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.\textsuperscript{[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.\textsuperscript{[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.\textsuperscript{[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\textsuperscript{[25]} but later, it emerged as a dosimetric verification tool also. Curtin-Savard and Podgorsak\textsuperscript{[26]} and Pasma et al.\textsuperscript{[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),\textsuperscript{[28-31]} transit dosimetry,\textsuperscript{[32]} and routine linac QA,\textsuperscript{[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.

\section*{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\textsubscript{2}O\textsubscript{3}: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 detector layer of EPID was positioned at 100 cm source to detector distance (SDD), and all the measurements were performed at d\textsubscript{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

\begin{figure}[h]
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\includegraphics[width=\textwidth]{figure1.png}
\caption{(a) Amorphous silicon flat panel imager from Varian Medical Systems, (b) internal structure of the imager}
\end{figure}
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 \(d_{\text{max}}\), 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 \(\times\) 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.\cite{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 \(\times\) 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 \(\times\) 2 cm, and after that (>2 cm \(\times\) 2 cm), the deviation was further less.

Maximum deviation was observed for 0.8 cm \(\times\) 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 \(\times\) 2 cm to 10 cm \(\times\) 10 cm.

EPID measured profiles along with SFD profiles for field sizes 1 cm \(\times\) 1 cm, 2 cm \(\times\) 2 cm, 3 cm \(\times\) 3 cm, 5 cm \(\times\) 5 cm, and 10 cm \(\times\) 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 \(\times\) 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 \(\pm\) 0.02) cm and that of SFD measured profiles was (0.34 \(\pm\) 0.14) cm for 6 MV while the corresponding values for 15 MV were (0.21 \(\pm\) 0.03) cm and (0.41 \(\pm\) 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 \(\times\) 0.8 cm to 10 cm \(\times\) 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 (cm\(^2\)) | 6 MV | 15 MV |
|------------------------|------|-------|
|                        | EPID OF | A16 OF | EPID OF/A16 OF | EPID OF | A16 OF | EPID OF/A16 OF |
| 0.8 \(\times\) 0.8      | 0.737 | 0.636 | 1.160 | 0.701 | 0.569 | 1.231 |
| 1.0 \(\times\) 1.0      | 0.760 | 0.686 | 1.108 | 0.728 | 0.640 | 1.138 |
| 1.5 \(\times\) 1.5      | 0.780 | 0.752 | 1.037 | 0.776 | 0.740 | 1.049 |
| 2.0 \(\times\) 2.0      | 0.798 | 0.782 | 1.021 | 0.814 | 0.802 | 1.016 |
| 3.0 \(\times\) 3.0      | 0.832 | 0.824 | 1.010 | 0.866 | 0.867 | 0.999 |
| 4.0 \(\times\) 4.0      | 0.862 | 0.858 | 1.004 | 0.901 | 0.902 | 0.998 |
| 5.0 \(\times\) 5.0      | 0.890 | 0.890 | 1.000 | 0.926 | 0.927 | 0.999 |
| 8.0 \(\times\) 8.0      | 0.959 | 0.963 | 0.995 | 0.977 | 0.977 | 1.000 |
| 10.0 \(\times\) 10.0    | 1.000 | 1.000 | 1.000 | 1.000 | 1.000 | 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.
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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

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 |
|--------------------------|------|-------|
|                          | EPID | SFD   | EPID | SFD   |
| 1×1                      | 0.17 | 0.23  | 0.98 | 1.02  |
| 2×2                      | 0.19 | 0.24  | 1.96 | 2.00  |
| 3×3                      | 0.19 | 0.24  | 2.97 | 3.04  |
| 4×4                      | 0.20 | 0.27  | 3.98 | 4.09  |
| 5×5                      | 0.20 | 0.30  | 4.98 | 5.07  |
| 8×8                      | 0.22 | 0.53  | 8.09 | 8.19  |
| 10×10                    | 0.23 | 0.54  | 10.12| 10.20 |

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

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
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.\textsuperscript{[42]} and Sabet et al.\textsuperscript{[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.\textsuperscript{[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 $2 \text{ cm} \times 2 \text{ cm}$ in the absence of appropriate small field detectors.

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**Conflicts of interest**

There are no conflicts of interest.
REFERENCES

1. IAEA. Report No. 398, Absorbed Dose Determination in External Beam Radiotherapy: An International Code of Practice for Dosimetry on Standards of Absorbed Dose to Water. Technical Reports Series No. 398: International Atomic Energy Agency; 2000.

2. Almond PR, Biggs PJ, Coursey BM, Hanson WF, Huq MS, Nath R, et al. AAPM’s TG-51 protocol for clinical reference dosimetry of high-energy photon and electron beams. Med Phys 1999;26:1847-70.

3. Das U, Ding GX, Ahnesjö A. Small fields: Nonequilibrium radiation dosimetry. Med Phys 2000;25:306-15.

4. Sharma SD. Challenges of small photon field dosimetry are still challenging. J Med Phys 2014;39:131-2.

5. Charles PH, Cranmer-Sargison G, Thwaites DI, Crowe SB, Kaim T, Knight RT, et al. A practical and theoretical definition of very small field to detector corrections: A comprehensive analysis using a PinPoint air ion chamber, a diamond detector, a novel silicon-diode array (DOSI), and polymer gel dosimetry. Analysis and intercomparison. Med Phys 2008;35:4640-8.

6. Pantelis E, Antypas C, Petrokokkinos L, Karaiskos P, Papagiannis P, et al. Dosimetric characterization of CyberKnife radiosurgical photon beams using polymer gels. Med Phys 2008;35:2312-20.

7. Derreumaux S, Etard C, Huet C, Trompier F, Clairand I, Bottollier-Depois JF, et al. Lessons from recent accidents in radiation therapy in France. Radiat Prot Dosimetry 2008;131:130-5.

8. Benedict SH, Schlesinger DJ, Goetsch SJ, Kavanagh BD. Stereotactic Radiosurgery and Stereotactic Body Radiation Therapy. CRC Press; 2014.

9. Stasi M, Baitto B, Barboni G, Scielzo G. The behavior of several microionization chambers in small intensity modulated radiotherapy fields. Med Phys 2004;31:2792-5.

10. Sauer OA, Wilbert J. Measurement of output factors for small photon beams. Med Phys 2007;34:1983-8.

11. Laub WU, Wong T. The volume effect of detectors in the dosimetry of small fields used in IMRT. Med Phys 2003;30:341-7.

12. Scott AJ, Nahum AE, Fenwick JD. Using a Monte Carlo model to predict dosimetric properties of small radiotherapy photon fields. Med Phys 2008;35:4671-84.

13. Dieterich S, Sherouse GW. Experimental comparison of seven commercial dosimetry diodes for measurement of stereotactic radiosurgery cone factors. Med Phys 2011;38:4166-73.

14. Klein DM, Tailor RC, Archambault L, Wang L, Therriault-Proulx F, Beddar AS. Measuring output factors of small fields formed by collimator jaws and multileaf collimator using plastic scintillation detectors. Med Phys 2010;37:5541-9.

15. Wang LL, Beddar S. Study of the response of plastic scintillation detectors in small-field 6 MV photon beams by Monte Carlo simulations. Med Phys 2011;38:1596-9.

16. Pappas E, Seimenis I, Angelopoulos A, Georgolopoulos P, Kamariotakis-Paparigopoulou M, Maris T, et al. Narrow stereotactic beam profile measurements using N-vinylpyrrolidone based polymer gels and magnetic resonance imaging. Phys Med Biol 2001;46:783-97.

17. Pappas E, Petrokokkinos L, Angelopoulos A, Maris TG, Kozicki M, Dalezos I, et al. Relative output factor measurements of a 5 mm diameter radiosurgical photon beam using polymer gel dosimetry. Med Phys 2005;32:1513-20.

18. Pappas E, Maris TG, Zacharopoulou F, Papadakis A, Manolopoulos S, Green S, et al. Small SRS photon field profile dosimetry performed using a PinPoint air ion chamber, a diamond detector, a novel silicon-diode array (DOSI), and polymer gel dosimetry. Analysis and intercomparison. Med Phys 2008;35:4640-8.

19. Pantelis E, Antypas C, Petrokokkinos L, Kanniskos P, Papagiannis P, Kozicki M, et al. Dosimetric characterization of CyberKnife radiosurgical photon beams using polymer gels. Med Phys 2008;35:2312-20.

20. Aaki F, Ishidoya T, Ikegami T, Moribe N, Yamashita Y. Application of a radiophotoluminescent glass plate dosimeter for small field dosimetry. Med Phys 2005;32:1548-54.

21. Larraga-Gutierrez JM, Garcia-Hernandez D, Garcia-Garduno OA, Galvan de la Cruz OO, Ballesteros-Zebadua P, Espanza-Moreno KP. Evaluation of the Gafchromic® EBT2 film for the dosimetry of radiosurgical beams. Med Phys 2012;39:6111-7.

22. Garcia-Garduño OA, Lárraga-Gutiérrez JM, Rodríguez-Villafuerte M, Martínez-Dávalos A, Celis MA. Small photon beam measurements using radiochromic film and Monte Carlo simulations in a water phantom. Radiother Oncol 2010;96:250-3.

23. Gonzalez-Lopez A, Vera-Sanchez JA, Lago-Martin JD. Small fields measurements with radiochromic films. J Med Phys 2015;40:61-7.

24. Azangwe G, Grochowska P, Georg D, Izwiska J, Hopfartner J, Lechner W, et al. Detector to detector corrections: A comprehensive experimental study of detector specific correction factors for beam output measurements for small radiotherapy beams. Med Phys 2014;41:072103.

25. Bel A, van Herk M, Bartelink H, Lebesque JV. A verification procedure to improve patient set-up accuracy using portal images. Radiother Oncol 1993;29:253-60.

26. Curtin-Savaj A, Podgorsak EB. Verification of segmented beam delivery using a commercial electronic portal imaging device. Med Phys 1999;26:737-42.

27. Pasma KL, Dirks ML, Koonwijk M, Visser AG, Heijmen BJ. Dosimetric verification of intensity modulated beams produced with dynamic multileaf collimation using an electronic portal imaging device. Med Phys 1999;26:2373-8.

28. Greb PB, Popescu CC. Dosimetric properties of an amorphous silicon electronic portal imaging device for verification of dynamic intensity modulated radiation therapy. Med Phys 2003;30:1618-27.

29. Warkentin B, Steciw S, Rathee S, Fallone BG. Dosimetric IMRT verification with a flat-panel EPID. Med Phys 2003;30:3143-55.

30. Steciw S, Warkentin B, Rathee S, Fallone BG. Three-dimensional IMRT verification with a flat-panel EPID. Med Phys 2005;32:600-12.

31. Nelms BE, Rasmussen KH, Tome WA. Evaluation of a fast method of EPID-based dosimetry for intensity-modulated radiation therapy. J Appl Clin Med Phys 2010;11:3185.

32. Tan YI. 2D Transit Dosimetry Using Electronic Portal Imaging Device (Doctoral Dissertation, University of Glasgow); 2016.

33. Dawoud SM, Weston SJ, Bond I, Ward GC, Rixham PA, Mason J, et al. Medical linear accelerator photon beam energy through EPID imaging analysis of physically wedged fields. Med Phys 2014;41:021708.

34. Sun B, Guddo SM, Yaddanapudi S, Noel C, Li H, Cai B, et al. Daily QA of linear accelerators using only EPID and OBI. Med Phys 2015;42:5584-94.

35. Wang Y, Heaton R, Norrlinger B, Islam M. Quality assurance of electron beams using a Varian electronic portal imaging device. Phys Med Biol 2013;58:5461-75.

36. Rowshanfarzad P, Sabet M, O’Connor DJ, Greer PB. Verification of the linac isocenter for stereotactic radiosurgery using cine-EPID imaging and arc delivery. Med Phys 2011;38:3963-70.

37. Surendran S, Rao DP, Kumanathan J, Cyriac SL. Dynamic MLC-QA based on portal dosimetry. Int J Radiat Oncol Biol Phys 2010;76:1486-90.

38. Alfonso R, Andreo P, Capote R, Huq MS, Kilby W, Kjäll P. Dosimetric verification with a flat-panel EPID. Med Phys 2003;30:3143-55.

39. Moore JA, Siebers JV. Verification of the optimal backscatter for an aSi electronic portal imaging device. Med Phys Biol 2005;50:2341-50.

40. Ko L, Kim JO, Siebers JV. Investigation of the optimal backscatter for an aSi electronic portal imaging device. Med Phys Biol 2004;49:1723-38.

41. Rowshanfarzad P, McCurdy BM, Sabet M, Lee C, O’Connor DJ, Greer PB. Dosimetric verification of intensity modulated beams produced with dynamic multileaf collimation using an electronic portal imaging device. Med Phys 2005;32:600-12.

42. Vial P, Greer PB, Oliver L, Baldock C. Initial evaluation of a commercial EPID modified to a novel direct-detection configuration for radiotherapy dosimetry. Med Phys 2010;37:1459-67.

43. Sabet M, Menk FW, Greer PB. Evaluation of an a-Si EPID in direct detection configuration as a water-equivalent dosimeter for transit dosimetry. Med Phys 2010;37:1459-67.