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Original Article

Assessment of an Unshielded Electron Field Diode Dosimeter for Beam Scanning in Small- to Medium-Sized 6 MV Photon Fields

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Abstract

Introduction
Radiotherapy planning systems require many percentage depth dose (PDD) and profile measurements and there are various dosimeters that can be used to obtain these scans. As dose perturbation is particularly troublesome in smaller photon fields, using a low-perturbation, unshielded electron field diode (EFD) in these fields is of interest. The aim of this work was to investigate the suitability of an unshielded diode for beam scanning in 3×3 cm^2, 5×5 cm^2, and 10×10 cm^2, 6 MV fields.
Materials and Methods
An EFD was used for all the scans. For comparison, in profile measurements, a tungsten-shielded photon field diode (PFD) was also used. PDDs were measured using the PFD and an RK ionization chamber.
Results
Very good agreement (0.4%) was found between the PDDs measured with EFD and PFD for the two larger fields. However, the difference between them exceeded 1.0% slightly for the smallest field, which may be attributed to the effect of the larger PFD perturbation. The RK chamber PDDs around 10 cm depth were 1-2% lower than those measured with the diodes. There was good agreement (<1 mm) between EFD- and PFD-measured penumbra widths.
Conclusion
The EFD generally agrees well with the PFD and may even perform better in smaller fields.

Keywords: Electron Field Diode, Photon Field Diode, Radiotherapy Beam Scanning, RK Ionization Chamber, Small and Medium Fields

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1. Introduction

Treatment planning systems require percentage depth dose (PDD) and profile measurements for various field sizes as input for beam modeling and verification of its results [1]. Small- to medium-sized photon fields are widely used in many types of modern radiotherapy techniques [2-4]. There are a variety of radiation dosimeters that can be used to obtain these required beam scans. Choosing a suitable dosimeter appropriate for the required conditions such as beam energy and field size is an important task for radiotherapy physicists.

Semiconductor diode detectors can be used for beam data commissioning [5, 6]. Clinical *in-vivo* dosimetry using diodes is also well established [7, 8]. Diodes have a number of desirable characteristics for radiotherapy dosimetry. These characteristics include high sensitivity, small volume, good mechanical rigidity, and obviation of the need for applied external voltage. In particular, diodes offer the opportunity to perform beam scanning with fairly high spatial resolution due to their compact size [9-12]. However, diodes often show dependence on many factors including energy, dose rate, source-to-detector distance, direction of incidence, and temperature [8, 13-15].

Stemming from the higher atomic number of silicon and therefore increased influence of the photoelectric effect, diode sensitivity to low-energy photons is higher than air-filled ionization chambers, which leads to its higher energy dependence. As an attempt to overcome this problem, low-energy sensitivity of photon field diodes (PFDs) is reduced by employing a shield; for instance, a small amount of tungsten-doped epoxy added in the diode construction. The number of low-energy photons reaching the detector is reduced by the shield thereby improving its energy dependence. For example, it was shown that addition of a small amount of tungsten behind the silicon reduced PDD overestimation from 3% to 1% for a 20×20 cm^2 cobalt-60 field [16]. Therefore, semiconductor diodes are useful radiation detectors, particularly for small field dose measurements where there are fewer low-energy photons [6, 17, 18].

Given the differences between the interaction mechanisms of photons and electrons, such a shield in the diode detector is not required in an electron field diode (EFD), which is an unshielded silicon detector designed primarily for use in electron beams. Since scatter-to-primary ratio is relatively low in small photon fields, the shield used in PFDs may not be necessary and, in fact, may increase dose perturbation due to the presence of tungsten near the silicon detector. As dose perturbation is particularly troublesome in small fields (where electronic non-equilibrium conditions exist), using a low-perturbation, unshielded electron diode in small photon fields is of interest. Monte Carlo modeling has been used to demonstrate the benefits of employing a low-buildup diode utilizing carbon-epoxy instead of tungsten-epoxy in correctly measuring small-field output factors in megavoltage X-ray beams [19]. It has also been reported that an unshielded diode has been used experimentally for measurement of small-field megavoltage photon output factors [17].

The aim of this work was to investigate the suitability of a commercial unshielded EFD, in comparison with a shielded PFD and an ionization chamber, for beam-scanning purposes to obtain PDDs and profiles in small- to medium-sized 6 MV photon fields.

2. Materials and Methods

The measurements were performed in 6 MV X-ray beams of an Elekta Compact linear accelerator. The measurements included profiles and central-axis PDDs in small- to medium-sized fields (3×3 cm^2, 5×5 cm^2, and 10×10 cm^2). The profiles were taken at depths 1.5, 5, and 10 cm. An unshielded diode (EFD) (IBA, Sweden) was used for all of the scans. For comparison, in profile measurements, a tungsten-shielded diode (PFD) from the same manufacturer was also used. As for PDD comparisons, they were also measured using the same PFD as well as an RK ionization chamber from the same manufacturer.

Both shielded and unshielded diodes have a detection area of 2.5 mm diameter and a sensitive volume thickness of 60 µm. During measurements of PDD curves and beam profiles, a diode was placed with its long axis aligned with the beam's central axis to give the best spatial resolution.

The RK chamber is a cylindrical ionization chamber with a fairly small sensitive volume of 0.12 cm^3, outer diameter of 7 mm, inner diameter of 4 mm, and length of 10 mm. The chamber was positioned with its long axis perpendicular to the beam axis.

The measurements were performed in an RFA-300 computerized scanning water phantom (IBA, Sweden). The measurements were performed with 1 mm resolution (data point spacing) for all PDD curves and beam profiles. All measurements were made at a source-to-surface distance of 100 cm. A reference diode detector was placed in the field to correct for beam output variations during scanning. As the scans included a field size of 3×3 cm^2, in order to avoid the perturbation effect of the reference detector in this small field, the detector was placed inside the accelerator's head above the secondary collimators (out of the defined field).

3. Results

The PDDs obtained with the RK chamber as well as the shielded and unshielded diodes for the three field sizes are shown in Figure 1. The PDDs were normalized to 100% at the depth of maximum dose (d_{max}). For all of the considered field sizes, disagreements between PDDs were specified by local relative differences between PDDs averaged over the depth range of 9–11 cm. These differences are quantified in Table 1. A comparison of the PDDs at phantom surface, measured using these detectors, are quantified in Table 2.

Lateral dose profiles obtained with the shielded and unshielded diodes at the depth of 1.5 cm in water for the same three fields are shown in Figure 2.

Table 1. Comparison of the PDDs near the depth of 10 cm in water, measured using the three detectors (EFD, PFD, and RK chamber).

	PDD around depth 10 cm (%)			Local difference (%)	
Field size (cm^2)	EFD	PFD	RK	(EFD – PFD)/EFD	(EFD – RK)/EFD
10×10	66.1	66.5	65.0	-0.4	1.7
5×5	62.0	62.3	61.2	-0.4	1.3
3×3	59.3	59.9	58.7	-1.1	1.1

Table 2. Comparison of the PDDs at phantom surface, measured using the three detectors (EFD, PFD, and RK chamber).

	PDD at surface			Local difference (%)	
Field size (cm^2)	EFD	PFD	RK	(EFD – PFD)/EFD	(EFD – RK)/EFD
10×10	37.7	48.2	65.2	-27.8	-72.9
5×5	35.6	44.7	62.0	-25.6	-74.2
3×3	32.1	34.5	61.0	-7.4	-89.9

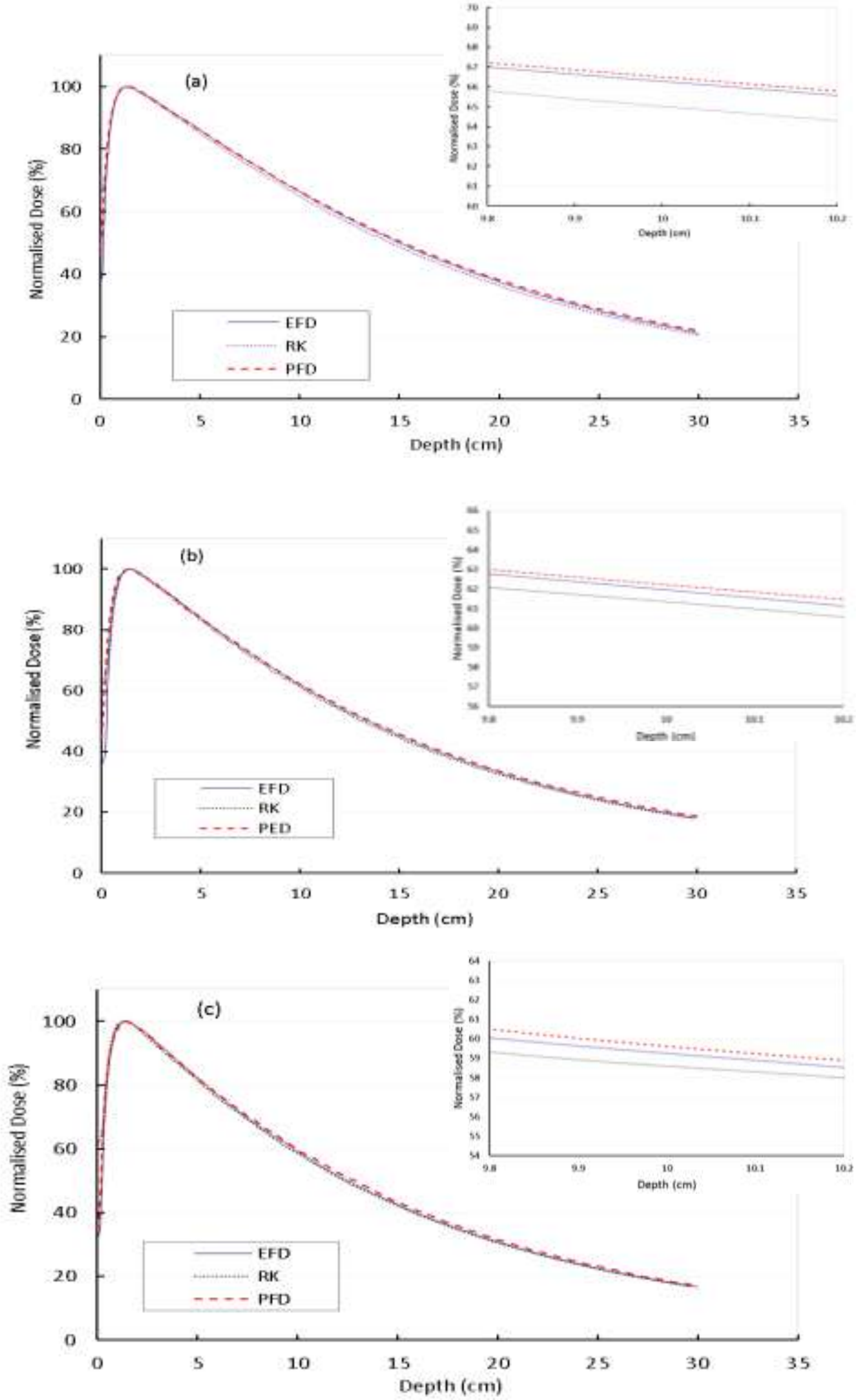

Figure 1. Percentage depth dose curves for different field sizes: a) 10×10 cm^2, b) 5×5 cm^2, and c) 3×3 cm^2 (EFD: electron field detector, PFD: photon field detector, RK: RK ionization chamber).

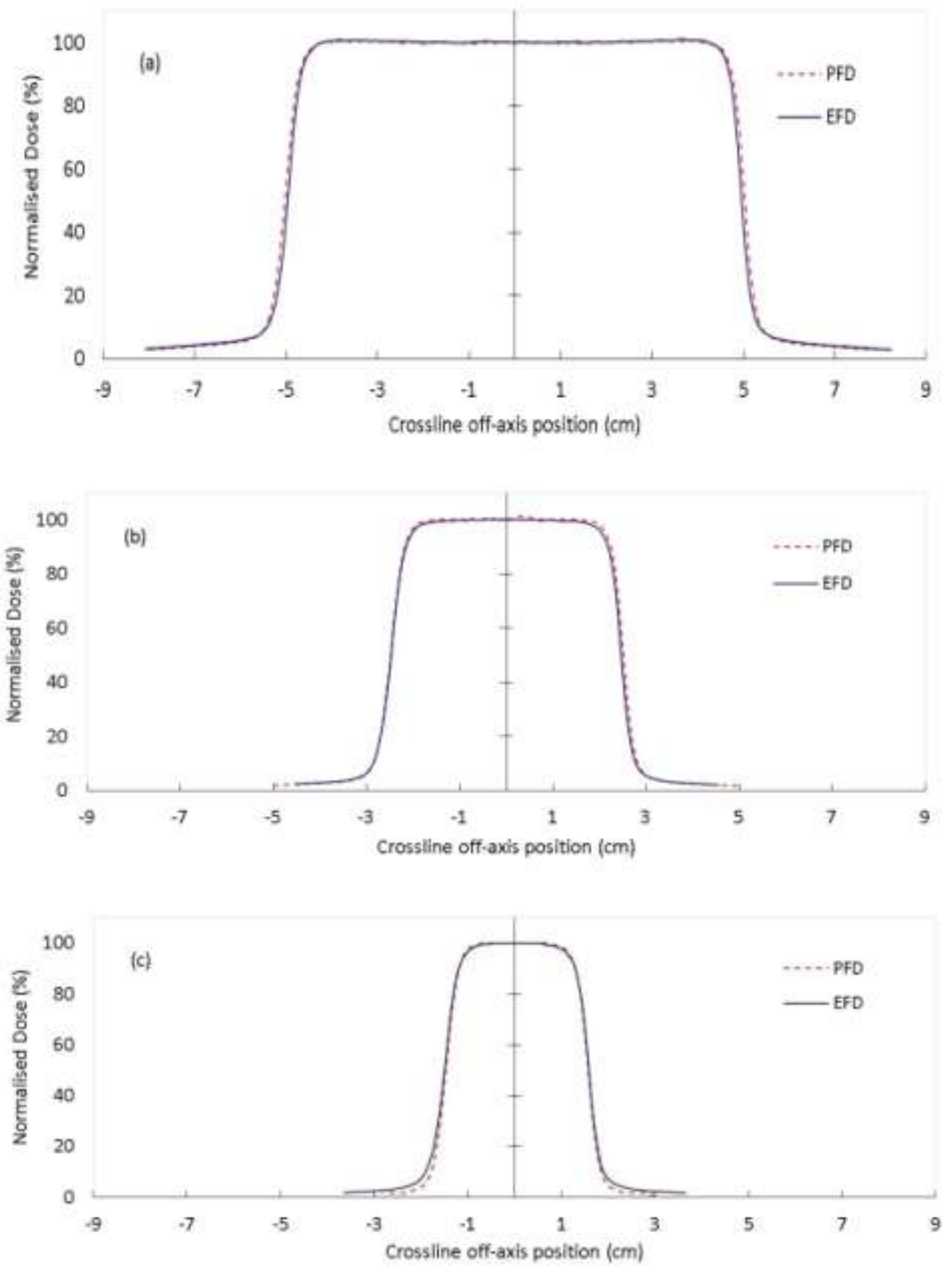

Figure 2. Dose profiles at depth of 1.5 cm for different field sizes: a) 10×10 cm^2, b) 5×5 cm^2, and c) 3×3 cm^2 (EFD: electron field detector, PFD: photon field detector).

4. Discussion

In our measurements, positioning uncertainties were less than ±1 mm. The scanning system had a positional accuracy of ±0.5 mm and a reproducibility of ±0.1 mm. Average differences between dosimeter readings in successive repeated scans were found to be 0.5%.

Very good agreement (0.4%) was found between the PDDs measured with EFD and PFD for the two larger fields. However, the difference between them exceeded 1.0% slightly for the smallest field, which may be attributed to the effect of the larger perturbation of the PFD.

The RK chamber PDDs around 10 cm depth were 1-2% lower than those measured with the diodes. EFD-to-RK difference was the greatest in the case of the 10×10 cm^2 field. Large differences between the diodes and RK chamber can also be seen in the buildup region close to the surface, where the RK chamber again underestimated dose. Although the differences after d_{max} were not large, these results confirm that the size of dosimeters normally used for measuring in larger fields, such as the RK chamber, makes them less suitable for use in a 3×3 cm^2 (or smaller) field due to the perturbation effect of the detector. Furthermore, the RK chamber, due to the volume averaging effect, can be seen to be generally unsuitable for PDD measurements in very shallow depths in water (less than 3 mm).

There is good agreement between EFD-measured penumbra widths and those measured with the PFD in these photon fields. The 50–90% penumbra distance obtained with EFD and PFD were different by less than 1 mm. The PFD, however, gave lower relative measurements than those of the EFD for the out-of-field region of the smallest field, which may be due to the presence of its shield, and requires further investigation. The trends seen at the three depths of measurement were similar. The averaging effect of a detector is most important in the beam penumbra region. Measurements with diode detectors, due to their small sensitive volume, are expected to give better spatial resolution and be the most accurate in the penumbra region.

Our results show similar trends to those obtained previously in a study regarding output factor measurements using similar detectors [20].

It is worth pointing out that, in preference to the RK chamber, a very small volume (<0.05 cc) ion chamber would be a better choice for comparisons with the diodes in small-field, near-surface, and lateral-dose measurements. Nonetheless, the RK chamber is a fairly widely available chamber in many centers and its evaluation is worthwhile.

Moreover, for the points at or near surface, knowing the dose contribution from electron contamination is of interest. Investigation of electron contamination is, however, outside the scope of this paper.

5. Conclusion

For the beam energy and range of field sizes studied here, the EFD generally agreed very well with the measurements using the PFD. Our results suggest that the EFD may even perform better in smaller fields due to its lower beam perturbation. The results suggest that an unshielded diode is an appropriate choice of detector for scanning in small- to medium-sized radiation fields instead of an RK chamber or PFD. The RK chamber is a less suitable detector when high spatial resolution is required, as it exhibits some degree of volume averaging.

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