STUDY OF AMORPHOUS SILICON ELECTRONIC PORTAL IMAGING DEVICE AS A DOSIMETRY FOR DYNAMIC INTENSITY MODULATED RADIATION THERAPY VERIFICATION

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ABSTRACT

The purpose of this study is to investigate the basic dosimetric characteristics of Varian flat panel amorphous silicon electronic portal imaging detectors (EPID) for the possibility of using a silicon portal imager for absolute dosimetric verification of the delivery of dynamic intensity modulated radiation treatment (IMRT) fields. The measurements were performed with 6 MV X-ray beams from Varian Clinac 23EX. The studies included field size dependence, dose rate, dose response, effect of dead time, relative and absolute dosimetry. The portal dose image was tested by comparing the EPID profiles with the ion chamber both for open and wedge fields. The portal dose image calculated by EPID dosimetry was compared with the EPID measurement for clinical IMRT fields. The results showed field size dependence of EPID, which was more sensitive than ion-chamber for larger field size but less than ion chamber in smaller field size, the maximum deviation of 4.9% was observed. The EPID was linear with dose rate and integral dose. The effect of dead time in frame acquisition due to transfer to the CPU was found to start at 40 MU of field size studied. The dead time resulted in dynamic field caused error that increased with leaf speed, the error was 17.62% for a 1 cm leaf gap moving at 1 cm/s. The comparison of profiles from EPID and ion chamber measurement for 10x10 cm^2 normal field showed the good agreement. For wedge field, both of EPID and ion-chamber profiles showed the agreement in the center part but slightly shift in the penumbra region. The pre-treatment verification for IMRT fields of 15 plans showed the agreement stribution between EPID calculation and EPID measurement within 3% difference in dose and 3 mm. difference in distance. The profile in the direction of MLC movement also showed good correlation between calculation and measurement.

EPID	=	Electronic portal imaging detectors	**PDI**	=	Predicted portal dose image
IMRT	=	Intersity Modulated radiation treatment	**QA**	=	Quality assurance
CPU	=	Central processing unit	**DMLC**	=	Dynamic multileaf collimater
MU	=	Monitor unit	**SDD**	=	Source detector distance
MLC	=	Multileaf collimator	**FF**	=	Flood field
CU	=	Calibration unit	**AM**	=	Acquisition mode
R2	=	The Correlation Coefficient	**DTA**	=	Distance to agreement

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INTRODUCTION

The most widely used form of pre-treatment quality assurance (QA) for IMRT verification generally consists of absolute dose measurements with ionization chamber combined with isodose distribution measurements in a phantom with film, or even by means of gel dosimetry.[1] The data acquisition as well as the data handling for comparison remains a time consuming task.

A new efficient tool for IMRT pre-treatment QA is the electronic portal imaging device (EPID). It was originally designed and developed to replace radiographic films for purpose of geometric verification of patient set-up during treatment. The new current generation of EPID is based on semiconductor materials, namely, amorphous silicon photodiodes.[2] This device is mounted on the linear accelerator providing real-time and digital feedback to the user. EPID showed high quality image than previous devices. Until recently EPID is possible to use as a dosimetry.[3] For pre-treatment verification, the EPID image can be compared to a predicted portal dose image (PDI) calculated from the fluence map from the Eclipse treatment planning. Before using EPID as a dosimetry, the relationship between EPID response and dose delivery parameters, such as dose and dose rate should be understood.

In this study the dosimetric properties of amorphous silicon EPID for verification of dynamic IMRT pre-treatment QA are investigated for 6 MV x-ray beams. The portal dosimetry software is used to measure the clinical IMRT fields. All investigations in this study are used at the dose rate of 300 MU/min.

MATERIALS AND METHODS

1. Electronic portal imaging device (EPID)

The amorphous silicon EPID[4] (aS500, Varian, Palo Alto, CA) consists of a 1 mm copper metal plate, a 134 mg/cm^2 gadolinium oxysulphide phosphor screen (Kodak, Lanex Fast B) that includes a 0.18 mm polyester reflector, and a 40x30 cm^2 (512x384 pixel) a silicon array. Each pixel consists of a light sensitive photodiode and a thin-film transistor with a pixel pitch of 0.78x0.78 mm^2. A 1.6-mm-thick plastic collision cover (epoxy with glass and foam) encloses the detector with an air gap of approximately 1.5 cm between the cover and the detector surface. The EPID was integrated with a 6 and 15 MV x-ray beams from linear accelerator with a dynamic multileaf collimator (DMLC) of 120 leaf (Clinac 23EX, Varian, Palo Alto, CA).

2. AM maintenance mode

This mode is used for tuning and maintaining the PortalVision image acquisition system that can read line profile, pixel value, pixel region of interest, acquisition mode, time/frame and number of frames. Two possible modes of acquisition for the EPID systems are multiple image acquisition and continuous frame averaging. We used continuous mode for the experiments, a single image consisting of the average of many image frames is acquired during radiation delivery. The EPID will average successively acquired frames up to a limit of 9999 frames.

3. Portal dosimetry mode

The portal dosimetry is consisted of Portal Vision hardware (EPID), acquisition module (4DTC/ standalone PV), and algorithm for dosimetric image prediction (Eclipse treatment olanning) and evaluation module (Review). This mode is available for point dose measurement, line dose measurement, isodose overlays, relative and absolute dose comparison with treatment planning, relative and absolute gamma evaluation. The pixel value in term of calibration unit (CU) is shown.

4. EPID calibration

4.1 AM maintenance

The EPID was calibrated by the acquisition of dark field and flood field. The calibration field size was 40x30 cm^2 at isocenter with the detector at a source-detector distance (SDD) of 140 cm. The calibration of the EPID with a flood field (FF) image

is important for accurate signal response as all acquired images are divided by the normalized FF image. This image is acquired to correct for non -uniformities in the EPID response, and after calibration, the input beam profile for the FF acquisition is uniform. The image should be calibrated every month for high quality image.[5]

4.2 Portal dosimetry

The detector was calibrated to yield a predicted portal dose (PD) of 1 CU for a 10x10 cm^2 field size and a dose of 100 MU at SDD = 100 cm. Since in practice, the SDD cannot be reduced beyond 105 cm. when the robotic arm is in clinical mode, the actual calibration was performed at SDD = 105 cm, setting the PD to be 0.90702 CU (i.e. calculated by inverse square law).

5. Parameters influence EPID dosimetry

The EPID was used in AM maintenance program with continuous mode of 10 fixed frames for the parameters studied.

5.1 The response of EPID with field size

In this experiment, the EPID was irradia ted with 50 MU and the field size was varied from 4x4 to 24x24 cm^2. At each field size, three images are acquired and the mean pixel values in a 9x9 pixel region at the center of field size were recorded. The doses were measured for comparison by the 0.13 cc ion-chamber with Dose 1 dosemeter (IC13, Wellhoffer, Schwarzenbruck, Germany) in a solid water phantom at SDD 105 cm, 1.5 cm depth with 5 cm of backscatter at each field size.

5.2 The response of EPID with dose rate

In order to find the relationship between the signal and dose rate, EPID was irradiated with 100 MU at 10x10 cm^2 field size. The changes in dose rate (300-132 MU/min) were the results of changes with SSD (100, 105, 120.2, 130.2, 140 and 151.2 cm). At each distance, three images were acquired and the mean pixel values in a 9x9 pixel region at the center of field size were recorded. To determine the relation of dose rate with distance; the dose rate were measured with ion-chamber in a solid water phantom at a 3.0 cm depth at each SDD.

5.3 The response of EPID with dose

Normally, the total dose in term of pixel values can be found by the average pixel values multiplied by frame number. The experiment was performed at 10x10 cm^2 field size with the varied dose of 10-200 MU. EPID was set at 105 cm SDD. Three images are acquired and the pixel values were recorded from the mean pixel values in a 9x9 pixel region at the center of field size.

5.4 Effect of dead time related to leaf speed

Sliding window deliveries were performed with a uniform 1 cm leaf gap between two banks of multileaf collimator (MLC) and a 10x10 cm^2 field size. The speed of the MLC depended on the MU. The MU used was 50, 100 and 200, so the speeds of MLC were 1.0, 0.5 and 0.25 cm/s, respectively. Reduction in signal from a uniform profile occurred due to dead time in frame acquisition was quantified for each leaf speed. Profiles were obtained along the direction of leaf motion directly under the center of the MLC leaf adjacent to the central axis. The dropping of the profile near the end of the field represented the effect of the dead time.

6. EPID dosimetry

This part has been performed in portal dosimetry mode.

6.1 Relative dose measured for open and wedge fields

The beam profiles at 1.5 cm depth from EPID were compared with the profile measured from ion-chamber in water. Images were acquired with open field and 45 degree wedge of 10x10 cm^2 field size. The EPID was at 105 cm from source. The EPID data were scaled to 101.5 cm for comparison.

b. IMRT pre-treatment verification

For pre-treatment verification of the IMRT fluence, an image of clinical IMRT field of

naspharynx cancer were taken without the patient at zero degree gantry angle. The predicted isodose distribution calculated by treatment planning (Eclipse, Varian, Palo Alto, CA) was compared with the isodose measured from EPID. The gamma value of 3% difference in percentage depth dose and 3 mm difference in distance were selected for analyzing the result.

RESULTS AND DISCUSSION

1. Parameters influence EPID dosimetry

1.1 The response of EPID with field size

The EPID response in term of the mean pixel values in 9x9 pixel region at the center of field and ion-chamber reading with field size normalized to the 10x10 cm^2 values are shown in figure 1. Second -order polynomials were fitted to the data. The EPID response was shown the deviation of 4.09% for a 4x4 cm^2 and 4.90% for a 24x24 cm^2 field size when compared with ion-chamber. The areas which were close to 10x10 cm^2 normalized field had less error.

The graph showed increasing in EPID and ion-chamber responses with field size which means that the scatter radiation was increasing when field size was increased. Since the scatter has a low energy component, its effect on the EPID's phosphor response for field size larger than 10x10 cm^2 was enhanced compared to ion-chamber due to the presence of high atomic number components in the phosphor. The response of EPID was less for small field size.

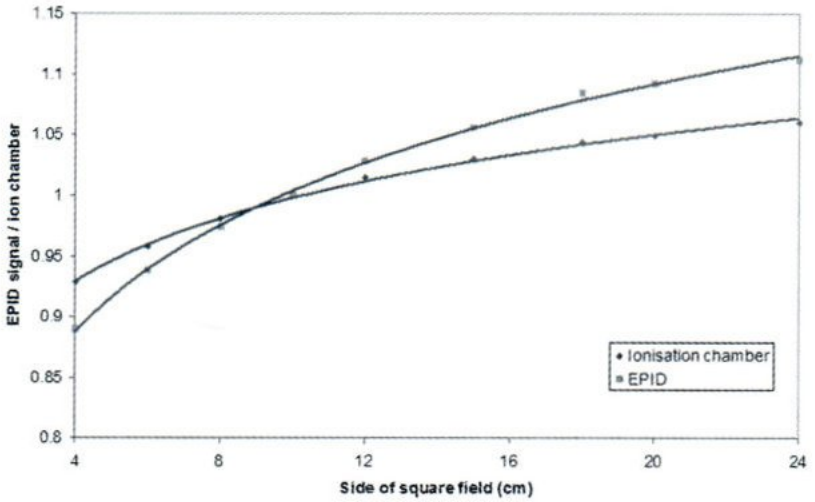


Fig.1 Field size dependence on the EPID and ion-chamber

1.2 The response of EPID with dose rate

The relationships between the dose rate (MU/ min) measured by ion-chamber and mean pixel values are shown in figure 2. The linearity of the EPID with dose rate are shown with $R^2 = 1$. From this result, it can be seen that when the source surface distance was increased which mean that the dose rate was decreased, there would be a decrease in pixel values.

EPID = Electronic Portal Imaging Device

1.3 The response of EPID with dose

The linearity with integral dose had been reported in many researches.[4,6,7] The integral doses of EPID were obtained by multiplication of the pixel values by the number of frames. The experiment's result of the relationship between integral dose in term of MU and the mean values of EPID pixel values multiply by number of frames can be seen in figure 3 for 10x10 cm^2 field sizes. The linearity was shown with $R^2 = 0.9979$. From the results, it can be seen that when doses were increased, there would be an increasing in pixel values and frames. During irradia-

tion, if the dose rate was fluctuated, the pixel values would show slightly non-linearity with dose. When the mean pixel values multiplied by the frames, the result showed linearity with the dose. This is due to the compensation of pixel values with the frame.

The effect of dead time was occurred every 64 frames.[4,6,7] The acquisition time per frame usually is 0.111 sec, therefore we can find the acquisition time per frame dealing with dead time by dividing the total acquisition time reading by number of frame reading. The results showed the acquisition time per frame of greater value than 0.111 sec when the dead time had been occurred. If there was no dead time, the number of frames would be the actual acquisition time divided by 0.111 sec. The frame without dead time showed higher value than the frame with dead time for the dose greater or equal to 40 MU. The frames without dead time multiplied by pixel value were higher when compared with the frame with dead time multiplied by pixel value as shown in figure 4 for 10x10 cm^2 field size. The error signal due to dead time increased when the dose was increasing. So for the static field of 200 MU maximum doses, the error due to dead time were 2.89%.

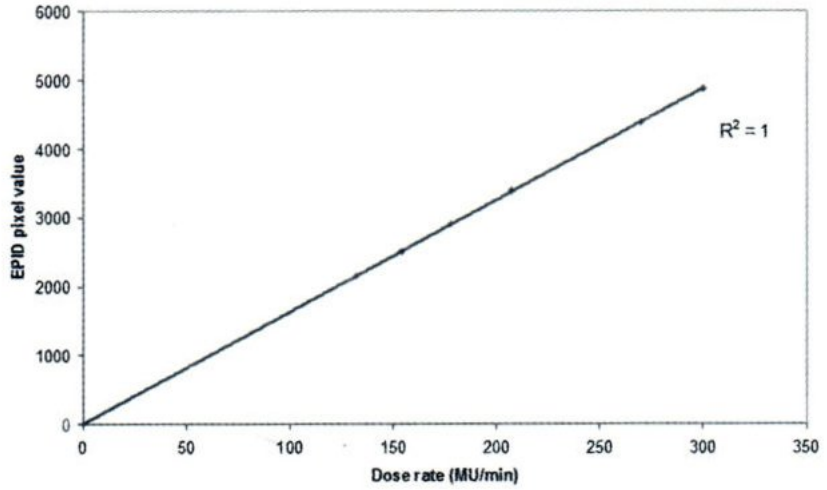


Fig.2 The response of EPID with dose rate for 10 x 10 cm2 field size.

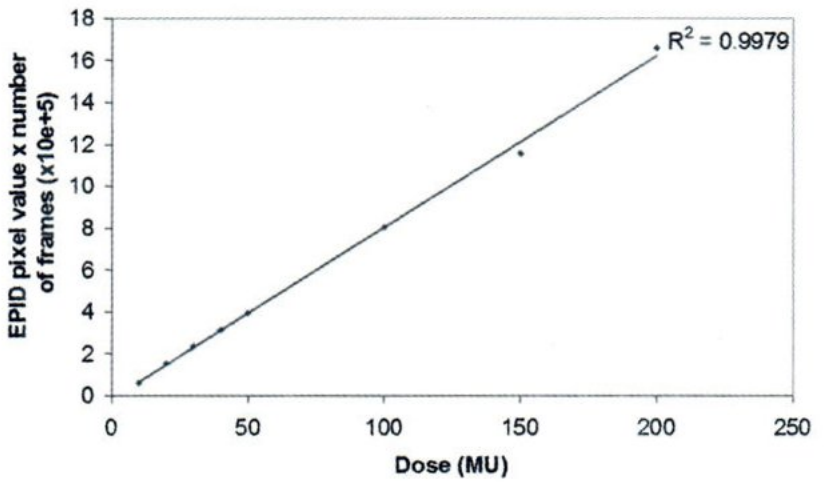


Fig.3 The response of EPID with integral dose for 10x10 cm^2 field size.

1.4 Effect of dead time related to leaf speed in frame acquisition in dynamic field

In the past study on the effect of dead times,[4] it was found that during EPID read out in every 64 frames, there would be data transfer to the CPU (Center Process Unit), with total time loss of 0.28 seconds, which was equal to 2 frames losses. While the data were transferred, EPID will not be able to collect signals, even if radiation were still delivered. Due to effect of dead times, EPID will have loss some signal. The resulted of static field has been shown in 1.3 as mentioned. For dynamic field, the profiles of the EPID are shown at various leaf speeds of 0.25, 0.5 and 1 cm/s in figure 5 by giving the dose of 200, 100 and 50 MU, respectively. The part of profile that shifts from the flat part represented the errors of each leaf speed. From this result, with the increase in leaf speed, there would be an increase in signal errors. The highest signal error value was equal to 17.62% at leaf speed of 1 cm/s and the lowest error value was equal to 3.37% at leaf speed of 0.25 cm/s. Therefore in IMRT treatment, with high leaf speed, the profile could show a higher error signal in EPID. For accurate dosimetry in EPID, the leaf speed should be slower or with larger MU.

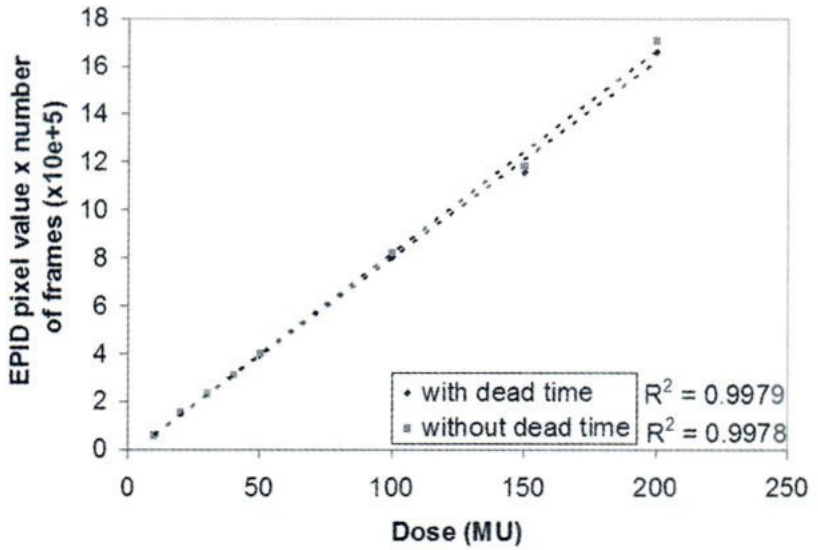
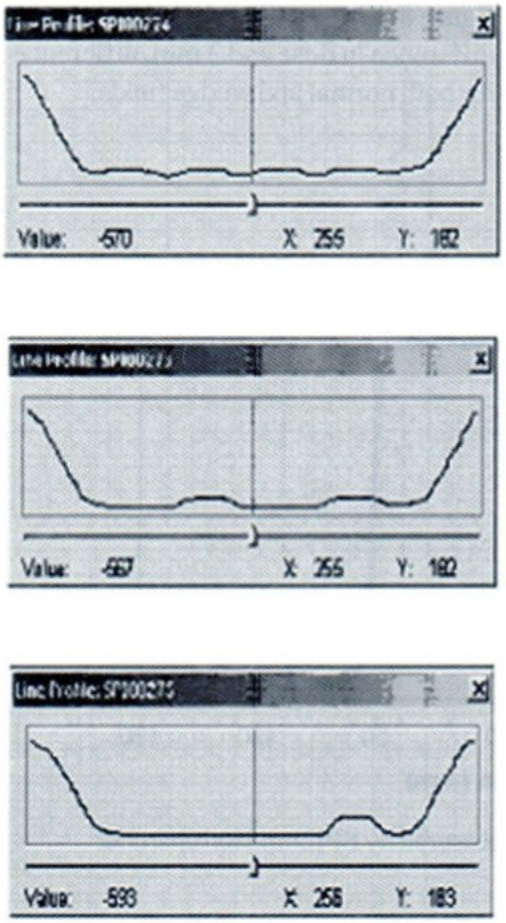


Fig.4 The response of EPID with integral dose in 10 10 cm2 field size with and without dead time.



A. 0.25 cm/s leaf speed

B. 0.50 cm/s leaf speed

C. 1.00 cm/s leaf speed

Fig. 5 The profile of sliding window delivery of EPID on x-asix with the effect of dead time for different leaf speed.

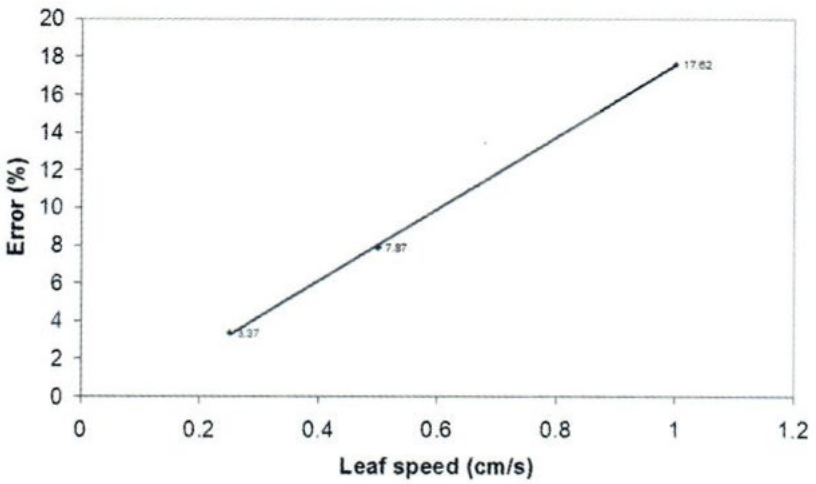


Fig. 6 The percent error due to dead time when increasing the leaf speed.

2. EPID dosimetry

2.1 Relative dose measurement for open and wedge fields

The comparison between the profile measured by EPID and ion chamber[5,6] of 10x10 cm^2 field size is shown in figure 7. The same comparison of 45 of wedge profile of 10x10 cm^2 is shown in figure 8. The profile became agreeable within 3% difference in dose and 3 mm. difference in distance for both normal and wedge fields.

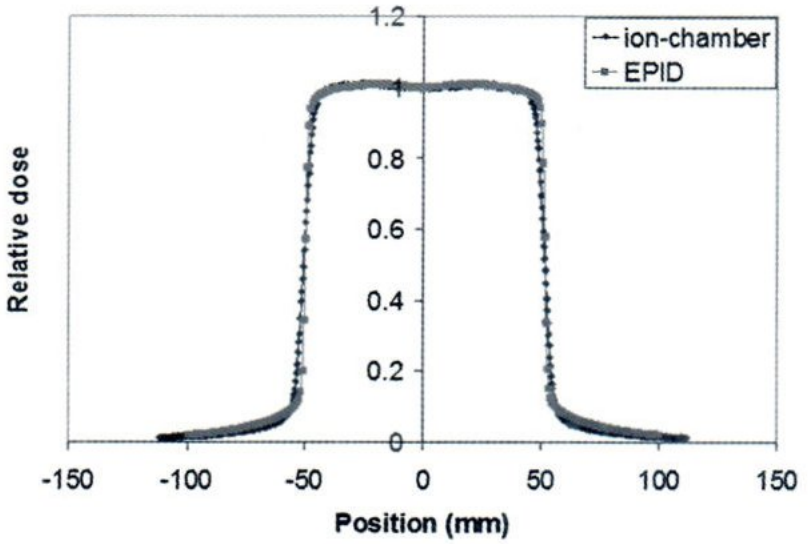


Fig. 7 The comparison of profiles measured by EPID and ion chamber for 10x10 cm^2

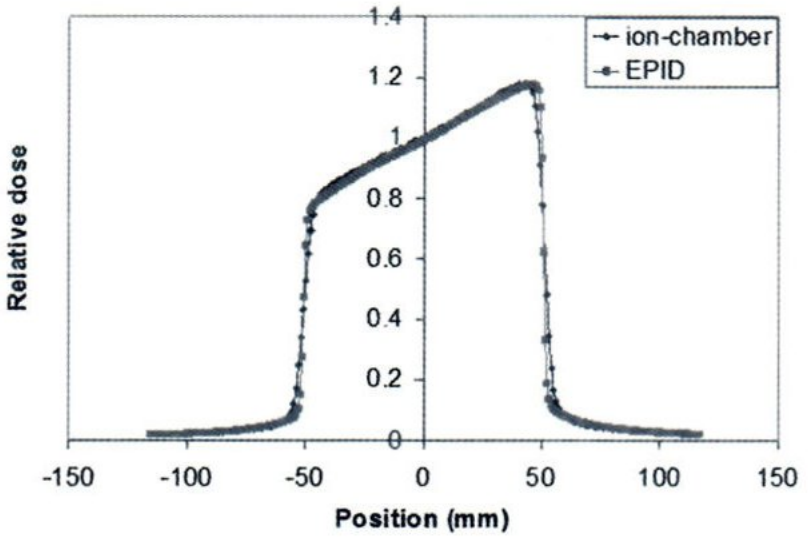


Fig. 8 The comparison of profiles measured by EPID and ion chamber for 10x10 cm^2 of 45^0 wedge.

2.2 IMRT pre-treatment verification

The example of one filed comparison between EPID calculation and EPID measurement in IMRT pre-treatment QA of the nasopharynx plan are shown in figure 9. The absolute isodose distribution showed the agreement of calculation and measurement. The profiles in the direction of MLC in figure10 showed the agreement between EPID calculation and EPID measurement within 3% difference in dose and 3 mm. difference in distance. The verification of 15 IMRT plans which mostly are Nasopharynx plan showed good correlation between measured and calculated.

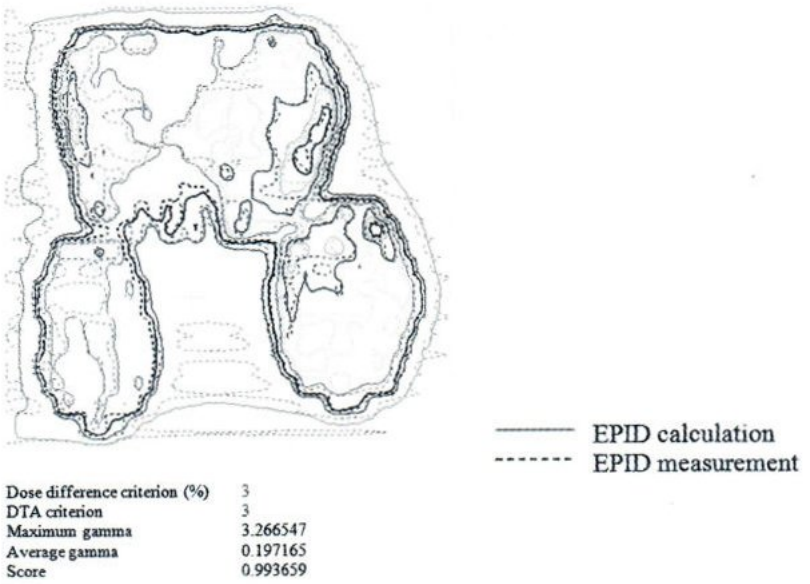


Fig. 9 The comparison of isodose distribution of nasopharynx field EPID calculation and EPID measurement.

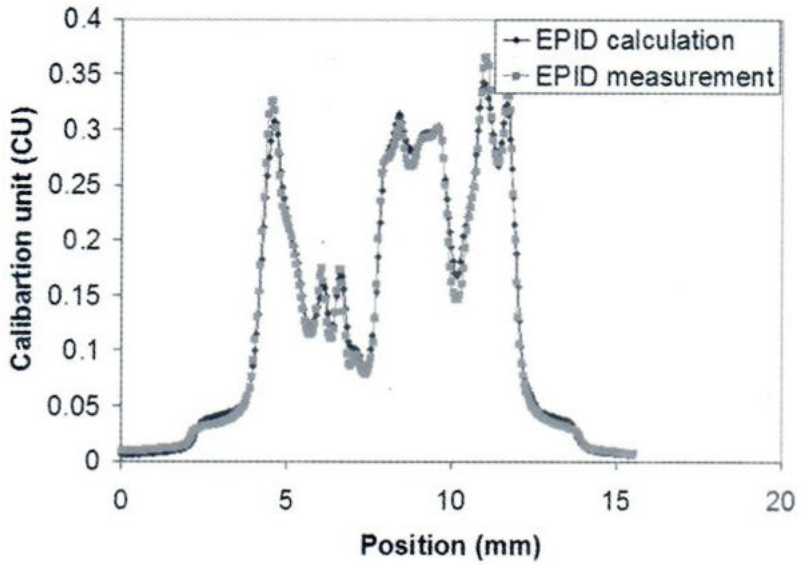


Fig.10 The EPID profile in x direction in a plane as shown in figure 9.

CONCLUSION

The result of dosimetric properties showed that most of the response of EPID are comparable to the response of ion chamber, the only deviation was the field size. This effect was corrected by using field size factor measured by EPID for the predicted dose made by Eclipse treatment planning. The problem of dead time in image acquisition dynamic IMRT delivery was less for IMRT plan used in the clinic due to the high MU of each field. Using EPID as a dosimetry for verification of dynamic IMRT plan showed good result comparable to the film. The process is simple, easy set up and less time consume. However, EPID is limited only for the measurement in air and only at the gantry angle of zero degree.

The research has demonstrated that an understanding of the relationship between pixel value reading and dose or fluence is a prerequisite for portal dosimetry. The EPID is suitable to be used for the IMRT pre-treatment verification. Clinical verification of IMRT plan showed good result with accurate dose measurements.

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