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Development of the Use of Amorphous Silicon (ASi) Electronic Portal Imaging Devices as a Physics Tool for Routine Linear Accelerator QA

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Abstract: ***__Background__: Electronic portal imaging device(EPID)has different dosimetric characteristics than the ionization chamber, which is considered as the gold standard detector in radiation dosimetry. The main purpose of this study was to develop the applications of EPID. Dosimetric properties of amorphous silicon EPID (aS500) need to be investigated. __Materials and methods__: To verify linear response with dose, images of a 10×10 cm² open field were acquired. The EPID was positioned at a fixed detector distance of 150 cm, and varying doses were delivered with monitor unit settings of 1MU and 12MU. __Results__: The flatness should be less than 3%. The maximum flatness value was 2.7% for field size 10×10 cm² and 1.8% for field size 18×8 cm², which are within tolerance. EPID response was compared with the chamber dose. It was found that by increasing field size, both the EPID response and chamber dose were increased. The study showed that the EPID aSi500 has the potential to be used as a relative dosimeter, making it a very simple and efficient tool for daily QA. __Conclusion__: All EPID measurements were performed using the linear accelerator Varian DMX. The physical characteristics measured in this work suggest that the SLIC-EPID can be used be as a relative dosimeter.***

Keywords: Portal imaging, dosimetric properties, Electronic Portal Imaging Devices (EPID), radiation dosimetry

1. Introduction

The success of radiation therapy is critically dependent on the accuracy of patient alignment in treatment position day after day. Therefore, patient positioning is verified before treatment delivery. The electronic portal imaging device (EPID) enables the acquisition of an image of the exit radiation from the patient, immediately before or during the treatment delivery. Portal images are usually taken to verify patient setup and positioning prior to radiation therapy treatment. Historically these images were taken using films, but this method has gradually been phased out.

Early studies considered EPID to be generally as good as film in delivering the localization of quality images[1-4]. In fact, EPID is better than film imaging with respect to acquisition speed and the potential to use computer aided analysis. For these reasons, electronic portal imaging has become an important tool in radiation therapy. Recently, the role of EPIDs has been expanded beyond patient imaging to become a useful tool for radiotherapy dosimetry. A current developing area of research with portal imaging devices is their use in determining patient dose information[5-7].

Quality Assurance(QA) tests are an indirect measure of dosimetric properties of the linear accelerator (linac). The QA test could be conducted more efficiently than they are currently by using EPID. The purpose of this study is to first study the dosimetric characteristics of the available EPID and to investigate its potential ability to perform linac's QA.

2. Materials and Methods

All measurements were performed using the Varian DMX linac equipped with Amorphous Silicone (aSi)500 EPID. The linac is able to produce a standard 6 MV and 15 MV photon beam with a range of dose rates from 100 to 600 MU/min. Image acquisition was performed using available repetition modes (100MU/min), with one monitor unit corresponding to a calibrated dose delivery of 1 cGy (1 rad) under the reference conditions (SSD = 100cm, with a 10 × 10 cm² field at depth of d*max*).

Electronic portal imaging device(EPID)

The Varian amorphous silicon (aSi)EPID is used for patient set-up verification. Its active detector area is 30 × 30 cm^2 at SSD 100 cm.The sensitive area, at 150 cm source detector distance (SDD), is 22 × 18 cm^2. The EPID system consists of an image detection unit (IDU) featuring a detector and accessory electronics, an image acquisition system (IAS2) containing acquisition electronics for the IDU and interfacing hardware, and a dedicated workstation for off-line image review. An image of almost 200, 000 pixels is obtained by activating the pixels row after row.

The scintillator converts the incoming X-rays into visible photons. The light is sensed by a photodiode array attached to the amorphus sillicon panel. The photodiodes integrate the incoming light into charge captures and the detector electronics transfer the charges from pixels to read-out electronics.

Phantom studies

The acrylic slab phantom is a phantom that is used for calibration and depth dose measurements in radiation therapy. The phantom consists of 33 acrylic plates with dimensions of 30 cm × 30 cm. The phantom is designed for a range of 70 kV to 50 MV photon radiation and 1 MeV to 50 MeV electron radiation.

Routine calibration of SLIC-EPID

The system requires a set of calibration images for each combination of acquisition mode, energy, and dose rate parameters of the treatment machine used. An imager calibration set comprises of two images: a dark-field image and a flood-field image. Each set is stored in the IAS database. The dark-field image is taken without radiation passing through the cassette. Portal Vision uses the averaged result of all images for correction.

The standard-automatic calibration of the EPID using a dark image (non-irradiated image) and a flood field image (uniform radiation image) was performed by Portal Vision.

All measurements, including the ionization chamber, were repeated three times and the average and standard deviation (SD) were used.

For EPID dose calibration and measurements, the couch was moved out of the bath of the beam and a fixed source to EPID distance (SED) of 100 and150 cm were used.

Reproducibility and uniformity

In order to measure long term reproducibility of the EPID, 10 consecutive images were acquired for a field size of 10 × 10 cm² and SDD = 150 cm, and a dose rate of 100 MU/min. The experiment was then repeated for a period of two weeks to investigate long term reproducibility. The first image acquisition was performed following a standard EPID calibration. No calibration was performed for the subsequent acquisitions. The mean, maximum, minimum, and standard deviation of the pixel values in a 10 pixels × 10 pixels' region at the center of the field were recorded for 10 images. The relative percentage error was calculated as the ratio of maximum- minimum differences and mean pixel values in each selected region of interest (ROI) multipliedby100. In order to evaluate uniformity, the uniformity factor was measured for EPID acquired images using the following equation [1]:

$$\textbf{Uniformity factor} = [\frac{\textbf{Max}}{\textbf{Min}} - 1] \times 100 \quad (1)$$

Where Max and Min are the maximum and minimum pixel values in the ROI.

Dose dependence

The linearity of EPID response with dose was obtained. To verify linear response with dose, images of a 10×10 cm² open field were acquired. The EPID was positioned at a fixed detector distance of 150.0 cm, and varying doses were delivered with monitor unit settings of 1MU and 12MU. The pixel values at the center of the field were obtained. The linearity of the delivered dose with MU setting was compared with the ion-chamber measurement. To determine the relative dose with MU, the ion chamber was placed in a phantom at a 4 cm depth at each MU from 1MU to 12 MU at SDD 150 cm.

Dose rate dependence

The linearity of EPID response with the dose rate was obtained by changing the SDD and this dose rate was measured also using the ionization chamber. The linearity of the EPID to variations in dose rate was investigated by comparison to ion-chamber measurements. No extra buildup was utilized on the EPID. At each distance, three images of a 10×10 cm² field were acquired and the mean pixel values in a 10×10 pixel region at the center of each field were recorded. To determine the relative dose rate with distance, the farmer ion chamber was placed in a phantom at a 4 cm depth at each SDD.

Field size factor

The portal imager was positioned at a distance from the source at SDD = 100cm.The field size was changed from 4×4 cm² to 24×24 cm². The central axis reading of the EPID is compared to those measured by the ionization chamber.

The field size factor of the EPID was compared to the ion-chamber measurement. The detector was positioned at 100 cm from the source. Field sizes were varied from 4×4 cm² to 24 ×24 cm². Three images were acquired for each setting with no added buildup on the EPID. The images were taken and pixel values recorded as described earlier. To record the change in dose with field size, ion-chamber measurements were performed at a depth of 1.5 cm in a solid water phantom with 4 cm of backscatter, and 100 cm to the chamber. Both sets of measurements were normalized to the 10×10 cm² values.

Beam Flatness

The flatness was also calculated with the images obtained for 10 consecutive days. The EPID was placed at SDD=150cm and field size 10×10 cm². We analyzed the images obtained by EPID. The flatness thus calculated is compared to field size 18×18 cm² measurements at SDD=150cm. We calculated flatness using the two opposite equidistant points from the central axis.

Beam flatness F is assessed by finding the maximum(D_{max}) and minimum(D_{min}) dose point values on the beam profile within the central 80% of the beam width[8].

Beam flatness F is defined as:

$$F = 100\left(\frac{D_{max}-D_{min}}{D_{max}+D_{min}}\right) \quad (2)$$

The flatness should be less than 3%.

Coincidence of light field versus radiation field

The gantry angle used was set to 0º and EPID at SDD 100cm and field size 10×10 cm².EPID images are analyzed in the review workspace. Magnifying the image and using the distance tool helps to accurately measure the distance between the field edge at 50%. The discrepancy between the light field and radiation field can be determined by using the EPID.

3. Results

Reproducibility and uniformity

The average percentage for relative error was found to be 1.4 % and the maximum relative error was found to be 2.4%

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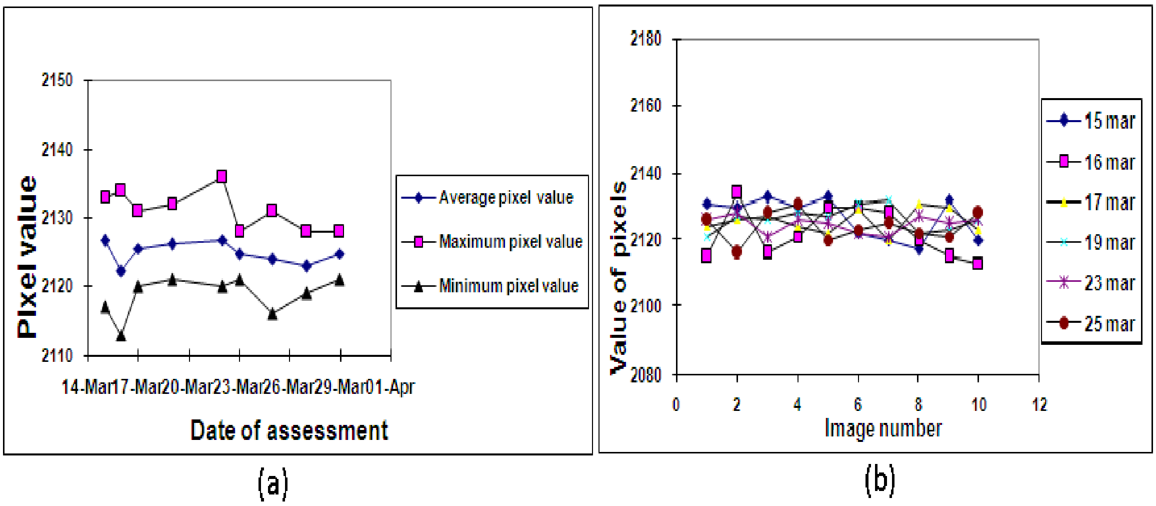

Figure 1: (a) The variation of pixel values of EPID images acquired in 3 series of 10 consecutive images. (b) The variation of average pixel values of 10 consecutive EPID images on the central axis as a function of time. All images were acquired in 100 MU/min using 6 MV photon energy, for 10× 10 cm² field size at the central axis at SDD = 150 cm.

In Figure(a),the pixel values were plotted against the date of assessment**.** The mean pixel values of a 10 × 10 matrix on the central axis of 10 daily images acquired consecutively were calculated for 7 series of images acquired with an interval of 2 days between acquisitions. The relative error was found to be 1.4% and average standard deviation was found to be 5.66.

Figure (b) shows that the range of variation can be found from the maximum and minimum pixel values for each measurement. The maximum and minimum acquired pixel values were found to be 2136 and 2113, respectively. The average pixel value was observed to be 2125. By using the equation (1) for long-term uniformity assessment, the results showed that the maximum uniformity factor was found to be 0.994 %.

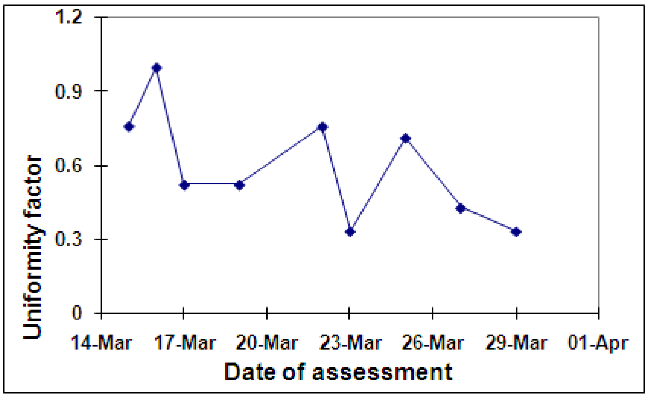

Figure 2: The long- term uniformity of EPID images acquired within two weeks. All images were acquired with 100 MU/min using a 6 MV photon beam, for 10 × 10 cm2 field size at the central axis at SED = 150 cm, 5-mm additional build-up layer, fast read-out, and full resolution mode

As shown in Figure 2, for long-term uniformity assessment, the mean pixel values of 10 daily images acquired consecutively were calculated for 7 series of acquired images. The minimum long-term uniformity obtained from mean pixel values was 0.33 % and maximum long-term uniformity observed was 0.76%.

Field size factor

The field size factor for both EPID and chamber normalized to 10× 10 cm^{2}was investigated.

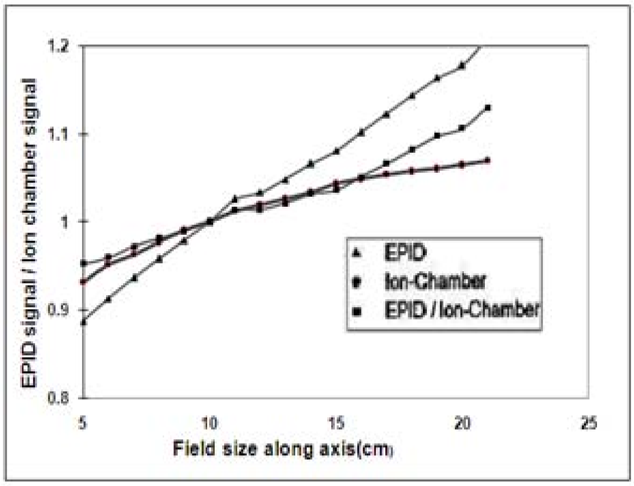

Figure 3: (a) The EPID signal and ion chamber signal are compared with the change in field size measured at depth 1.5 cm in a solid water phantom and backscatter 4cm. All data is normalized to 10×10 cm².

Figure (3) shows the variation of relative EPID dose and chamber with the increase of field size response**.**

Dose dependence

The linearity of EPID response with dose was investigated by increasing the number of MU with dose. The aS500 requires about 1 MU of dose to form an image; however, the total dose delivered by the linac was between 1–12 MU. The average pixel value (***P***)within a 10×10 ROI centered on the central beam axis with the portal imager positioned at the distance 150 cm from the source and for a radiation field size of 10×10 cm² was compared to the doses measured with the ion chamber at the same position as the EPID. This established the relationship between *P* to dose D for 6 MV, as shown in Figure (4).

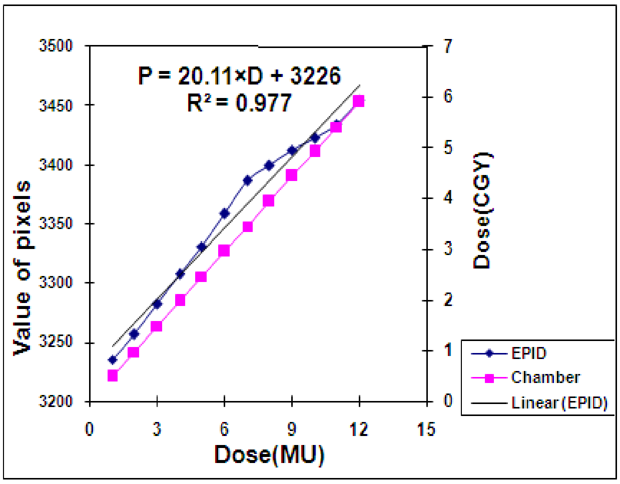

Figure 4: The relationship between the pixel value (P) and the absorbed dose (D) is shown for detector distance of 150 cm from the source and for 6 MV irradiation using field size 10×10 cm²

The radiation dose changed for both the EPID and the ion chamber. The relationship between ***P*** and dose (***D***) was found to be linear and in the form of ***P=a ×D +b***, where ***a*** and ***b***are constants. This relationship varied with radiation field size and energy but was not strongly dependent on the distance from the source. In the figure, the examined field sizes 10×10cm²and energy 6MV at SDD 150 cm yielded a relationship of the form:

$$P=22.11\times D+3226. \qquad (3)$$

Where p is the pixel value and D is the measured dose in cGy. This proves the linearity of dose.

Dose rate dependence

The linearity of EPID response with dose rate needs to be obtained by increasing the number of MU/min, as shown by Figure(5).

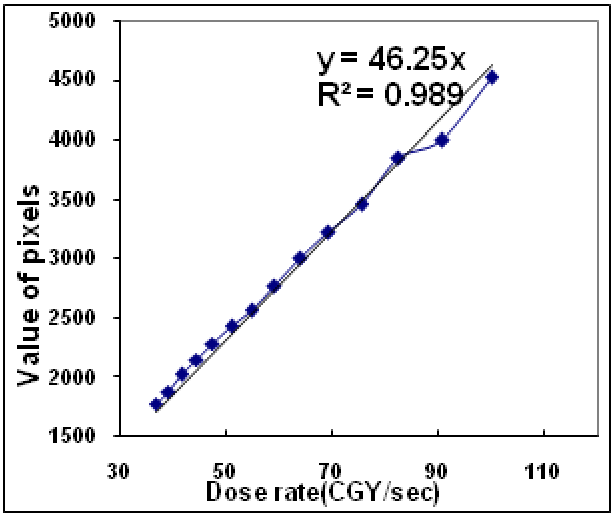

Figure 5: The relation between dose rate (cGy/sec)and EPID reading(p)

A linear function was fit to the data using an equation:

$$y = 46.25X \qquad (4)$$

The linear regression analysis produced a co-efficient of determination R^2 = 0.989. The linear fit also gave a proportionality constant of 46.25, showing that the detector is proportional over the entire measured range and does not deviate from the inverse square behavior. The maximum percentage for relative error was found to be 0.577 % of the relation between EPID response with the dose rate beinglinear.

Flatness

In this study, we analyzed the flatness of the photon beam using EPID. In Figure (6),the flatness values, which were calculated by equation (2), were plotted against the number of days**.** The mean pixel values of a 10 × 10 matrix and 18×18 cm² on the central axis of 10 daily images acquired consecutively were calculated for 7 series of images acquired with an interval of 2 days between acquisitions. From the result, we found that the maximum flatness value was 2.7 for field size 10×10 cm² and 1.8 for field size 18×8 cm², which is within tolerance.

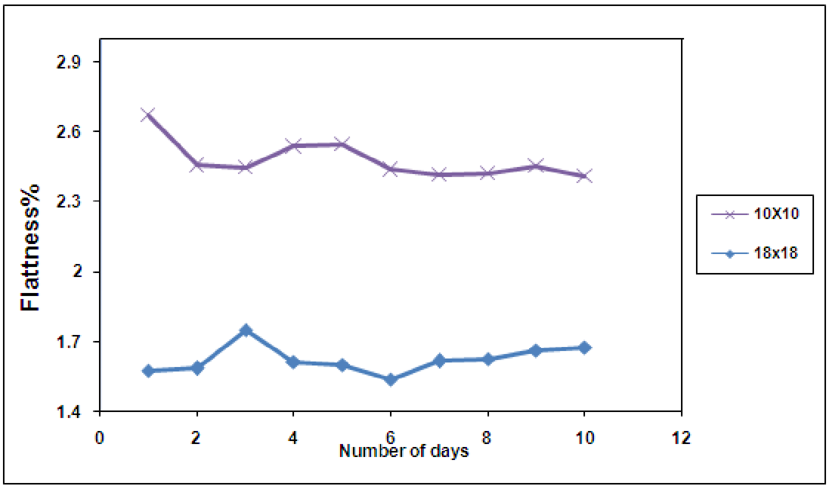

Figure 6: The relation between flatness and number of days for field sizes 10×10 cm² and 18×18 cm².

The standard deviation was found to be 0.82 for field size 10×10 cm².For field size 18×18 cm², the standard deviation was found to be0.6

Coincidence of light field versus radiation field

The EPID is a feasible tool for use in coincidence with the light field versus radiation field. After we took an image for field size 10×10 cm² at the edge of 50%by using the distance tool, we measured the distance.

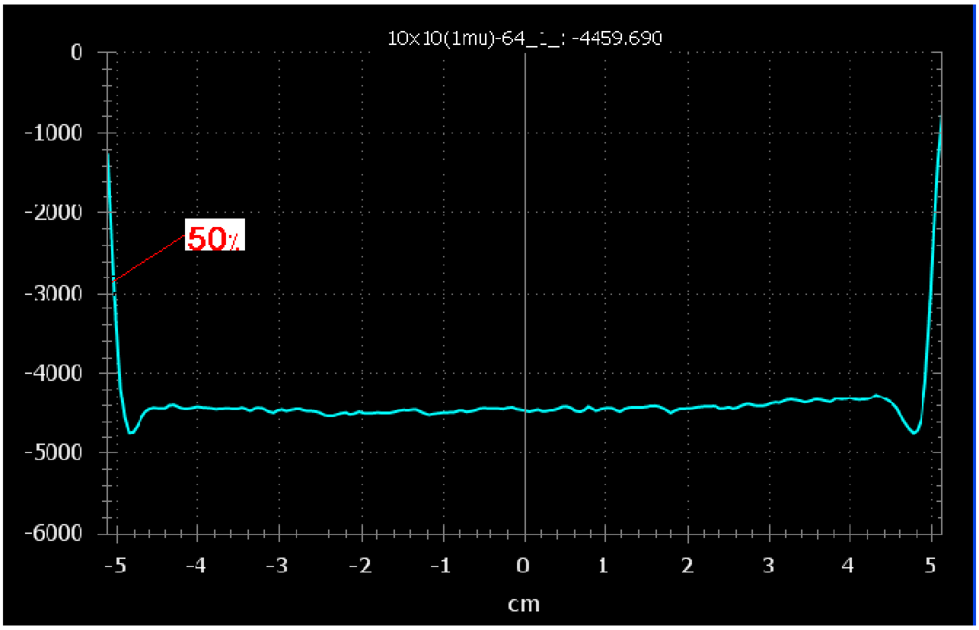

Figure 7: Dose profile of field size 10×10 cm² and the edge of 50%

By using the distance tool to measure the distance at the edge of 50%, the relative error was 1%. This error was accepted and proved that EPID is a good tool for the coincidence e of the light field VS radiation field.

4. Discussion

Although Electronic Portal Imaging Devices (EPIDs) were basically developed for positioning verification, they can also be used for dosimetric purposes. In this study, all of the aSi EPID measurements were measured at SDD of 150 cm. At small heights, more scattered photons fall on the EPID, decreasing the accuracy of the dosimetric calibration procedure. At 160 cm, less scattered photons reached the EPID; however, the maximum field of view(FOV) was decreased.

For this work, a height of 150 cm was chosen as a tradeoff between FOV and dosimetric accuracy. No saturation effects were noticed in the profiles measured at SDD = 150cm, showing good agreement with ion chamber profiles. Results proved that EPID can be used as a physics tool for routine linear accelerator QA. By taking several images for field sizes 10×10 cm² over a period of two weeks, short term repeatability was found to be excellent. The average percentage for relative error was found to be 1.4 %.The result of reproducibility was almost in agreement with another study [1], it was 1%. Results of reproducibility and uniformity confirmed the stability of short term as well as of long term scales of EPID. The results of field size show a good agreement with another study [9], it was about 1%. Grein at al. developed empirical corrections to compensate for similar observed effects. The causes of the differential response of EPID (Gd2O2S sensitive volume) with ion chamber are reported to be the varying energy absorption and spectral scattering properties of the different atomic compositions that make the detector and the surrounding media. Since the behavior of EPID although different from ion chamber was found to be self-consistent at different source to detector distances (SDD) and with ability to apply the concept of equivalent field size, the field size dependence can be modeled through a single analytical function. It was concluded that although the field size dependence of the EPID differed from that of an ion chamber in solid water phantom, it was useful for relative dosimetry.

The linearity of EPID response with dose rate and dose was investigated. The EPID response increases with the increasing of dose and dose rate[2,3]. The flatness results were good, as with another study[3]. The flatness result was less than 3%. The maximum flatness value was 2.7 for field size 10×10 cm² and 1.8 for field size 18×18 cm², which are within tolerance, while in the study [3], it was 1%. The standard deviation for the flatness of the EPID was found to be 0.82 for field size 10×10 cm². For field size 18×18 cm², the standard deviation was found to be0.6. We also can use EPID for coincidence of light field VS radiation field test, which shows a good agreement with another study[3]. By using the distance tool, it was found that at the edge of 50%the relative error was 1%. The results show that the aS500 EPID has the potential to be used as a relative dosimeter, making it a very simple and efficient tool for daily QA.

5. Conclusion

The accuracy of EPID as a dosimeter is dependent on the dose response characteristics. Without a comprehensive evaluation of dose response characteristics, EPIDs cannot produce reliable dose measurements. The reproducibility, uniformity, dose and dose rate linearity, and field size response measured in this work, proved that the SLIC-EPID can be used for dosimetric purposes. However, for the EPID to be used for dosimetric purposes, the extra build-up layer thickness and the field size response must be known.

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