Multi-parametric Improvements in the CCD Camera-based EPID for Portal Dosimetry

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Abstract

Dosimetric verification of radiation treatment has recently been extended by the introduction of electronic portal imaging devices (EPIDs). Detailed dose response specifications of EPID should be addressed prior to any dosimetric application. The present study evaluates improvements of dosimetric properties of the low elbow camera-based EPID Theraview (Cablon Medical, Leusden, The Netherlands) equipped with a cooled charge coupled device (CCD) for portal dosimetry. The dose response, warm-up behavior, stability over long- and short-term scales (throughout a day) were studied. The field size dependency of the EPID response was also investigated and compared with ion chamber measurements under the same conditions. The EPID response without saturation for doses up to 2 Gy was linear for both beam qualities (6 and 15 MV). There was no evident warm-up characteristic. The detector sensitivity showed excellent stability in short term [standard deviation (SD) 0.38%]. In long-term stability (over a period of approximately 3 months), a negligible linear decline of 0.01% per day was observed. It was concluded that the cooled CCD camera-based EPID could be used for portal dosimetry, after accurate corrections for the field size dependency and sensitivity loss.

Keywords: *Electronic portal imaging devices, elbow, portal dosimetry, radiometry*

Introduction

Radiation therapy efficacy is intensely affected by the real dose delivered to the target and sparing the surrounding normal tissue.[1] Experimental treatment dose verification is therefore essential, particularly in complicated treatment methods such as intensity modulated radiation therapy. Patient dose information provided with high resolution in electronic portal imaging device (EPID) images and other advantages such as no need to chemical processing, fast readout, and the capability for on-line analysis have extended the role of EPIDs in external radiation therapy.[2-7] Nowadays, treatment dosimetric verification is a routine application of the EPID in radiation therapy. EPID images can also be used for linac quality assurance, such as multi-leaf collimator (MLC) positioning,[8-10] beam flatness, and symmetry measurements.[3] Charge coupled device (CCD) camera-based EPIDs, in addition to their temporal stability and linear response to dose, are not influenced by ghosting effect unlike other commercial EPIDs such as amorphous silicon a-Si flat-panel detectors.[5] A prerequisite for dosimetric application of EPID is the determination of its dose response behavior. SRI-100 (Philips Medical Systems, Best, The Netherlands)[7,11] and iView (Elekta Oncology Systems, Crawley, UK)[12] are camera-based systems characterized by their dosimetric properties. The dose response of Theraview (low elbow design) equipped with Video-Optics Inc. camera (Los Gatos, CA, USA) was investigated by Glendenning. He reported pixel saturation and sublinear response for the applied dose.[6] In our study, the EPID has been equipped with a Peltier-cooled CCD camera, and therefore, different structural details such as the camera type and camera cooling have resulted in a different outcome for the EPID response to delivered dose. The purpose of this work is to quantify the EPID signal to delivered dose and special attention is given to the determination of the essential properties of EPID for portal dosimetry applications. Pixel saturation, temporal stability, linearity, warming up, and field size dependency EPID signal were investigated.

How to cite this article: Nazari V, Mahdavi SR, Mostaar A, Nedaei H, Mosleh Shirazi MA, Nikoofar A. *et al.* Multi-parametric improvements in the CCD camera-based EPID for portal dosimetry. J Med Sign Sence 2017;7:21-5.

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Materials and Methods

Equipment

Main components of the camera-based EPIDs consist of phosphor-screen, metal plate, and camera. Light photons originating from the phosphor screen were reflected onto photo detective layer of camera by means of mirror and lenses. The differences between several camera-based EPIDs are related to the mirror distance from the fluorescent screen, the kind of metal plate, and the camera type. The EPID in this study is described as the "low elbow" design (minimum separation, 6.6 cm). In the "high and mid elbow" designs, this distance is 22 and 10 cm, respectively. The detector was made of a 2-mm thick copper plate bonded to a 400 mg cm^{-2} terbium-doped gadolinium oxysulfide (Gd_2O_2S:Tb) phosphor screen (Carestream Inc., Lanex Fast, Rochester, NY, USA).[6] Metal plate acts as buildup material and provides electron equilibrium. The detector is covered by 2.2 mm thick, high impact polystyrene (density 1.04 g cm^{-3}). The maximum field of view of the system is 40.0 cm × 40.0 cm[6] with a fixed source to detector distance of 150 cm. The CCD camera (C3D) is Peltier-cooled to −20°C, with 1024 pixel × 1024 pixel. The camera cooling decreases dark current and improves the sensitivity and the lifetime of CCD camera.[4,5] We acquired all the images in the "dosimetry acquisition" mode using the Theraview classic software (version 5.1). The Theraview classic software records the mean pixel value of acquired frames over total exposure time for each image. Therefore the EPID signal for dosimetry measurements is calculated by multiplying the mean pixel value by the number of acquired frames. The raw data after the dark current subtraction, in dicom format, was used for analysis in a code written in Matlab (MathWorks Inc., Natick, MA, USA). The EPID was mounted on a Siemens Perimus linear accelerator (Siemens Medical Solutions, Erlangen, Germany). The measurements were performed with 6 and 15 MV energy photon beams energy in zero gantry with a collimator angle and fixed dose rate 200 MU/min. Reference dose was obtained by 2D array (PTW, Freiburg, Germany) in PMMA phantom slabs. Initially, 2D array for both beam qualities was cross-calibrated against a farmer-type ionization chamber (0.6 cc, PTW, Freiburg) and then 2D array with an adequate buildup layer was used for dose measurements. The 2D array consists of 729 ionization chambers (0.125 cm^3) and the center-to-center spacing of chambers is 10 mm. For dose measurements, this array was positioned in the same distance and geometric condition to the linac target as the fluorescent plate of the imager. All the images (except where stated otherwise) were analyzed in the region of interest of 1 cm^2 in the center of images.

Measurements

EPID dose response

The dose response was studied for monitor units of 5–200 with nominal dose rate of 200 MU/min for 10 cm × 10 cm open beam. In 6 MV photon beam, the thickness of the copper plate and its cover provide electronic equilibrium condition. Assessments of the buildup effect on EPID behavior for two beam qualities were performed with 1–3 cm PMMA slabs on top of the EPID surface as a buildup layer (density 1.19 g cm^{-3}). The measurement for each dose level was repeated three times to provide a mean pixel value. Pixel saturation was investigated for doses up to 2 Gy for 6 MV photons.

Temporal stability

The reproducibility or short-term stability was studied using EPID irradiation with identical consecutive exposures (10 cGy) with a fixed dose rate for 6 MV photon beam. This test was performed on 3 days in 1 week under the same conditions, and each irradiation was repeated seven times. According to the absolute dosimetry using ionization chamber, the variation of linac output during a single day was less than 1%. Long-term stability was also investigated over a period of 85 days and the EPID signal was normalized to linac output over this period. To prevent the warm-up effect, measurements were performed after several hours of EPID usage.

EPID warm-up behavior

In this study, immediately following camera power-on, EPID was irradiated with a series of exposures in approximately 1 min intervals. All the images were acquired under identical conditions, such as field size, dose (10 cGy), and energy (6 MV). This evaluation was repeated every 5 min for around 85 min. The values were normalized to the mean value of the repeated exposures in each series.

Field size dependency

To determine the field size dependency of the EPID response, the detector was irradiated by field sizes of 4 cm × 4 cm, 8 cm × 8 cm, 10 cm × 10 cm, 14 cm × 14 cm, and 16 cm × 16 cm in isocenter (approximately 6 cm × 6 cm to 24 cm × 24 cm in imager surface) without the absorber thickness in the beam. The field size response of the EPID was compared to 2D array ion-chambers measurement. Dose levels in this measurement were varied from 10 to 30 cGy in 5 cGy steps. The EPID response for different field sizes was also compared to the 2D array with a fixed dose (10 cGy).

Results

EPID dose response

The measurements were obtained for beam qualities of 6 and 15 MV, dose rate of 200 MU min^{-1}, and 10 × 10 open beam. Images were acquired after the detector was used for several hours and with minimum time intervals of 1 min. Therefore, the results were not influenced by the dose history and warming-up effect. Figures 1 and 2 show the portal images analyzed in Matlab written code for the central area of the detector. The mean gray level was calculated in a 1 cm^2 ROI (26 pixel × 26 pixel). The results of the regression analysis in Figures 1 and 2 show linear behavior in both of the energies for the EPID response to the radiation dose. The linearity to dose was independent of the additional buildup layers. Pixel saturation was not observed for doses up to 2 Gy for 6 MV photons.

Temporal stability

The temporal changes in the EPID response are summarized in Table 1. The detector reading was normalized to linac output for 6 MV photon. The standard deviation (SD) of the acquired signal during the reproducibility test was 0.38% in 3 cm^2 ROI in the center of image (averaged over 3 days in 1 week). For the identical exposure acquired over 85 days, the mean SD of the detector response was 0.37%. Some of these temporal changes can be related to the variation in the linac output over this period (SD 0.35%). Figure 3 shows the long-term EPID sensitivity variations.

Warming up

Investigation of the EPID warm-up behavior was performed for 6 MV photon beam. Following the EPID powering on, the detector sensitivity did not show any obvious changes over time [see Figure 4]. According to the results of the present study, warm-up effect for this detector is negligible (SD 0.03%).

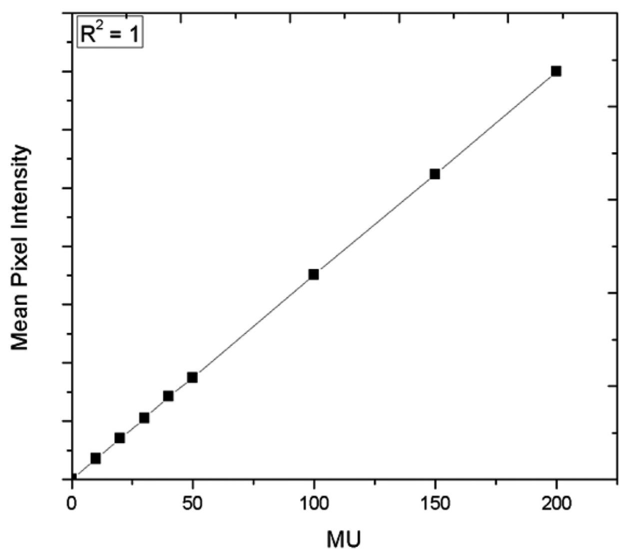

Figure 1: Dose response of electronic portal imaging device for 6 MV photons

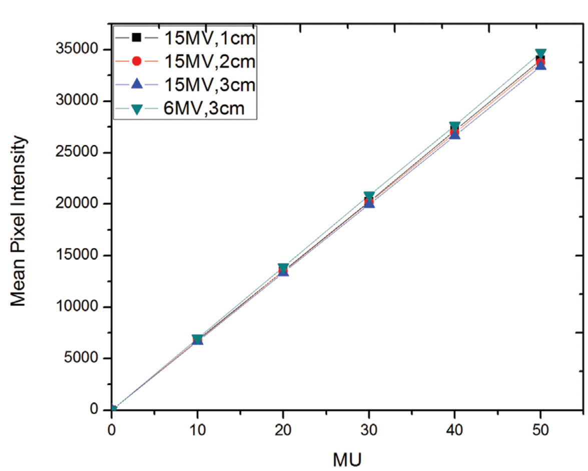

Figure 2: Buildup effects on EPID behavior to dose, for 6 and 15 MV photons

Field size dependency

This investigation was performed varying the square field size for 6 MV photon beam. Figure 5 shows the field size dependency of the EPID response. Multiple reflections of the optical photons increase pixel intensity and consequent dose.[5] Figure 6 compares the EPID response and the 2D array ionization chamber under identical conditions. The results for each detector have been normalized to their responses to the reference field size of 10 cm ×10 cm. The square equation describes the EPID and 2D array responses to field size changes. The difference in the dose responses between EPID and the 2D array was found to be 3.86% for the minimum field size and 9.4% for the maximum field size.

Discussion

Dose response and temporal stability

The CCD cooled camera has improved dosimetric behavior of Theraview EPIIDS. These systems owning to linear response to dose and higher stability in comparison with previous generation (equipped with video optic camera) are well suited for dosimetry. One of the main specifications of clinical detectors is temporal stability. The accuracy dose measurements and the timing of calibration for EPID dosimetry depend on temporal changes in the detector response.[3] The SD of the acquired signal during the reproducibility test was 0.38%. The SD of short-term stability of the SRI-100 camera-based EPID was reported to be 0.5%.[13] The results of our study indicated an approximate sensitivity loss of 0.01% day −1 [Figure 3]. One possible cause of sensitivity loss is radiation damage of photoconductive camera target, which has been reported for the CCD camera of SRI-100 to decrease in average response by 0.5% over a 2-month period.[6,11] Degradation of the camera target by exposure to ambient light, decreases in the phosphor efficiency, and radiation damage to the optical lens are other sources of this effect.[6]

Warming up

Changes in detector sensitivity after powering on can be attributed to the warming up effect.[6] This study did not show evident warm-up characteristic. Glendenning *et al.* reported a warm-up period at least 40 min for the

Table 1: Temporal changes EPID response in 6 MV photon beams in short-term and long-term scales*

	Reproducibility	Long-term stability	Mean linac output
Mean SD	0.38%	0.37%	0.35%

*Mean SD of all data collected with regard to linac output variations. For long-term stability, detector investigated approximately over 3 months.

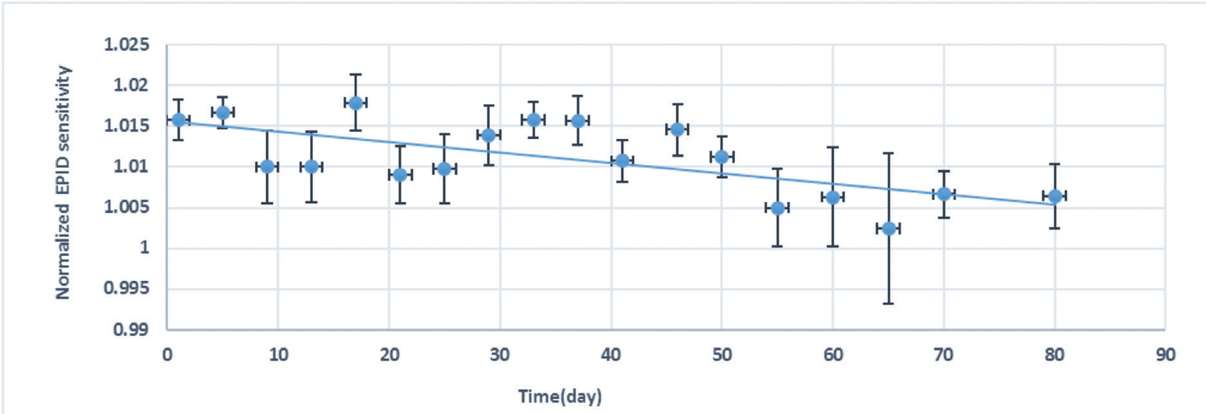

Figure 3: Sensitivity changes of EPID after 3 months, normalized to linac output

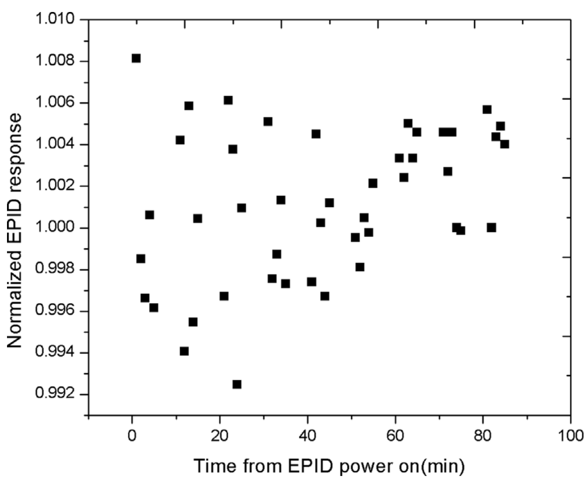

Figure 4: EPID warm-up behavior in 6 MV photons, detector response normalized to mean pixel intensity in each series

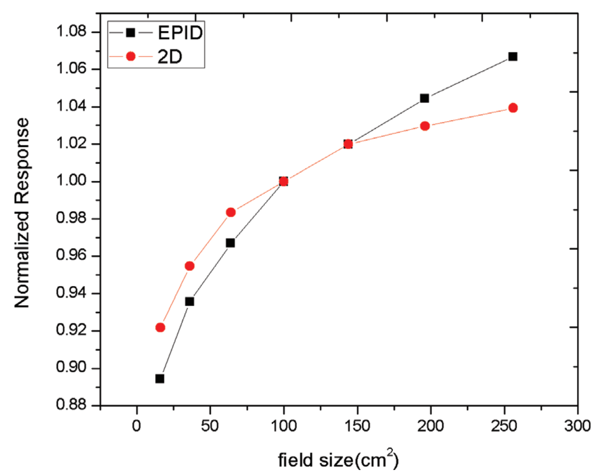

Figure 6: Field size dependency of EPID response in comparison to 2D array for the same geometry and fixed level, both of detector response normalized to 10 cm × 10 cm field size

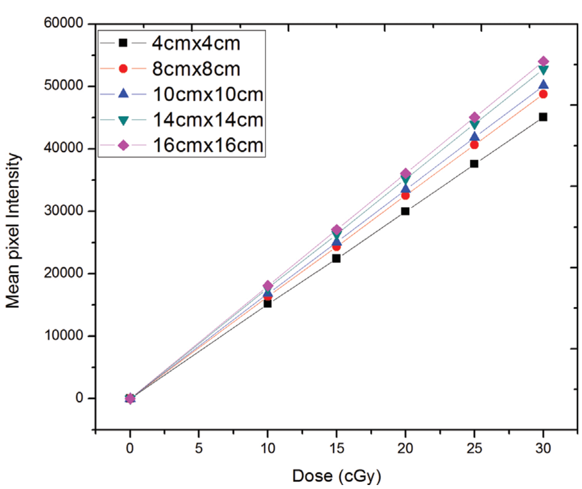

Figure 5: EPID response to dose in different field sizes for 6 MV photons

camera control unit. The temperature dependency of photoconductive camera target has been reported as underlying causes.[6] This effect has been corrected by the camera cooling.

Field size dependency

The magnitude of field size effect in camera-based EPID depends on the optical structure inside of system,[14] the field size, and also the field position on the EPID surface for a specific field size.[5] According to the Mike Partridge study, in large irradiation fields (40 cm × 40 cm), over 20% of the signal intensity in the image center can be related to optical scattering.[14] The difference in the dose responses between EPID and the 2D array in our study was found to be 3.86% and 9.4% for field sizes of 4 cm × 4 cm and 16 cm × 16 cm, respectively. This effect should be corrected for EPID-based portal dosimetry.

Conclusion

The purpose of this study is to evaluate the improvements in the dosimetric characteristics of the low elbow camera-based EPID (Theraview Classic) equipped with a CCD camera Peltier-cooled. The detector response to the dose was linear for both beam qualities, and the reproducibility, as a main property of dosimeter, was found to be acceptable for dosimetry applications. A negligible sensitivity reduction of 0.01% per day was observed over a period of approximately 3 months. On the basis of the results of the present study, after correcting the field size dependency and considering its sensitivity loss, the device has an acceptable level of accuracy for use in portal dosimetry.

Acknowledgements

The authors wish to thank Dr. Mike Partridge and Ruud Cools for many beneficial consultations on data analysis.

Financial support and sponsorship

Nil.

Conflicts of interest

There are no conflicts of interest.

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