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# Verification of dose delivery for a prostate sIMRT treatment using a SLIC–EPID

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ABSTRACT

The current work focuses on the verification of transmitted dose maps, measured using a scanning liquid ionization chamber–electronic portal imaging device (SLIC–EPID) for a typical step-and-shoot prostate IMRT treatment using an anthropomorphic phantom at anterior–posterior (A–P), and several non-zero gantry angles. The dose distributions measured using the SLIC–EPID were then compared with those calculated in the modelled EPID for each segment/subfield and also for the corresponding total fields using a gamma function algorithm with a distance to agreement and dose difference criteria of 2.54 mm and 3%, respectively.



## 1. Introduction

Although all types of electronic portal imaging devices (EPIDs) including fluoroscopic, scanning liquid ionization chamber (SLIC) and amorphous silicon (a-Si) EPIDs, are primarily used to verify the patient set up during radiation therapy courses, their use has been gradually extended for dosimetric purposes, including quality assurance (Kirby and Williams, 1995; Vieira, Dirkx et al., 2002; Yang and Xing, 2004), compensator design (Evans, Hansen et al., 1995; Curtin-Savard and Podgorsak, 1997), pre-treatment verification (Depuydt, Van Esch et al., 2002; Van Esch, Depuydt et al., 2004) and dose delivery verification (Pasma, Dirkx et al., 1999; Steciw, Warkentin et al., 2005).

As uniform images are acquired by EPIDs for patient set up verification, additional dosimetric calibration is required. The dosimetric calibration is mainly focused on: long-term, and short-term reproducibility of electronic portal image (EPI) pixel values (Essers, Hoogervorst et al., 1995; Louwe, Tielenburg et al., 2004), the lag of image acquisition time (Essers, Hoogervorst et al., 1995; Curtin-Savard and Podgorsak, 1999; Van Esch, Vanstraelen et al., 2001), the use of extra build-up layer (Chang, Mageras et al., 2000), conversion of EPIDs raw pixel values to dose values (Essers, Hoogervorst et al., 1995; Parsaei and El-Khatib et al., 1998; Van Esch, Vanstraelen et al., 2001), and reconstruction of radiation beam horns. The latter has been reported as being the most important part of a two-dimensional dosimetric calibration and can be achieved using empirical (Essers, Boellaard et al., 1996; Parsaei and El-Khatib et al., 1998; Chang, Mageras et al., 2001), and mathematical approaches (Boellaard, van Herk et al., 1997; Pasma, Vieira et al., 2002; Steciw, Warkentin et al., 2005).

Two general methods have been developed to verify the dose delivered to the patient, using portal dose distributions called "transmitted dose maps". In the first approach, the transmitted dose maps are back-projected to obtain either exit dose maps i.e. the dose distributions in the exit side of patient where electronic equilibrium is achieved, or mid-plane dose maps. For instance, a method was introduced to estimate the on-axis exit dose of a patient performing SRI-100 fluoroscopic EPID measurements (Kirby and Williams, 1993). This method has an inherent limitation of accuracy, especially for intensity modulated beams because of use of an on-axis beam. A kernel-based convolution model was also developed to reconstruct exit dose from the transmitted dose values measured using the SLIC–EPID. The accuracy of this model was reported to be within 2% and 2.5% for homogeneous and inhomogeneous phantoms, respectively (Boellaard, van Herk et al., 1997). In another study, the back-projection of transmitted dose values obtained from EPIs was performed through the planning computerized tomography (CT) to yield a primary fluence distribution inside the patient. The dose distribution was then convolved with dose deposition kernels to calculate a mid-plane dose map. The results were found to be in agreement with radiographic film and thermo-luminescence

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dosimeter (TLD) measurements (within 2%) for a pelvic region of an anthropomorphic phantom (Hansen, Evans et al., 1996).

Transmitted dose maps, measured using two-dimensional portal dosimeters, have been compared with the corresponding calculated dose maps, using treatment planning systems (TPSs). Due to the limitation of TPSs to calculate the transmitted dose beyond the patient CT data, several methods have been proposed to develop calculated dose maps. A method called "delta volume" was introduced (Wong, Slessinger et al., 1990) and the calculated dose maps were compared with radiographic film and TLD measurements. Arguing that the "delta volume" method is not well suited for large air gaps, (i.e. distances between phantom/patient and portal imager), a novel approach was introduced based on convolution/superposition algorithm. The aim was to predict the transmitted dose distributions through an "extended phantom" including a phantom, an air gap (up to 22 cm) and a modelled EPID (McNutt, Mackie et al., 1996). The calculated dose maps were generally found to be in agreement with SLIC–EPID measurements within 4%. For larger air gaps, from 30 to 50 cm, an algorithm was developed to calculate the dose maps for open fields (Pasma, Heijmen et al., 1998; Reich, Bezak et al., 2006) and wedged fields (Pasma, Vieira et al., 2002). A good agreement (approximately 1%) has been reported for regions excluding the penumbra for open, wedged and smoothly modulated IMRT fields, and a large deviation, greater than 10%, was reported for the use of this algorithm in the penumbra regions (Pasma, Dirkx et al., 1999). The transmitted dose maps calculated using a full Monte Carlo simulation technique were also compared with those measured using the a-Si EPID (Siebers, Kim et al., 2004). A Monte Carlo simulation using BEAMnrc/DOSXYZnrc code was also developed to calculate dose maps at oblique gantry angles (Chin, Spezi et al., 2003). Furthermore, several new approaches have been recently developed for three-dimensional dose verification using EPIDs (Renner, Sarfaraz et al., 2003; Ansbacher, 2006; van Elmpt, Nijsten et al., 2006).

Although several studies have been reported to investigate either conformal radiotherapy (CRT) or IMRT dose verification using EPIDs (Chang, Mageras et al., 2000; Fielding, Evans et al., 2002; Vieira, Dirkx et al., 2002; Zeidan, Li et al., 2004), majority of studies have been performed for either primary radiation fluence or homogeneous attenuators in anterior–posterior (A–P) directions only. Only in one case, performed by Kroonwijk et al. (1998), an in-vivo dose verification based on comparison of predicted and measured portal dose images for 10 prostate patients for lateral and A–P beams was done (1998). This however, does not readily apply to CRT and IMRT treatments where multiple gantry angles other than zero are generally used. These observations motivated us to investigate the transmitted dose distributions, measured using the SLIC–EPID, for a typical step-and-shoot prostate IMRT applied to an anthropomorphic phantom using A–P direction as well as all other typically used oblique gantry angles. EPIs acquired for each subfield in five radiation fields were converted into the transmitted dose maps using an appropriate calibration method. The results of these measurements were then compared with the transmitted dose maps, calculated by the Pinnacle$^3$ TPS, using the gamma function algorithm.

## 2. Materials and methods

### 2.1. Materials

All transmitted dose maps were measured using a SLIC–EPID (LC250, PortalVision MK2, Varian Medical System, Palo Alto, CA) incorporated in a Varian 600CD linac, equipped with an 80-leaf standard MLC (Varian Medical Systems, Palo Alto, CA). The linac produces a standard 6 MV photon beam with a range of repetition rates from 100 to 600 MU/min. The detector matrix of the SLIC–EPID has a sensitive area of $32.5 \times 32.5\,cm^2$. It contains $256 \times 256$ liquid ionization chambers with the volume of $1.27 \times 1.27 \times 1\,mm^3$. All EPIs were acquired in fast read-out and full resolution mode as routinely used for image acquisition in our clinic. In addition, the accuracy of this setting has been reported to be better than other available options (Chang, Mageras et al., 2003). A commercial Pinnacle$^3$ TPS, version 6-2b (ADAC Inc. PHILIPS Medical System, Milpitas, CA) was also used to calculate the transmitted dose delivered to the EPID sensitive layer. The TPS calculates the dose using collapsed-cone convolution superposition algorithm (Mackie, Scrimger et al., 1985). An anthropomorphic Rando phantom, containing real bony anatomy inside a solid water material was used to measure and to calculate the dose transmitted through the phantom. All image processing and dose distribution comparison procedures were performed using in-house codes written in MATLAB 7 (MathWorks Inc, Natick, MA).

### 2.2. Methods

EPIs acquired using repetition rate of 300 MU/min, with one MU corresponding to a calibrated dose delivery of 1 cGy under the reference conditions (SSD = 100 cm, for a $10 \times 10\,cm^2$ field size at the depth of $d_{max}$). Due to the EPI short acquisition time (0.0015 s/two rows) and in order to reduce statistical fluctuations of EPI pixel values, each EPI used in the current study was to determine the average of three consecutive acquired EPIs with pixel value standard deviation of less than 1% on the central part of radiation field.

#### 2.2.1. SLIC–EPID calibration for dosimetric purposes

For dosimetric purposes, a comprehensive calibration of SLIC–EPID is required including: evaluation of EPIs reproducibility, the evaluation of EPI pixel values with acquisition time lag, the use of an extra build-up layer, conversion of EPI pixel values to dose, correction of EPID dose values in off-axis regions. These have been discussed in depth elsewhere (Mohammadi and Bezak, 2005, 2006).

#### 2.2.2. SLIC–EPID response correction for oblique beams

In the current work, a systematic variation in EPI pixel values with gantry angle observed for SLIC–EPIDs called "bulging effect" (a correction algorithm developed by Van Esch et al. (2001)) was used to remove this effect from the measured EPIs.

Typical crossplane profiles extracted from EPIs acquired at 0°, 90°, 180°, and 270° gantry angles are illustrated in Fig. 1(a). A systematic variation of EPI pixel values was observed for a range of gantry positions. The maximum differences in SLIC–EPID response (compared to the response at 0°) were found to be at gantry positions 90° and 270°. For these angles, the observed variation in EPI pixel values corresponds to the measured transmitted dose variation in the off-axis regions by 3%.

Typical line profiles of an acquired relative primary fluence map before and after the correction for the bulging effect for a 90° gantry position are shown in Fig. 1(b). In addition, a comparison of relative dose difference profiles before and after the correction with a corresponding profile measured at 0° is also displayed. At the edge of corresponding profiles, the difference was found to be around 3% compared to the profiles acquired at 0°. However, it was found that while the proposed method corrects all EPIs acquired at all non-zero gantry angles, several inconsistencies in the penumbra region were observed between line profiles corrected and those measured at 0° gantry position.