Original Article

Investigating the Electronic Portal Imaging Device for Small Radiation Field Measurements

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Abstract

Purpose: With the advent of state-of-the-art treatment technologies, the use of small fields has increased, and dosimetry in small fields is highly challenging. In this study, the potential use of Varian electronic portal imaging device (EPID) for small field measurements was explored for 6 and 15 MV photon beams. **Materials and Methods:** The output factors and profiles were measured for a range of jaw-collimated square field sizes starting from 0.8 cm × 0.8 cm to 10 cm × 10 cm using EPID. For evaluation purpose, reference data were acquired using Exradin A16 microionization chamber (0.007 cc) for output factors and stereotactic field diode for profile measurements in a radiation field analyzer. **Results:** The output factors of EPID were in agreement with the reference data for field sizes down to 2 cm × 2 cm and for 2 cm × 2 cm; the difference in output factors was +2.06% for 6 MV and +1.56% for 15 MV. For the lowest field size studied (0.8 cm × 0.8 cm), the differences were maximum; +16% for 6 MV and +23% for 15 MV photon beam. EPID profiles of both energies were closely matching with reference profiles for field sizes down to 2 cm × 2 cm; however, penumbra and measured field size of EPID profiles were slightly lower compared to its counterpart. **Conclusions:** EPID is a viable option for profile and output factor measurements for field sizes down to 2 cm × 2 cm in the absence of appropriate small field dosimeters.

Keywords: Dosimetry, electronic portal imaging device, portal dosimetry, small field dosimetry

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Introduction

Recent advances in radiation oncology have resulted in state-of-the-art treatment technologies such as stereotactic radiosurgery, stereotactic radiotherapy, and stereotactic body radiotherapy which commonly use small radiation beam apertures. Unlike reference field (10 cm × 10 cm) dosimetry which has established dosimetry protocols,[1,2] small field dosimetry is challenging due to the breakdown of lateral electronic equilibrium, source occlusion, and choice of appropriate radiation detectors.[3,4] The definition of small fields was very subjective, and recently, Charles *et al*.[5] provided a meaningful definition of small fields using Monte Carlo simulations and concluded that <15 mm × 15 mm field should be considered as very small field for 6 MV photon beams at 1% uncertainty level. However, if the uncertainty level is relaxed to 2%, then <12 mm × 12 mm field should be considered as very small field. Furthermore, in realistic situations, this definition may vary depending on the selection of detector.

In case of small field dosimetry, choice of appropriate detector is very critical as it affects not only the dose distribution near to the edges but inside the target also.[6] Improper selection of radiation detector for the commissioning of small radiation fields resulted in wrong radiation therapy treatment to 145 patients in Toulouse, France[7] and to 152 patients in Springfield, Missouri.[8] This highlights the importance and continuing challenges of small radiation field measurements. A range of detectors broadly categorized into active (ionization chambers, solid state detectors, and plastic scintillator) and passive (TLD microcubes, gafchromic film, alanine pallets, radio photoluminescent dosimeter, and gel dosimeter) detectors have been investigated by numerous authors for small field measurements.[9-24]

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Stasi *et al*.[9] showed that all types of small volume ion chambers (0.13 cc, 0.015 cc, 0.009 cc, and 0.007 cc) can accurately measure output factors for 2 cm × 2 cm and bigger field sizes. However, for fields down to 1 cm × 1 cm, smallest size chamber, i.e. 0.007 cc can produce best results. In other studies, solid state detectors (shielded diode, unshielded diode, and diamond detector) have been shown as suitable detectors for small field dosimetry.[10-13] In addition, plastic scintillator detector, gel dosimeter, and radio photoluminescent dosimeter are found to be very good choice for output factor and profile measurements even for very small fields.[14-20]

Amorphous silicon electronic portal imaging device (aSi EPID) is a two-dimensional (2D) detector array attached to the linear accelerator (linac). Initially, it was developed as a verification tool for patient setup[25] but later, it emerged as a dosimetric verification tool also. Curtin-Savard and Podgorsak[26] and Pasma *et al*.[27] studied the dosimetric properties of EPID for pretreatment dosimetric verification of intensity-modulated radiation therapy (IMRT). Later, various authors also studied EPID response for pretreatment IMRT quality assurance (QA),[28-31] transit dosimetry,[32] and routine linac QA,[33-37] but EPID has not been investigated thoroughly for small field dosimetry. The main advantage of using EPID for small field dosimetry is that being a 2D detector, it eliminates the placement uncertainty, and secondly, it is commonly available with new machines.

Therefore, the purpose of this work is to investigate the EPID for output factor and profile measurements for 6 and 15 MV small field photon beams.

Materials and Methods

All the measurements were carried out on a medical linear accelerator (CL2100 CD, Varian Medical Systems, Palo Alto, CA, USA). The linac has dual photon beam energies (6 and 15 MV) and six electron energies with a maximum deliverable dose rate of 600 MU/min. The linac is equipped with amorphous silicon flat panel aSi EPID mounted on a robotic arm (Exact-arm, aSi 500 II portal imager) as shown in Figure 1a. The EPID system includes image detection unit IDU-20 with image acquisition system IAS3. The active area of the EPID system is 40 cm × 30 cm at the isocenter with a pixel matrix of 512 × 384 providing a resolution of 0.781 mm. The 2D detector is encompassed inside a plastic cover and has four major 2D layers inside it as shown in Figure 1b. First one is a copper plate of 1 mm thickness which provides an intrinsic buildup of 8 mm water equivalent thickness and also absorbs scattered radiation. Second is a 0.34 mm thick terbium-doped gadolinium oxysulfide (Gd_2O_2S: Tb) phosphor plate which converts incident radiation into visible light photons. Beneath, this is the array of Si detectors deposited on a 1 mm glass substrate. The aSi array is a photodiode array which senses the light photons. The light photons are converted into charge and transferred to image acquisition system for image formation.

Before performing any measurements, imager calibration as well as dosimetric calibration were performed as per the Varian recommended protocol. Imager calibration is performed to improve the image quality while dosimetric calibration is performed so that EPID can be used for dosimetry purpose. In imager calibration process, first, a dark field is acquired without any radiation to correct for background radiation. Then, flood field (FF) is acquired with uniform dose over the entire imager area to correct for any pixel sensitivity variation. During the imager calibration process, the beam characteristics are washed out; hence, during dosimetric calibration, a beam profile is fed to the system to retain the dosimetric characteristics. Further, a known dose is given to the EPID to calibrate the pixel values in terms of dose.

For the measurements, the active detective layer of EPID was positioned at 100 cm source to detector distance (SDD), and all the measurements were performed at d_{max} by placing appropriate water equivalent slab thickness in addition to intrinsic buildup of 8 mm (6 mm slab for 6 MV and 20 mm slab for 15 MV) over the EPID. 6 and 15 MV beams were delivered for jaw-collimated square field sizes ranging from 0.8 cm × 0.8 cm to 10 cm × 10 cm (0.8 cm × 0.8 cm, 1 cm × 1 cm, 1.5 cm × 1.5 cm, 2 cm × 2 cm, 3 cm × 3 cm, 4 cm × 4 cm, 5 cm × 5 cm, 8 cm × 8 cm, 10 cm × 10 cm) for profile and output factor measurements. Only in-plane/gun-target profiles are presented in the manuscript as we observed in-plane and cross-plane profiles were matching very well. Two hundred monitor units were delivered for each measurement. The EPID 2D images were saved in DICOM image format and analyzed using in-house program. This program was developed in Matlab (version 7.0). It could extract the profiles along central area as well as central dose over a region of interest (ROI). 2 × 2 pixels ROI was used to extract the central dose. To calculate output factors, the central dose values were normalized with respect to 10 cm × 10 cm field.

For reference data, microionization chamber Exradin A16 (Standard Imaging, Middleton, WI, USA) having sensitive volume of 0.007 cc (outer diameter 3.4 mm and outer

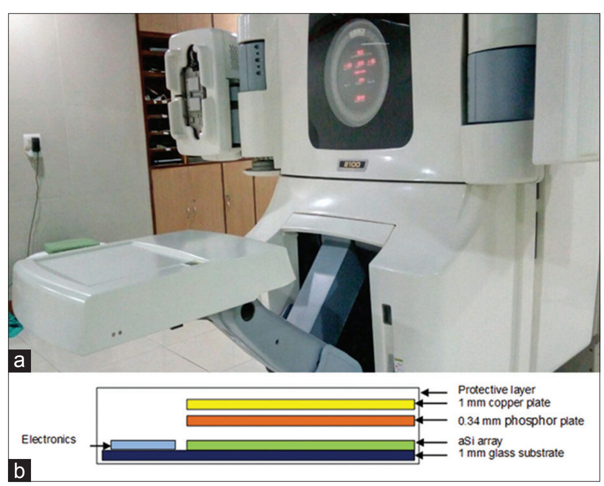

Figure 1: (a) Amorphous silicon flat panel imager from Varian Medical Systems, (b) internal structure of the imager

length 2.4 mm) was used for output factor measurements and stereotactic field diode (SFD; IBA Dosimetry, Schwarzenbruck, Germany), having 0.06 mm thickness and 0.6 mm diameter of active area, was used for profile measurements. This reference data were acquired using a radiation field analyzer (RFA, BP2, IBA Dosimetry, Schwarzenbruck, Germany) at a depth of d_{max}, and SDD was set to be 100 cm. Ionization chamber was placed perpendicular to the beam axis while SFD was placed parallel to the beam axis. While measuring small fields <2 cm × 2 cm, reference detector was not used, and measurement time was increased to two-fold to decrease the instantaneous fluctuations in the measurement. For output factors, Alfonso *et al*.[38] correction factors were not applied.

Results

EPID measured output factors for 6 and 15 MV photon beams were compared with corresponding output factors of microionization chamber Exradin A16, and the results are shown in Table 1. Similarly, Figures 2a and b show the comparison of EPID measured output factors with the reference output factors for 6 and 15 MV photon beams, respectively. It was observed that the output factors were closely matching with the reference data for field sizes down to 2 cm × 2 cm.

There was a difference of +2.06% for 6 MV and +1.56% for 15 MV in output factors for field size 2 cm × 2 cm, and after that (>2 cm × 2 cm), the deviation was further less. Maximum deviation was observed for 0.8 cm × 0.8 cm field size, and it was +16% for 6 MV and +23% for 15 MV. Output factors measured by EPID were consistently higher than corresponding reference values for small field sizes [Table 1]. When comparing the EPID measured output factors between 6 and 15 MV, the EPID performance was slightly better for 15 MV from 2 cm × 2 cm to 10 cm × 10 cm.

EPID measured profiles along with SFD profiles for field sizes 1 cm × 1 cm, 2 cm × 2 cm, 3 cm × 3 cm, 5 cm × 5 cm, and 10 cm × 10 cm are shown in Figure 3 for 6 MV; similarly, Figure 4 shows the profiles for 15 MV. It is evident that profiles are matching very well for field sizes down to 2 cm × 2 cm. However, penumbra and measured field size were slightly less for EPID compared to SFD for all field sizes as shown in Table 2. The average penumbra of EPID measured profiles was (0.20 ± 0.02) cm and that of SFD measured profiles was (0.34 ± 0.14) cm for 6 MV while the corresponding values for 15 MV were (0.21 ± 0.03) cm and (0.41 ± 0.16) cm.

Discussion

In this work, the performance of EPID was evaluated for output factor and profile measurements of radiation fields ranging from 0.8 cm × 0.8 cm to 10 cm × 10 cm for 6 and 15 MV photon beams. The advantage of using EPID for small field dosimetry is its good spatial resolution and being a 2D dosimeter, it eliminates the errors due to uncertainties in detector placement, unlike point detectors.

Table 1: Output factors for 6 and 15 MV photon beams using electronic portal imaging device and A16 microionization chamber

Field size (cm²)	6 MV			15 MV		
	EPID OF	A16 OF	EPID OF/A16 OF	EPID OF	A16 OF	EPID OF/A16 OF
0.8×0.8	0.737	0.636	1.160	0.701	0.569	1.231
1.0×1.0	0.760	0.686	1.108	0.728	0.640	1.138
1.5×1.5	0.780	0.752	1.037	0.776	0.740	1.049
2.0×2.0	0.798	0.782	1.021	0.814	0.802	1.016
3.0×3.0	0.832	0.824	1.010	0.866	0.867	0.999
4.0×4.0	0.862	0.858	1.004	0.901	0.902	0.998
5.0×5.0	0.890	0.890	1.000	0.926	0.927	0.999
8.0×8.0	0.959	0.963	0.995	0.977	0.977	1.000
10.0×10.0	1.00	1.00	1.000	1.00	1.00	1.000

OF: Output factor, EPID: Electronic portal imaging device

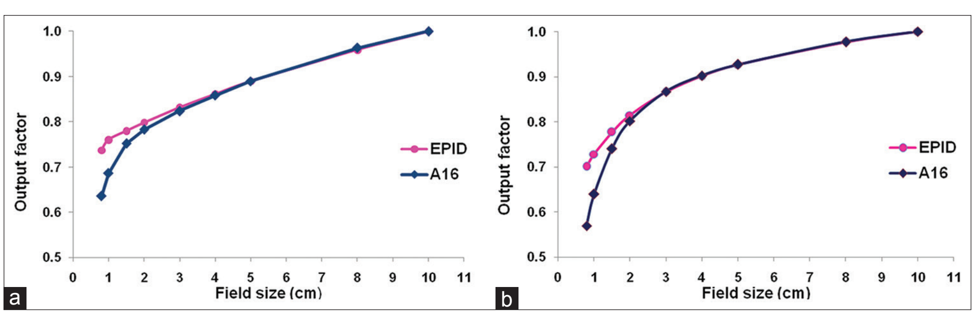

Figure 2: Electronic portal imaging device output factors compared with A16 microionization chamber are shown in (a) 6 MV and in (b)15 MV

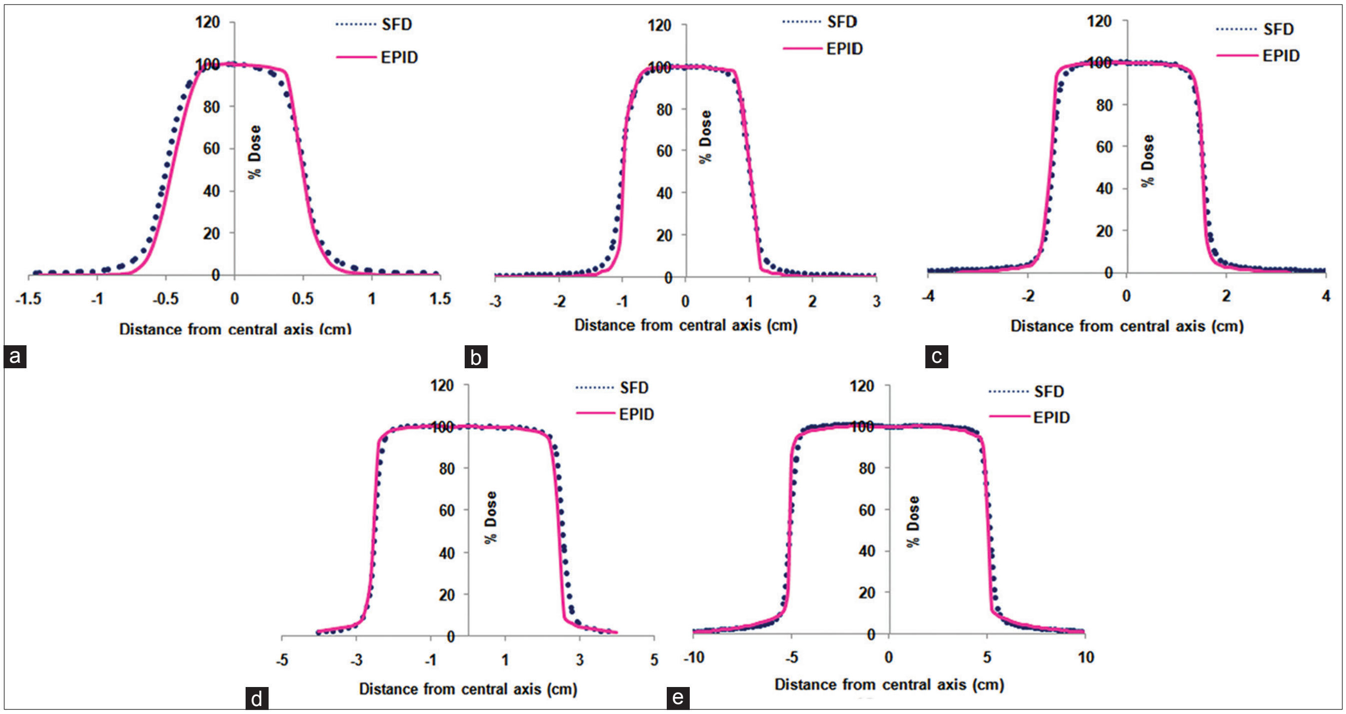

Figure 3: Dose profiles (gun-target only) of electronic portal imaging device compared with SFD for 6 MV photon beam for field sizes (a) 1 cm × 1 cm, (b) 2 cm × 2 cm, (c) 3 cm × 3 cm, (d) 5 cm × 5 cm, and (e) 10 cm × 10 cm

Table 2: Penumbra and measured field size for 6 and 15 MV photon beams using electronic portal imaging device and stereotactic field diode

Defined field size (cm²)	6 MV				15 MV			
	Penumbra (cm)		Measured field size (cm)		Penumbra (cm)		Measured field size (cm)	
	EPID	SFD	EPID	SFD	EPID	SFD	EPID	SFD
1×1	0.17	0.23	0.98	1.02	0.16	0.25	1.00	1.03
2×2	0.19	0.24	1.96	2.00	0.19	0.30	2.00	2.05
3×3	0.19	0.24	2.97	3.04	0.20	0.34	3.01	3.09
4×4	0.20	0.27	3.98	4.09	0.22	0.36	4.02	4.18
5×5	0.20	0.30	4.98	5.07	0.23	0.38	5.02	5.14
8×8	0.22	0.53	8.09	8.19	0.25	0.63	8.13	8.33
10×10	0.23	0.54	10.12	10.20	0.25	0.64	10.11	10.44

SFD: Stereotactic field diode, EPID: Electronic portal imaging device

EPID output factors were compared with Exradin A16 microionization chamber and, profiles were compared with SFD detector measurements. A16 microionization chamber measured output factors were closely matching with Stasi *et al*.,[9] and this ensures the accuracy of the reference data. For output factor and profile measurements, the behavior of EPID was observed to be good for field sizes down to 2 cm × 2 cm and below this appropriate correction factors are required. Penumbra and field size of EPID measured profiles were always smaller than that measured by SFD. In this study, aSi 500 portal imager was used which has a resolution of 0.783 mm while aSi 1000 portal imager has a higher resolution, i.e., 0.391 mm and for that reason, the latter may provide better results for even further smaller fields.

One important fact associated with EPID is backscatter radiation from its metallic support arm, which is used to attach it with linac. Several authors have reported different methods to eliminate this effect.[39-41] Rowshanfarzad *et al*.[41] reported that below 3 cm × 3 cm field, there is no arm backscatter, while for large fields, substantial amount of backscatter is there which increases the radiation dose measured by the EPID. However, arm backscatter was not included in this study, and a separate study probably using Monte Carlo simulations to account for this effect may be useful for more realistic results.

While acquiring a planar image with EPID, different pixels respond differently for the same dose. To correct this pixel sensitivity variation, FF correction is applied; however, in this process, beam characteristics (beam horn) are washed out and

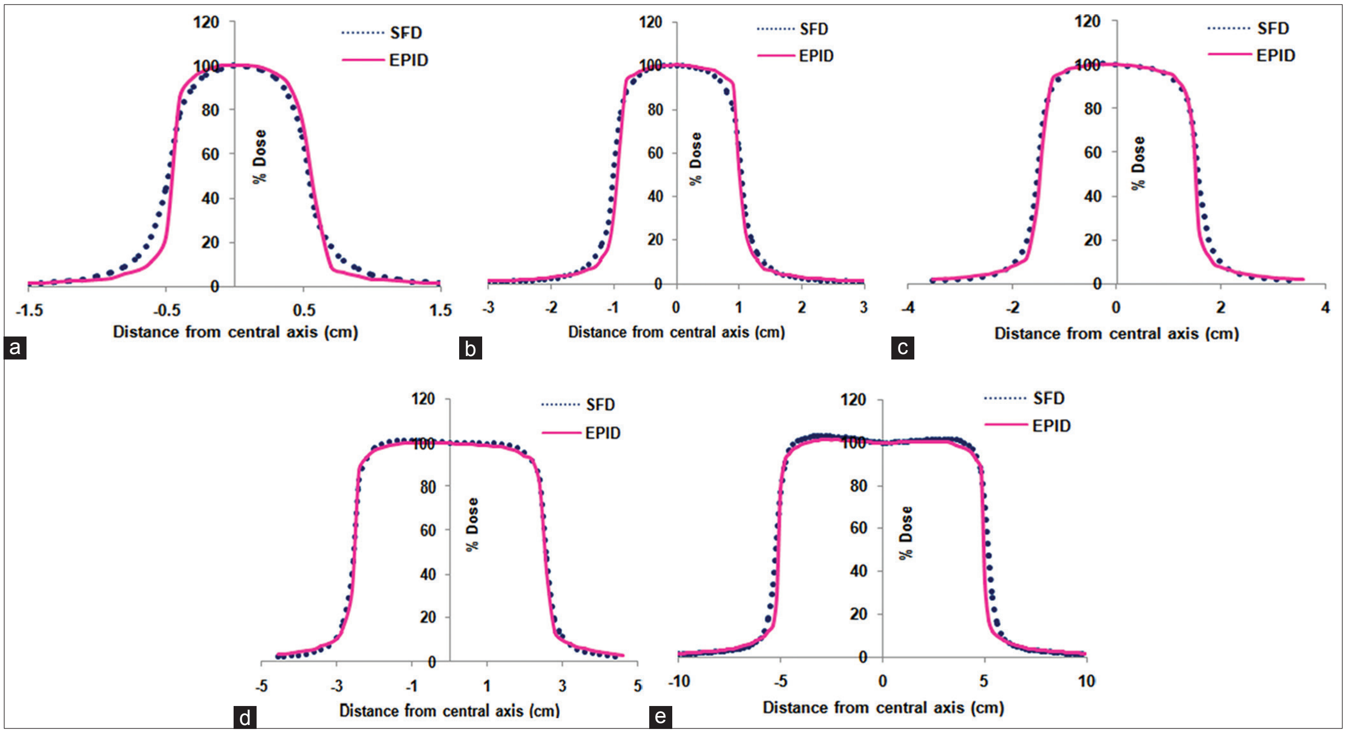

Figure 4: Dose profiles (gun-target only) of electronic portal imaging device compared with SFD for 15 MV photon beam for field sizes (a) 1 cm × 1 cm, (b) 2 cm × 2 cm, (c) 3 cm × 3 cm, (d) 5 cm × 5 cm, and (e) 10 cm × 10 cm

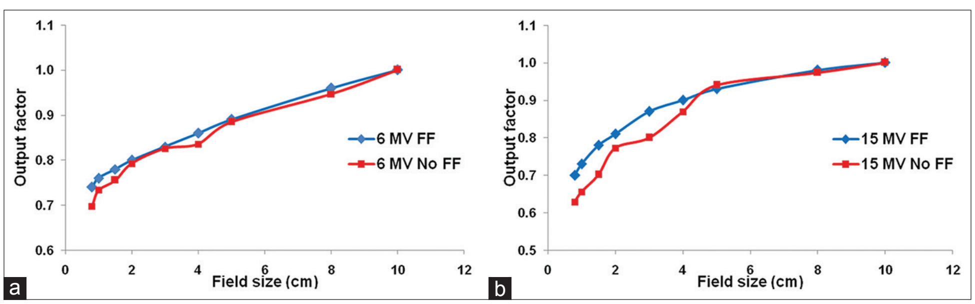

Figure 5: Output factors for (a) 6 MV and (b) 15 MV photon beams with and without FF correction

to overcome this problem, dosimetric calibration of EPID is performed. It is intuitive to know whether FF correction is really important for small fields also and for that purpose, we measured output factors without FF correction. The output factors with FF and without FF (no FF) correction for both energies are presented in Figure 5, and it is evident that FF correction is vital for small fields also.

From dosimetry point of view, commercial EPID have one flaw in their detection process, that is, they have phosphor layer and copper plate over the actual detector plate, and hence, these measurements are called indirect measurements. Vial *et al*.[42] and Sabet *et al*.[43] performed direct measurements with EPID and found that despite reduced sensitivity, direct measurements with EPID were more close to ion chamber measurements as compared to indirect measurements. However, direct measurements were beyond the scope of this study as removing the upper layers of EPID may damage the system.[42]

Conclusion

In this study, EPID was investigated for measuring output factors and profiles of small fields for 6 and 15 MV photon beams. The EPID data were slightly better for 15 MV as compared to 6 MV. Overall, it was observed that EPID is a viable option for output factor and profile measurements for small field sizes up to 2 cm × 2 cm in the absence of appropriate small field detectors.

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Nil.

Conflicts of interest

There are no conflicts of interest.

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