

# An Empirical Transmitted EPID Dosimetry Method using a Back-Projection Algorithm

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## ABSTRACT

**Background:** The present study aimed to introduce a rapid transmission dosimetry through an electronic portal-imaging device (EPID) to achieve two-dimensional (2D) dose distribution for homogenous environments.

**Material and Methods:** In this Phantom study, first, the EPID calibration curve and correction coefficients for field size were obtained from EPID and ionization chamber. Second, the EPID off-axis pixel response was measured, and the grey-scale image of the EPID was converted into portal dose image using the calibration curve. Next, the scattering contribution was calculated to obtain the primary dose. Then, by means of a verified back-projection algorithm and the Scatter-to-Primary dose ratio, a 2D dose distribution at the mid-plane was obtained.

**Results:** The results obtained from comparing the transmitted EPID dosimetry to the calculated dose, using commercial treatment planning system with gamma function while there is 3% dose difference and 3mm distance to agreement criteria, were in a good agreement. In addition, the pass rates of  $\gamma < 1$  was 94.89% for the homogeneous volumes.

**Conclusion:** Based on the results, the method proposed can be used in EPID dosimetry.

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## Keywords

Radiotherapy Planning, Computer-Assisted; Dose-Response Relationship; Radiotherapy; Algorithms

## Introduction

Patient-specific treatment verification is an unavoidable trend with the current complexity of modern radiotherapy plans and dose prescriptions [1]. Different devices have been used for the verification. Not only Electronic Portal Imaging Devices (EPIDs) are developed for patient position verification, but also they can be used for other tasks such as dosimetry and quality assurance [2,3]. Currently, the most common type of EPID available is the amorphous-silicon EPID (a-Si EPID) [1]. The advantages of a-Si EPID are as follows: positional accuracy, stability, high spatial resolution, real-time image acquisition, and signal digitization capabilities [4,5]. On the other hand, the over

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sensitivity to low-energy photons is the main disadvantage of this device [6].

Several researchers have showed the short and long-term stabilities [6-10]. The response of a-Si EPIDs is reportedly independent of dose rate and approximately linear with the dose delivered [11]. Regarding the mentioned advantages above, a-Si EPIDs are suitable devices for both pre-treatment and treatment (in vivo) verification approaches [12].

The EPID dosimetry can be performed in both transit and non-transit models [1]. The transit dosimetry is the measurement of the dose behind the patient/phantom at the detector plane, and the non-transit dosimetry, is the determination of dose without an attenuating medium between the linear accelerator's target and EPID [1]. Given the incapability of the non-transited model in detecting all errors during the treatment, the transit model is preferred over the non-transit one [13]. In both models, EPID dosimetry can be performed by either forward or backward approaches [14]. In the forward approach, the measured portal image can be converted into the transmitted dose using different methods. The Portal Dose Images (PDI) can then be compared with dose distribution in EPID position calculated by a treatment planning system (TPS) or another method like Monte Carlo simulation [15-17]. In contrast, in the backward approach (or back-projection), the measured electronic portal images (EPIs) are used to reconstruct the patient dose in the treatment position at any plane [18].

There are different studies investigating the transmitted EPID dosimetry for dose determination at the patient level using the back-projection methods [8,18-20]. Transit dosimetry based on the EPID has been also compared with those calculated with commercial TPS. The results indicated that there was a good agreement on gamma index analysis for the homogenous and anthropomorphic phantoms [21].

This study aims to perform the transmission

dosimetry in clinical workflow, in a way that the isocentric dose plane at the patient's position is estimated using back projecting of the exit energy fluency recorded by the EPID. The results obtained were only for mid-plane dose; however, with regard to the applied calculation method, the 2D dose map could be calculated for any source-to-image distance (SID) using the same procedure. Therefore, the results can be generalized to any distance from the accelerator.

## Material and Methods

In this Phantom study, the measurements were made on a Precise linear accelerator (Elekta Oncology Systems, Crawley, UK) with a multileaf collimator, consisting of 40 leaf pairs with 1 cm width and the source to axis distance of 100 cm. The detector panel was the PerkinElmer Amorphous Silicon (a-Si) with IviewGT supporting software. More details can be found in the machine's manual [22].

The integrated pixel value for each field was obtained using Equation 1:

$$\text{Integrated Pixel Value} = \frac{65535 - \text{RawPixelValue}}{\text{PSF}} \quad (1)$$

Where, PSF is the pixel-scaling factor, related to the number of frames for each image [23,24].

### A. Calibration of EPID

To determine the relationship between EPID signal and ion chamber, EPIs were obtained from a slab phantom, 20 cm, by setting a 10×10 cm<sup>2</sup> radiation field size and delivering the varying number of MU (5-150 MUs). The homogeneous slab phantom was placed on the treatment couch at a source-to-detector distance (SDD) of 160 cm.

The procedure was repeated with the same scenario for a calibrated 0.6 cc Farmer ionization chamber that was inserted in the EPID position at the maximum distance of 1.5 cm from the slabs.

These processes were repeated to determine the field size corrections for EPID and ion chamber when the slab phantoms, 20 cm, was irradiated with 50 MU in 4×4, 5×5, 7×7, 10×10 and 15×15 cm<sup>2</sup> field sizes. All fields were normalized to a standard field size 10×10 cm<sup>2</sup> and the curves were then fitted.

### B. Beam hardening and scatter correction for water medium

The attenuation function for primary dose in water was expressed as follows [25,20]:

$$A(T_{Mid}) = \exp(-\mu T_{Mid} (1 - \eta T_{Mid})) \quad (2)$$

Where  $\eta$  is the beam-hardening coefficient. The above equation can be written as:

$$A(T_{Mid}) = \exp(-\mu_{Hd} T_{Mid}) \quad (3)$$

Where

$$\mu_{Hd} = \mu(1 - \eta T_{Mid}) \quad (4)$$

Where  $\mu_{Hd}$  represents the linear attenuation coefficient applying beam hardening, and  $T_{Mid}$  denotes the thickness matrix obtained for the mid-plane. The  $\mu_{Hd}$  matrix was obtained from both mid-plane and the EPID position. To determine the ratio of scattered radiation in dose distribution, the scatter-to-primary dose ratio (SPR) reported by WANG *et al.* was employed using the following equation [26].

$$SPR = \frac{a_0 s (T_{Mid} + d_0)}{w_0 s + (T_{Mid} + d_0)} \quad (5)$$

Where,  $a_0$ ,  $w_0$ , and  $d_0$  are fitting parameters on the linear attenuation coefficient ( $\mu$ ), and  $s$  is the field size.

### C. Off-axis correction for EPID

First, the portal image was obtained from slab phantom, 20 cm, placing on the couch with delivering a 25×25 cm<sup>2</sup> irradiation field to correct the off-axis response of EPID. The EPID image was normalized to the center. Considering, the beam divergence, the matrix of beam attenuation was calculated for 20 cm thickness of slabs using the attenuation

function (Equation 3) by MATLAB software R2016b (Mathworks Inc., Natick, Massachusetts, USA), then the result was normalized to the center. Second, the normalized EPID matrix determined at the first step was multiplied pixel-wise by the normalized attenuation function to obtain the off-axis response.

### D. Back-Projection method and verification

The method obtains the dose delivered to the mid plane by means of the back-projection algorithm involving, a) the calculation of the primary dose by means of EPID and b) its back projection to the mid plane and applying the SPR [18]. In the first step, the equations obtained for the EPID field size correction in section A were utilized to calculate the primary dose for the intended field size. At the second stage, the following function was run:

$$PrDose_{Mid} = PrDose_{EPID} \left( \frac{d_{EPID}}{d_{Mid}} \right)^2 A(T_{Mid}) \quad (6)$$

Where  $PrDose_{EPID}$  and  $PrDose_{Mid}$  are the matrixes of the primary dose at EPID position and mid-plane, respectively. Furthermore,  $d_{EPID}$  and  $d_{Mid}$  are the matrix distances from the accelerator target to EPID and mid-plane, respectively.

### E. verification of the Method

For the verification of the method in a homogeneous volume, a slab phantom, 20 cm, was located on the treatment couch and irradiated with 60 MU at a field size of 8×8 cm<sup>2</sup>. Gafchromic EBT3 film was used to evaluate the penumbra region at the same beam configuration.

## Results

### A. EPID Calibration

Equation 7 reveals the linear relationship between the dose at the EPID position and the mean pixel value acquired from EPI central point of the slab phantoms for the field size of

a  $10 \times 10 \text{ cm}^2$ .

$$\text{Dose (cGy)} = 3.26 \times 10^{(-5)} \times \text{Pixel Value} + 0.02787 \quad (7)$$

Based on the quadratic functions, beam scat-

$$\text{F.S Scatter Factor for EPID} = -5.65 \times 10^{(-5)} \times s^2 + 2.12 \times 10^{(-2)} \times s + 7.92 \times 10^{(-1)} \quad (8)$$

$$\text{F.S Scatter Factor for Ion Chamber} = -5.276 \times 10^{(-5)} \times s^2 + 1.63 \times 10^{(-2)} \times s + 8.404 \times 10^{(-1)} \quad (9)$$

Where,  $s$  is the desired field size.

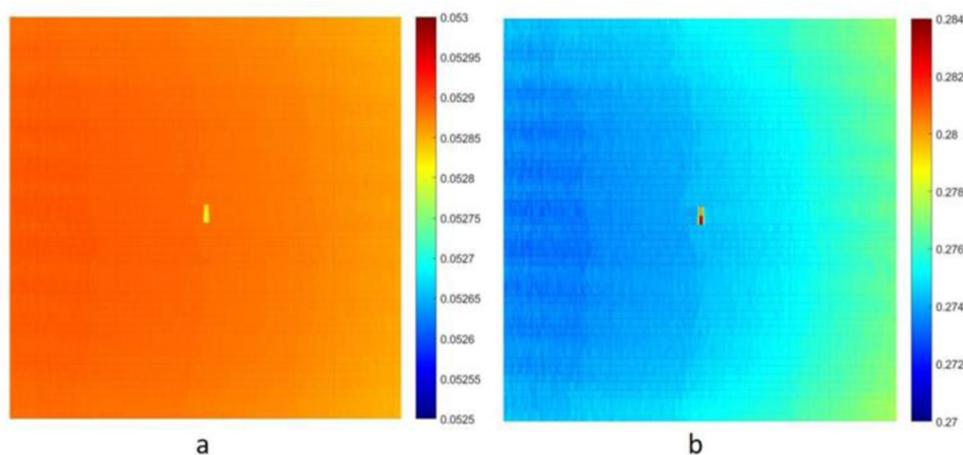
### B. Beam hardening and scattering Correction

Figure 1a displays the linear attenuation coefficient map ( $\mu_{\text{Hd}}$ ) used to compensate beam hardening at the mid-plane for the slab phantom using Equation 4. In this equation, the data

tering is dependent on the radiation field size. Equations 8 and 9 present the quadratic functions obtained from the field size effects when the slab phantoms, 20 cm, were placed on the couch for the EPID and Ion chamber.

presented by WANG *et al.*, for various Linac and beam energies calculated using the Monte Carlo simulation method [26] were used for the  $\mu$  and  $\eta$  parameters. The  $\mu_{\text{Hd}}$  map for mid-plane is shown in Figure 1a.

Figure 1b demonstrates the obtained SPR based on Equation 5. This matrix was developed for the determination of the scatter radia-



**Figure 1:** a) The  $\mu_{\text{Hd}}$  matrix in mid-plane b) scatter-to-primary ratio in mid-plane

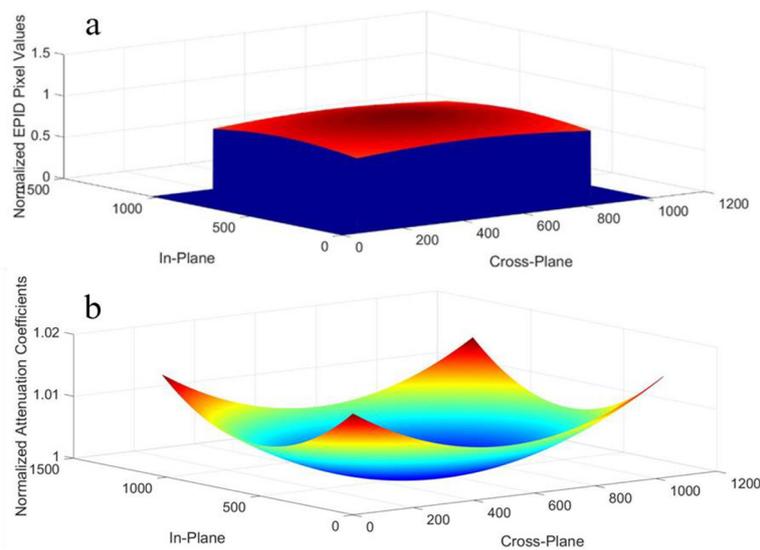
tion contribution to the transmitted dose maps.

### C. Off-axis correction for EPID

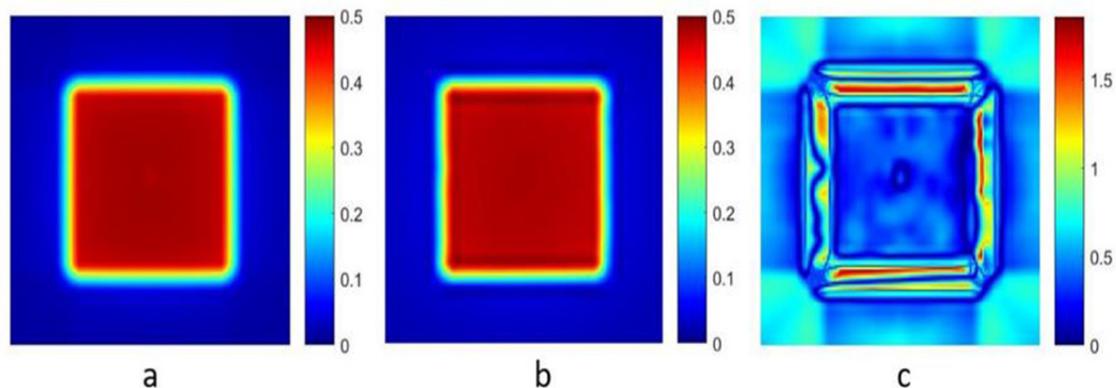
As the off-axis response of EPID pixels is different, a correction should be applied to obtain the correct transmitted dose. Figure 2 (a) and (b) represent the normalized EPID response and attenuation matrixes for 20 cm slabs, respectively. By multiplying these two matrixes, the off-axis response of EPID was obtained.

### D. Back-Projection and verification

Figure 3 illustrates the dose matrix extracted from TPS. The corresponding back projected dose was originated from an EPI with the same beam configuration. Gamma index with 3 mm distance to agreement (DTA) and 3% dose difference was used to compare the TPS calculated dose with the EPID dose maps. In 94.89% of the points, the gamma value was less than 1 ( $\gamma < 1$ ), that indicates the acceptance criteria to be passed.



**Figure 2:** a) The 2D matrix of EPID response for a 25×25 cm<sup>2</sup> field size. b) The normalized attenuation matrix



**Figure 3:** The dose matrices arising from a) TPS, b) EPID and c) Gamma comparison results.

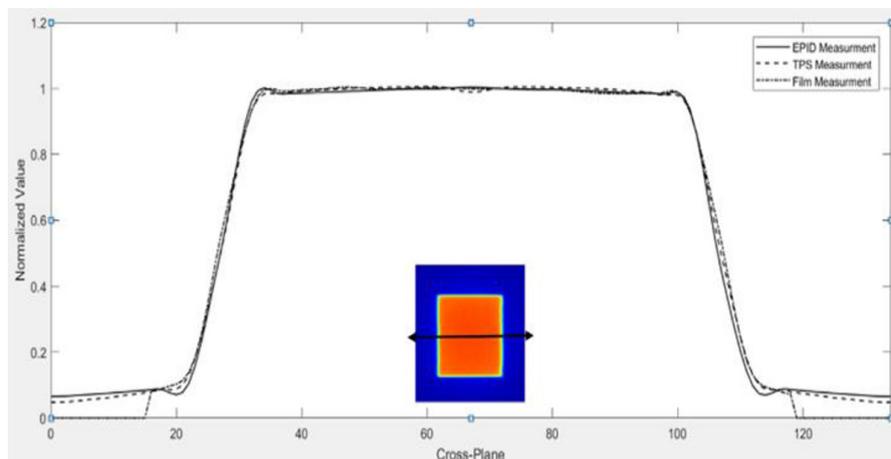
## Discussion

In the present study, the two-dimensional dose distribution at the EPID position and back-projected into the mid-plane in the homogeneous medium were obtained.

According to the results, one of the main differences between the TPS measurements and those obtained in the present study, regarding the dose distribution, was related to the shoulder and penumbra regions. No proper judgment can be made in these areas. In the same vein, Tan *et al.* stated that the TPS cannot ac-

curately calculate the dose in shoulder and penumbra regions [13]. However, other researchers, evaluating the accuracy of dose calculation by different TPSs, have confirmed the inaccuracy of these systems [27], the various calculation algorithms have different levels of inaccuracy [28]. Therefore, the assessment of these regions was made using the GAF-CHROMIC EBT3 film as an independent tool. The results of this assessment are shown in Figure 4.

Based on the results published before, the



**Figure 4:** Dose profile (normalized to the central axis) comparisons between TPS, EPID and GAF-CHROMIC EBT3 film results in the slab phantom.

behavior of the EPID calibration curve for converting the pixel values to dose is linear [29-32] and in the current study, similar results were obtained. To solve the problem of the off-axis response of the a-Si EPID, some researchers used a copper plate with different thicknesses placed on the EPID surface [9,33-35]. The clinical implementation of the method has some problems. For example, in the gantry angle of  $180^\circ$ , an air gap may be created between the copper plate and the EPID, or the copper plate may fall down due to gravity. In the current study, the copper plate was not used, and the responses of all EPID pixels were determined independently. According to the previous investigations on the reproducibility of the a-Si EPIDs response [7,10], the calculations of all EPID pixels such as SPR,  $\mu_{\text{Hd}}$  and the back projection, were performed independently due to the stable response of all pixels in order to achieve the dose distribution. The calibration of EPID was performed for 6 MV photon beam and 400 MU/min dose rate. The beam divergence should also be considered in all calculations.

Elekta with the collaboration of Netherlands Cancer Institute has recently introduced a solution (iViewDose, Elekta AB, Stockholm,

Sweden) that used a convolution model for transmission EPID dosimetry [36]. However, the empirical methods are more practical for clinical implementation, compared with the convolution model [13,37,38]. In the present study, it was attempted to verify the a-Si EPID for dosimetry purposes using an empirical method.

One of the main differences of the empirical method employed in this research with those presented in other studies is that the calculation of dose does not limit to one or two situations [13,39] and that our method can calculate the 2D dose map at any SID.

## Conclusion

In recent years, the inherent complexity of advanced treatment techniques requires new dosimetry tool for quality assurance. The presented method is not time-consuming and does not require high-speed computers, which allows the user to calculate the dose map easily at any SID and angle. However, in the first step, the method was an attempt for an angle of  $0^\circ$  in an AP view and all measurements were made using the SAD technique. In conclusion, the method presented in this study can facilitate the determination of a 2D dose dis-

tribution in a short period in the homogeneous phantom.

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## Conflict of Interest

None

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