ion chamber and the high resolution and small sensitive volume of the edge detector.

5. Percentage depth dose (PDD)

Fig. 5 shows a comparison of the percentage depth dose for different field sizes and detectors for a 6 MV photon beam. We found that the PDD measured with diode detectors had some signal fluctuation at the buildup region for the smallest field size when compared to the standard ionization chamber. As shown in Fig. 5(b) and (c), when compared to the ionization chamber, the depth dose measured with the PFD was overestimated, while the edge detector underestimated the depth dose.

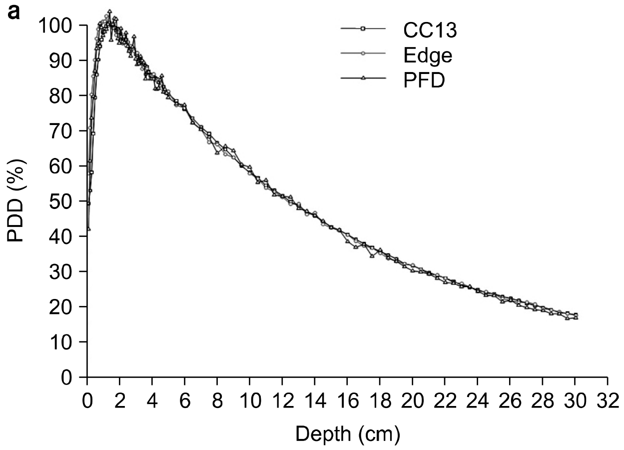
DISCUSSION

In this study, we evaluated the suitability and performance

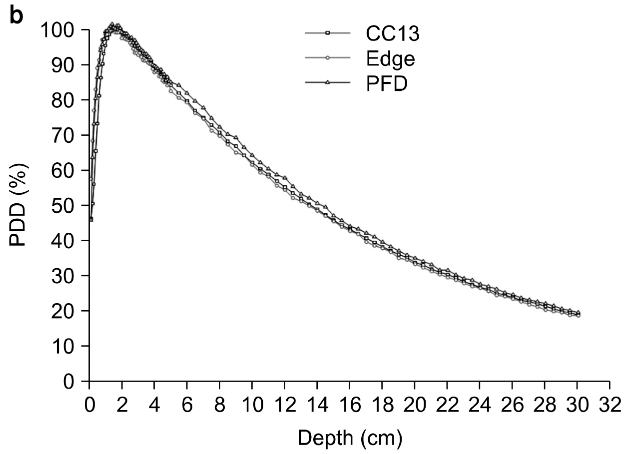
Table 2. Comparison of penumbra widths (10~90%, 20~80%) and FWHM (50%) of the beam profile at 10 cm depth evaluated by three dosimeters.

INPLANE	20~80% (mm)			10~90% (mm)			FWHM (mm)		
Field size	CC13	PFD	Edge	CC13	PFD	Edge	CC13	PFD	Edge
1×1 cm	4.55	2.88	2.47	6.73	4.80	4.03	10.59	10.26	9.80
2×2 cm	5.19	3.25	2.50	7.86	5.58	4.69	21.28	21.20	21.01
4×4 cm	5.66	3.57	2.85	9.61	6.97	5.99	43.84	43.52	43.13
6×6 cm	5.87	4.09	3.14	11.22	9.70	8.13	66.10	66.28	65.52
8×8 cm	6.29	4.15	3.30	13.26	13.44	10.27	88.01	88.25	87.50
10×10 cm	7.01	4.64	3.48	18.43	17.73	12.63	111.37	110.25	109.58
CROSSPLANE	20~80% (mm)			10~90% (mm)			FWHM (mm)		
Field size	CC13	PFD	Edge	CC13	PFD	Edge	CC13	PFD	Edge
1×1 cm	4.77	2.59	2.22	7.04	4.17	3.67	11.52	10.54	10.41
2×2 cm	5.43	2.93	2.44	8.29	5.20	4.55	22.50	21.97	21.50
4×4 cm	5.79	3.07	2.83	9.69	6.35	5.97	44.65	44.06	43.98
6×6 cm	6.20	3.46	2.99	11.39	8.69	7.54	66.58	66.05	65.91
8×8 cm	6.67	3.68	3.52	13.38	11.64	10.15	88.53	88.00	87.95
10×10 cm	6.96	4.32	3.43	16.40	15.21	12.77	111.33	110.63	110.23

a



b



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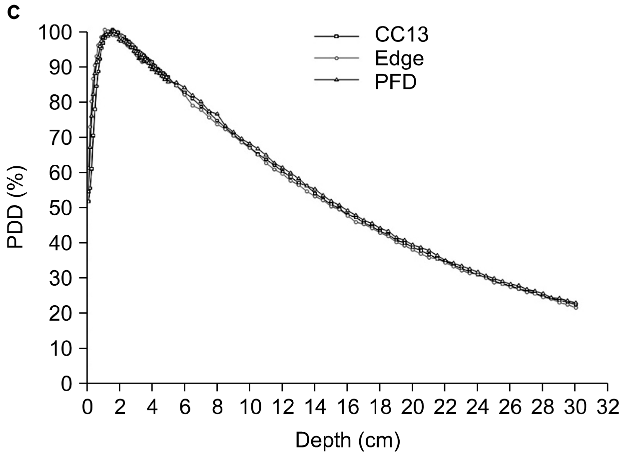

Fig. 5. Comparison of percentage depth dose curves for different field sizes and dosimeters for a 6 MV photon beam. Field sizes: (a) 1×1, (b) 5×5, and (c) 10×10 cm^2.

of the edge detector for small photon beams. We also confirmed several dosimetric characteristics of the three detectors for various specific field sizes and depths. Our findings point to promising potential applications for the newest beam delivery techniques with very small beamlets, such as IMRT, IMRS, SRS, volumetric arc therapy (VMAT), and intensity modulated arc therapy (IMAT). As mentioned earlier, it is reasonable to assume that the results were strongly dependent on the active volume of the individual detectors for all measurements excluding the linearity test. Fig. 3 shows that the ionization chamber is unsuitable for measuring the output factor for small field sizes due to the finite size of the detector volume.[8] As shown by Fig. 4 and Table 2, we found great discrepancies in the penumbra regions of the beam profiles and the FWHMs. As our work progressed, it became apparent that the edge detector provided a better performance than the other detector for small field sizes. Inaccurate measurements were generated by the effect of volume averaging for a small field.[9] Recently, small radiation beams are being used for more accurate therapy, so exact dosimetry is required. Therefore, we suggest that the edge detector is suitable for use in commissioning and quality assurance (QA) of narrow photon beams.

During our small field dosimetry measurements, we had some difficulties. The gain between the field and reference detectors was not well adjusted. Therefore, some noise in the signal was generated due to the high sensitivity of the diode-type detectors. Because the effective measurement point of the two diode detectors were located 0.5±0.15 mm below the surface of the detector, the setup was not easy. The setup error may affect small beam dosimetry. Hence, we should minimize the uncertainty related to the setup.

There are a number of problems that remain to be investigated. We did not evaluate the stereotactic diode detector and diamond detectors, which are commonly used for small field dosimetry. Although some of the advantages and disadvantages are known for semiconductor detectors, which have a very small sensitive volume and very high resolution,[10-12] further studies should be performed to evaluate stereotactic and diamond detectors as compared to the edge detector for small beam dosimetry.

CONCLUSION

The edge detector showed a greater suitability for small beam dosimetry than the other detectors tested. We compared the detectors and found that as they have relatively large volumes, significant discrepancies could occur during the small beam measurements. In particular, the sensitive volume of the detector had a substantial influence on penumbra regions with a steep dose gradient. Thus, the edge detector was shown to be suitable for accurate commissioning and quality assurance (QA) of small beam dosimetry. In the future, more studies are necessary to investigate the detector-volume effects on stereotactic radiosurgery dose planning, which is based on beam commissioning data from dedicated small beam detectors such as the edge detector.

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소조사면 선량 계측을 위한 엣지검출기의 특성 분석

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이 연구의 목적은 소조사면 선량계측을 위하여 엣지검출기의 성능을 평가하기 위함이다. 다양한 소조사면과 깊이에서 엣지검출기(Model 1118 Edge)를 이용하여 6 MV 광자선의 선량 직선성, 선량률 의존도, 출력 계수, 선량 측면도 및 심부 선량 백분율을 따라 측정하였으며, 이를 표준용적의 이온전리함(CC13)과 광자선 다이오드 검출기(PFD)와 비교하였다. 선량 직선성을 일차 선형 맞춤 함수와 비교하였을 때, 세 검출기 모두 1% 미만의 차이를 나타냈으며, 엣지검출기는 −0.08∼0.08%의 가장 낮은 차이를 보였다. 선량율의 변화(100∼600 MU/min)에 따라 PFD와 엣지검출기의 정규화된 반응비는 1% 미만의 일정한 값을 보였으나, CC13은 100 MU/min에서 약 −5%의 변화를 나타냈다. 조사면의 크기(4×4 cm^2∼10×10 cm^2)에 따른 출력계수는 세 검출기 모두 거의 같은 값을 보였으나, 4×4 cm^2 이하의 소조사면에서는 엣지검출기와 PFD의 출력 계수가 CC13과 최대 21%의 차이보였다. 각 조사면에서 20∼80%의 반음영 폭을 측정하였을 때, 평균적으로 CC13은 엣지검출기보다 2배, PFD는 약 30% 정도 더 넓게 나타났다. 또한 10∼90%의 반음영의 경우, CC13과 PFD가 각각 55%와 19% 정도 더 넓은 폭을 나타냈다. 엣지검출기는 선량 측면도의 반치폭이 조사면의 크기와 거의 일치하였으나, 다른 두 검출기는 조사면의 크기보다 약 8∼10% 더 크게 나타났으며, 심부선량백분율은 각 조사면에서 세 검출기 모두 거의 일치하였다. 엣지검출기의 성능평가를 위한 선량특성을 분석한 결과, 4×4 cm^2 이하의 소조사면에서 가장 적합한 특성을 나타냈으며, CC13과 PFD와 같은 검출기는 조사면이 작을수록 상당한 오차를 나타낼 수 있음을 알 수 있었다.

중심단어: 엣지검출기, 소조사면, 반음영