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Experimental validation of a Monte Carlo model to predict EPID images for online verification in radiotherapy

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I. INTRODUCTION

Thanks to recent improvements in external beam radiotherapy, it has become possible to deliver accurately very high doses to the tumor. The increasing complexity of the treatments has driven the need for a thorough verification of the delivered dose, either pretreatment or *in vivo*. Electronic portal imaging devices (EPIDs), initially introduced for patient positioning, have also demonstrated their great potential for dosimetric verification [1]. To achieve this goal, one proposed strategy is based on the comparison of a predicted dose image with a portal image acquired before and/or during treatment. Monte Carlo (MC) simulations (mainly using the EGSnrc code) were recently shown to predict reliably portal images of conventional and intensity modulated fields [2,3]. The purpose of this study is to investigate the feasibility of using the MC code PENELOPE to predict portal images and to validate a portal prediction model against measurements.

II. MATERIAL AND METHODS

A. Experimental set-up

Measurements were carried out at the LNHB laboratory (CEA-LIST, France) using a Saturne 43 accelerator (GEMS) equipped with a fluoroscopic Lynx2D EPID (FIMEL, France). This EPID consists of a fluorescent screen, made of a 1 mm thick copper plate coated with a Gd_2O_2S:Tb (GOS) fluorescent layer, viewed by a CCD camera via a mirror tilted at an angle of 45°. The CCD camera contains 600×600 pixels of 0.5x0.5 mm² each and has a 10 bit dynamic range. The active area of the EPID at the level of the fluorescent screen is 30×30 cm².

Open-field portal images were acquired for different field sizes (4×4, 10×10 and 15×15 cm²), both without object in the beam (in-air images) and with a 30×30×30 cm^3 water cubic phantom placed so that its entrance surface was located at 90 cm from the source. The source-to-isocenter distance and the source detector distance (SDD) were set to 100 cm and 150 cm, respectively. Each acquired image was formed by averaging 15 images of 10 s each, at a dose rate of 200 MU/min (1.7 Gy/min) with a photon beam energy of 12 MV. EPID images were then corrected for the difference in pixel gain and offset values by subtracting a dark-field image and dividing by a flood-field image.

B. Monte Carlo simulations

1) Modeling of the accelerator treatment head and the EPID

The PENELOPE MC code [4] was used to model the accelerator treatment head and compute portal images. In a first step, phase space files (PSF) storing information about each particle at the exit of the accelerator head (position, direction and energy) were pre-computed using a previously commissioned model of the accelerator head [5]. One PSF was computed per field size and scored about 150 million particles. Secondly, portal images at the EPID plane were simulated by using the pre-computed PSF as input data. The photon and electron/positron transport cut-offs were set to 0.01 MeV and 0.70 MeV respectively.

Two kinds of EPID models were investigated, differing by the complexity level in the geometry. A detailed geometry was first built following the manufacturer specifications and included every EPID components (fluorescent screen, mirror and shielding). A simplified model was also implemented, in which the fluorescent screen was modeled as two uniform layers of copper and GOS; beneath them was added a uniform water slab to take into account for the photons undergoing backscatter within the EPID structure and on the lab walls. In order to adjust the backscatter compartment thickness, average values were calculated on a 6×6 cm² central area of measured and computed portal images for 10×10 cm² and 15×15 cm² open fields. The ratio R of the average values between the 10×10 cm² field and the 15×15 cm² field was determined on measured images and the backscatter compartment thickness was varied until the same value of R was found on simulated images [6]. The EPID response was then computed by scoring the energy deposited in the GOS layer, represented by a virtual grid of 150×150 pixels of 2×2 mm² each.

2) Simulated configurations

A first set of simulations was conducted to determine which EPID model performed at best to compute portal images. For that, in-air portal images were simulated at SDD = 150 cm using a standard 10×10 cm² open field, for several EPID geometries: (1) the detailed model, (2) the simplified model without backscatter, (3) the simplified model with a 5 cm backscatter water layer and (4) the simplified model with an 8 cm backscatter water layer. Once the optimal EPID model determined, portal images were simulated for all open field sizes (4×4, 10×10 and 15×15 cm²) without object in the beam and with the 30×30x30 cm² water phantom placed at 90 cm from the source. For these simulations, the SDD was set to 150 cm as in the experimental configurations.

C. Determination and validation of the EPID model

The determination of the optimal EPID model was done by comparing the measured profile with the profiles drawn on the central axis through simulated images using the four different models described above. Simulated profiles were normalized to the averaged value on the three central points of the measured profile. In order to validate the EPID model for all field sizes and all configurations (in air and with the water phantom in the beam), on-axis profiles drawn through measured and simulated EPID images, as well as measured and simulated images themselves, were then compared to corresponding measured profiles and portal images, respectively. The difference between simulation and measurements was assessed by calculating the gamma index [4] both on profiles and images, using 3% and 3 mm as values for the dose-difference and the distance-to-agreement criteria, respectively.

III. RESULTS AND DISCUSSION

A. Determination of the optimal EPID model

The comparison between profiles computed for the four different EPID geometries shown on Fig.1 demonstrates clearly that the presence of a backscatter compartment is mandatory in the model to correctly simulate the EPID signal inside and outside the field. Moreover, the profiles obtained when simulating the whole EPID (detailed geometry) and without backscatter are almost identical and show that the mirror and the shielding do not affect significantly the EPID signal inside and outside the field. This means that the EPID signal is increased either by photons backscattering on the lab walls or by optical photons backscattering within the EPID structure or both. Portal images were computed for a backscatter compartment thickness of 5, 8 and 10 cm and values of the ratio R of 0.918, 0.907 and 0.898 were obtained, respectively. As an R value of 0.906 was determined experimentally, the thickness of the backscatter compartment in the simulation model was finally set to 8 cm to match the experimental result.

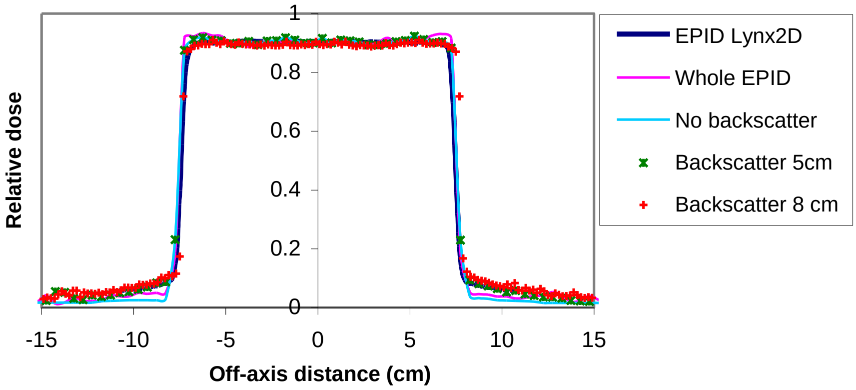

Fig.1. Comparison of the measured profile with simulated profiles for the four tested EPID models, for a 10x10 cm² field.

B. Validation of the EPID model for in-air and water phantom images

Simulated and measured profiles drawn for in-air and the water phantom configurations are shown on Fig.2, for the 4×4, 10×10 and 15×5 cm² open fields, whereas gamma index values for both the profiles (1D) and the images (2D) are presented in Table 1. Gamma analysis between computed and measured profiles reveals a gamma value less than 1 for 98% of all points. Discrepancies are mostly observed in the steep dose gradient regions and are mainly due to the uncertainty in the positioning of the EPID. For portal images, a gamma value less than 1 for 90% of the pixels when considering large field sizes and for 96% of the pixels when considering fields of size 10×10 cm² or less. Results are a little bit degraded outside the field for large field sizes because measured portal images were not corrected for the cross-talk effect. These results show a good agreement between simulation and experiment and exhibit that the model of the EPID implemented allows computing accurately portal images of open fields, with or without an object in the beam.

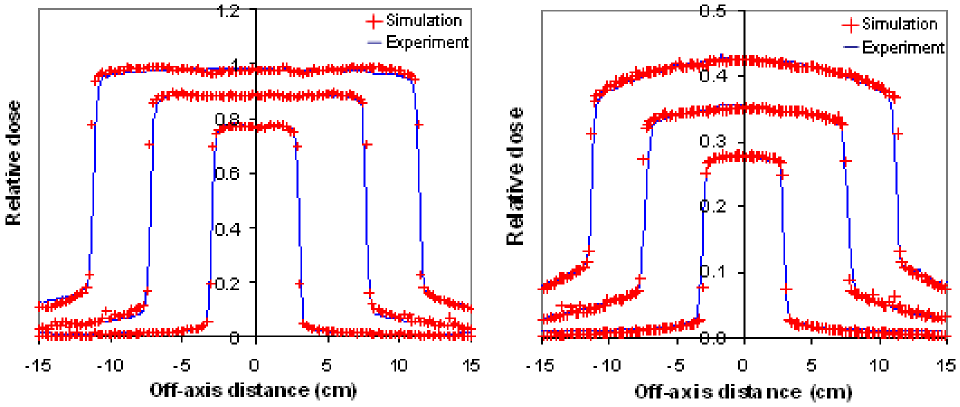

Fig.2. Comparison of measured and simulated profiles drawn through in-air images (left) and images of the water phantom (right).

Portal image	Field size (cm²)	Gamma index (%)	
		1D	2D
In-air	4×4	99.3	98.6
	10×10	98.1	96.4
	15×15	98.3	90.2
Water phantom	4×4	99.6	98.7
	10×10	99.0	96.5
	15×15	99.3	91.8

Table 1. Gamma index values computed on 1D profiles and 2D images, between measured and simulated configurations.

IV. CONCLUSION

This study shows that portal images can be computed accurately by using the MC code PENELOPE. A simple model of the EPID, based on three layers (copper, GOS, water), was validated: it was demonstrated that this model must include a backscatter compartment, whose thickness must be adjusted carefully to take into account the backscattered radiation within the EPID structure and on the lab walls. Using this model, we show that it is possible to predict reliably portal images acquired with a fluoroscopic EPID, in air or with an object in the beam, for open fields. This model can be used to compute MC predicted portal images for pre-treatment or online verification in radiotherapy or to help the development of dose reconstruction methods as a tool to investigate the influence of patient scatter on the EPID image formation.

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