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Original research article

A calibration method for patient specific IMRT QA using a single therapy verification film

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ARTICLE INFO

Article history:
Received 4 November 2012
Received in revised form
1 March 2013
Accepted 15 April 2013

Keywords:
IMRT
EDR 2 film
Patient specific quality assurance
Sensitometric curve

ABSTRACT

Aim: The aim of the present study is to develop and verify the single film calibration procedure used in intensity-modulated radiation therapy (IMRT) quality assurance.
Background: Radiographic films have been regularly used in routine commissioning of treatment modalities and verification of treatment planning system (TPS). The radiation dosimetery based on radiographic films has ability to give absolute two-dimension dose distribution and prefer for the IMRT quality assurance. However, the single therapy verification film gives a quick and significant reliable method for IMRT verification.
Materials and methods: A single extended dose rate (EDR 2) film was used to generate the sensitometric curve of film optical density and radiation dose. EDR 2 film was exposed with nine 6 cm × 6 cm fields of 6 MV photon beam obtained from a medical linear accelerator at 5-cm depth in solid water phantom. The nine regions of single film were exposed with radiation doses raging from 10 to 362 cGy. The actual dose measurements inside the field regions were performed using 0.6 cm^3 ionization chamber. The exposed film was processed after irradiation using a VIDAR film scanner and the value of optical density was noted for each region. Ten IMRT plans of head and neck carcinoma were used for verification using a dynamic IMRT technique, and evaluated using the gamma index method with TPS calculated dose distribution.
Results: Sensitometric curve has been generated using a single film exposed at nine field region to check quantitative dose verifications of IMRT treatments. The radiation scattered factor was observed to decrease exponentially with the increase in the distance from the centre of each field region. The IMRT plans based on calibration curve were verified using the gamma index method and found to be within acceptable criteria.
Conclusion: The single film method proved to be superior to the traditional calibration method and produce fast daily film calibration for highly accurate IMRT verification.

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http://dx.doi.org/10.1016/j.rpor.2013.04.033

1. Background

Intensity-modulated radiotherapy (IMRT) is a highly conformal treatment modality that requires precise dose verification. Due to the increased complexity of IMRT as compared to conventional radiotherapy, various experimental studies related to IMRT dosimetry have been performed.[1–7] The interest in film dosimetry for IMRT quality assurance is due to its ability to give precise two-dimensional absolute dose distributions having spatial resolution in the sub-mill metric range. The uses of radiographic films for IMRT dose verification require a quick and reliable method to generate an accurate dose response curve.[8–11] This reliability depends on a number of contributing errors viz., variations of film manufacturers, day to day variation in processing conditions and energy dependence of radiographic films. Errors due to film-to-film variation and geometrical conditions for film exposure can affect the calibration curve while using multiple films for different doses to generate a single sensitometric curve. In the case of multiple films, the error due to film storage, exposure conditions, film developer and scanner variation can be reduced by generating a calibration curve each day, rather than relying on old calibration curve. Such calibration techniques are at best inefficient, consuming as many as 15 films to generate a film sensitometric curve, and at worst unsuitable for exposure geometry.

On the other hand, the use of a single film can eliminate errors due to film to film variation and scattering response for low energy photons. The advantages of the single film calibration are exposure simplicity, time saving and minimum use of radiographic resources with improved processor quality control. Potential limitations of using single films are over response of film due to low energy photons originating from the penumbra region or edge of MLC treatments fields and significant scatter components resulting from all neighbouring fields. The over response of film with low energy photon can be minimized by using scattering filters and the use of high dose films.[12,13] The use of scatter filtering creates an additional unwanted component resulting from the Compton scattering of high energy photon, which can still expose the film. Response variations of a radiographic film under different exposure conditions are well known.[14] The high dose films are less sensitive to low energy photons and contain less silver halide crystals as compared to low dose films. The reduced effective Z lowers the photoelectric attenuation coefficient of a film; as a result the film responds to photons in a manner similar to tissue. EDR 2 high dose radiographic film has been established an accurate 2D dosimeter for IMRT QA, commissioning of treatment modalities and verification of treatment planning system (TPS).[15–18] The present work reports verification of the commission of patient specific intensity-modulated radiation therapy (IMRT) using a fast and efficient single film calibration method without any scatter filtering. We also investigate the contribution of scatter radiation to primary dose and scatter component on each field region. The present study is to introduce a fast calibration method to measure sensitometric curve using a single radiographic film and its verification in patient specific intensity-modulated radiation therapy (IMRT) quality assurance.

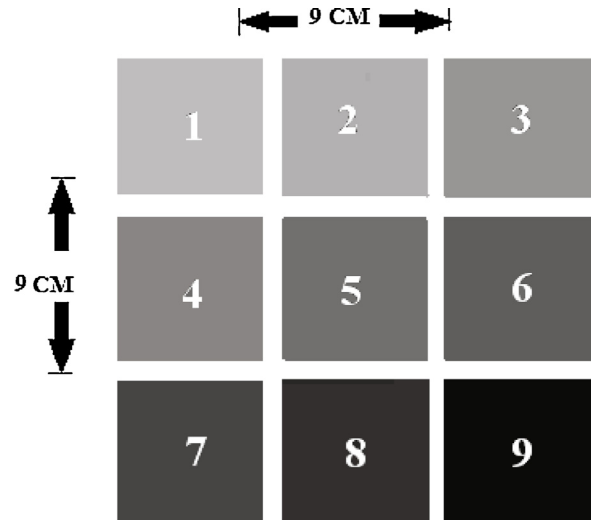

Fig. 1 – Field arrangement for EDR 2 film irradiation and scatter dose measurement.

2. Aim

Aim of the present study is to introduce a fast calibration method to measure sensitometric curve using a single radiographic film for patient specific intensity-modulated radiation therapy (IMRT) quality assurance.

3. Materials and methods

3.1. *Irradiation of EDR2 film*

A single extended dose rate (EDR 2, Radiation Products Design, Inc.) film was used to generate the sensitometric curve. All the nine fields of 6 cm × 6 cm field size with its centre were marked on the envelope of the ready pack EDR 2 film as well as on a white paper with the help of optical field. The centre to centre distance between fields in lateral and perpendicular direction was 9 cm and the distance between two adjacent fields was 3 cm (Fig. 1). The film was kept at 5 cm depth in solid water slab phantom SP34 (Gammex Inc., Middleton, WI) perpendicular to the central axis of the beam with the source to surface distance (SSD) of 100 cm and the paper was fixed on the surface. 10 cm extra margin of solid phantom are placed beneath the depth of dose measurement to provide sufficient backscatter factor. The film was exposed with 9 fields of 6 MV photon beam of Clinac DBX linear accelerator equipped with 80-leaf millennium MLC (Varian Medical System, Palo Alto, USA) using field size of 6 cm × 6 cm with the lateral and longitudinal movement of the treatment couch. The dose range covered by a calibration film was chosen to encompass the dose range typically used with clinical IMRT treatment fields. The doses delivered to each region of the EDR 2 film ranged from 7 to 380 Monitor Units (MU) which corresponds to 10–362 cGy, respectively.

Table 1 – Ion chamber measured data at each field position with all nine fields irradiated.

Field positions	MUs delivered	Dose/MU (cGy)	$D_{primary}$ (cGy)	$D_{scatter}$ (cGy)	D_{total} (cGy)	Optical density (OD)
1	7	0.9350	6.55	3.852	10.40	0.190
2	12	0.0085	11.22	5.187	16.41	0.220
3	60	0.0031	56.10	4.707	60.81	0.429
4	120	0.0085	112.20	6.428	118.63	0.778
5	170	0.0035	158.95	8.535	167.48	1.052
6	230	0.0013	215.05	7.180	222.23	1.398
7	280	0.0031	261.80	6.092	267.89	1.680
8	340	0.0013	317.90	8.412	326.31	1.963
9	380	0.0008	355.30	6.691	361.99	2.143

3.2. *Scattered dose measurement*

The primary and scattered absorbed dose measurements were performed using a 0.6 cm^3 thimble ionization chamber (PTW, Freigburg, Germany). The ion chamber was placed in a predrilled cavity at the midpoint of a 2 cm thick solid water slab. The dose measurements were performed with an additional 4 cm water slab produce buildup and sufficient attenuation. The field arrangement was kept identical as used for film irradiation. Daily machine output fluctuation was recorded based on measurements at the central axis of a 10 cm × 10 cm field with an ion chamber at 10 cm depth.

The primary and scattered doses at the centre of each individual field along the lateral and perpendicular directions from field number 1 (No. 1) were measured with ionization chamber. The radiation exposure due to accumulated scattered doses plus the primary radiation dose for each field were calculated using the relation

$$D_i = D_{pi} + \sum_{j=1}^{N} F_{ij} \cdot D_j \quad (1)$$

where D_i is the dose at *i*th field contributed by both primary radiation beam and scattered radiation from other fields and F_{ij} is the scattered factor on *i*th Field from *j*th field. D_j is the primary radiation dose delivered by *j*th field.

3.3. *Calibration of film*

The duly developed film was scanned at 300 dpi resolution in VIDAR film scanner (VXR-16 Dosimetry PRO plus, Vidar Systems Corp., Herndon) for the measurement of optical density (OD). The value of OD obtained from each exposed region was plotted against the effective doses contributed by primary radiation dose delivered from 7 to 380 MUs plus accumulated scattered dose from different 9 fields to generate the sensitometric curve.

The sensitometric curve was repeated for four dates and found at a very good agreement with the mean standard deviation of 0.48%. The generated sensitometric curve was used for IMRT patient specific QA to verify the measured and treatment planning system (TPS) calculated dose distribution of the IMRT fields.

3.4. *Verification of IMRT*

Ten IMRT plans for the treatment of head and neck carcinoma using dynamic IMRT technique of 7 fields of 6 MV photon beam were considered in this study. Three-dimensional treatment planning system Eclipse version 8.6 (Varian Medical Systems Inc., Palo Alto, CA) with inverse plan optimization was used in making the treatment plans. The optimal fluence profiles calculated by inverse plan optimization produce MLC motion patterns with the help of a computerized program to control the leaf motion. The dose calculation was done using pencil beam convolution (PBC) algorithm incorporated in the 3D-TPS. The patient specific hybrid IMRT verification plan was created in a solid water slab phantom using the same radiation fluence of each plan. The verification plan was executed on linear accelerator using 4 dimensional treatment console (4DTC) version 8.6 (Varian Medical Systems Inc., Palo Alto, CA). All the systems were networked through ARIA (Varian Medical Systems Inc., Palo Alto, CA) networking system. Gamma (γ) evaluation method was used to compare the planned dose distribution in TPS and delivered dose distribution.[15] Gamma method is useful in measuring distance to agreement (DTA) in a high gradient region, and sensitive to dose differences between calculated and delivered plan. The value of γ calculated by OmniPro I'mRT software was used for plan acceptance criteria of dose difference of 3% and distance to dose agreement (DTA) of 3 mm. The plan was accepted only if more than 95% pixels had the value of $\gamma \leq 1$ in planned active area.

4. Results and discussion

The irradiation of nine square field regions of single EDR 2 film was performed in less than 10 min. Childress et al.[8] reported the single film calibration method using two field step and shoot MLC treatment. However, the MLC driven step and shoot technique leads to a significant leakage factor and scatter radiation component from MLC. Later on, Kulasekere et al.[9] used the same method to irradiate eight field patterns on a single film using jaws plus MLC motion. The use of jaws plus MLC reduces the scatter and transmission component over the MLC driven technique. In our work, the same technique was used to irradiate nine square fields of 6 cm × 6 cm on a single film with X and Y jaws of medical linear accelerator. The method of irradiation with jaws only completely eliminates the MLC radiation leakage factor. The earlier measurements were performed by irradiating the field at the off axis regions

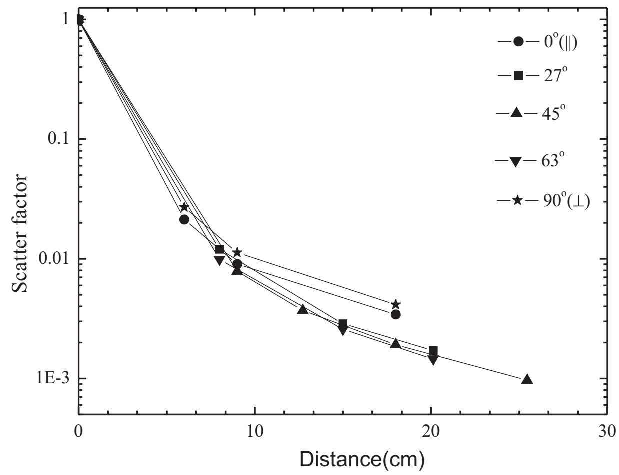

Fig. 2 – Variation of scatter factor with different angles from field region 1 (0° and 90° positions represent the parallel and perpendicular positioning of cylindrical ion-chamber along the direction of dose measurement respectively).

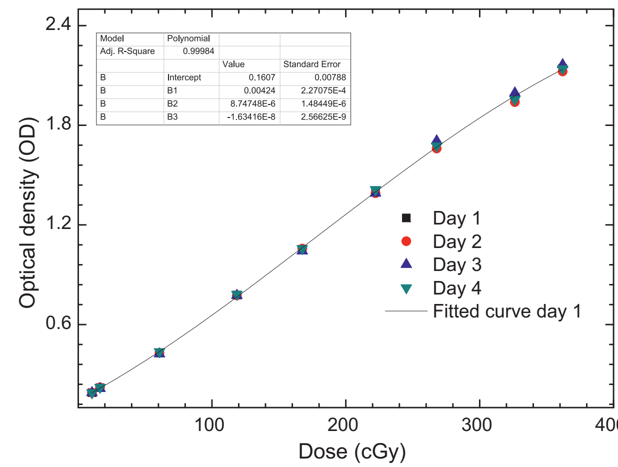

Fig. 3 – Sensitometric curves generated on four dates, using EDR2 film. The line is third order polynomial fit of Day 1 data.

with respect to the central axis of the beam profile. However, in the present method the film exposure was done on the central axis of the field with the use of lateral and longitudinal movement of the treatment couch. The present method is found to be less error prone and significantly reduces the error due to field geometry. Table 1 shows the ion chamber measured data at each field position with all nine fields irradiated to calculate the absorbed dose contributed from the corresponding monitor units (MU) delivered to each field. The value of optical density corresponding to each region was also given in Table 1.

The contributions of scatter doses in each field region from the other irradiated field regions were estimated using the scatter factors shown in Fig. 2. Fig. 2 shows the variation of scattered doses received by each field

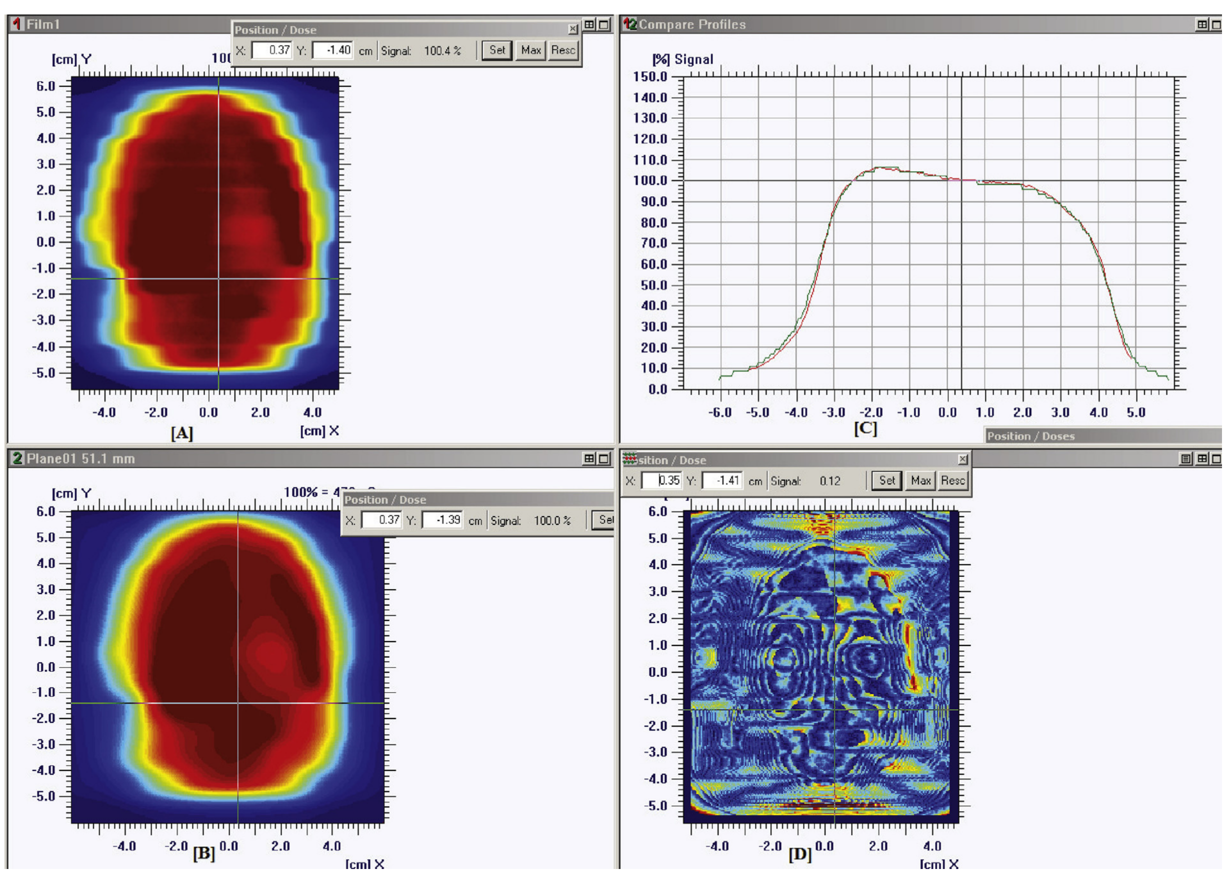

Fig. 4 – Plan verification for a typical IMRT plan using for EDR 2 film.

region from the primary irradiated field region 1 in lateral, perpendicular and other directions. There scattering factor decreases exponentially as a function of distance from the field centre due to the decrease of side scattered radiation from the field edge. It has been noticed that the value of scatter factor is approximately the same along parallel and perpendicular directions for all regions at the same distances from the primary irradiated region. The value of parallel positioning of ion-chamber is lower than that of perpendicular positioning, the differences ranging from 0.0057 to 0.00071 as a function of distance from the centre of primary radiation exposure using 6 cm × 6 cm. This is due to the orientation of chamber and a little effect produced by upper and lower jaws scattering. It was noticed that in the case of radiation exposure to region 1, the amount of scattered radiation dose at regions 2 and 4, regions 7 and 3, and regions 8 and 6 were the same, respectively. The same results were found for the other primary field regions.

The measured OD values of the calibrated EDR2 film were plotted against dose values to obtain sensitometric curve (Fig. 3). The third order fitted polynomial equation for the sensitometric curve is

$$\text{Dose}\quad(\text{cGy}) = b_o + b_1 x + b_2 x^2 + b_3 x^3 \tag{2}$$

where $b_o = 0.1607$, $b_1 = 0.00424$, $b_2 = 8.74748 \times 10^{-6}$, $b_3 = -1.63416 \times 10^{-8}$ and x is value of optical density. The calibration curve generated from the film data analysis was used by OmniPro I'mRT software to compare the measured dose from film with the corresponding treatment planning data. The patient-specific IMRT QA has been performed to ensure the accuracy of treatment planning. For this, ten IMRT plans with 6 MV photon beam were evaluated using the gamma index method with TPS calculated dose distribution to find an average of 97.86% pixel population and ranging from 95.53 to 99.57% passed for $\gamma < 1$ with standard deviation of 1.57%. Fig. 4a and b shows the coronal dose distribution for film and TPS calculated, respectively. Fig. 4c shows dose profiles along the X direction, where red and green profiles are film measured and TPS calculated, respectively, and Fig. 4d shows the gamma analysis of 3% delta dose and 3 mm distance to agreement (DTA).

5. Conclusion

This method eliminates the scattering and leakage contribution through MLC and provides a solution to reduce many film errors while using a single film and multiple fields for the creation of calibration curve each day, rather than relying on old calibrations or attempting to scale a standard curve. This method minimizes errors due to film storage, exposure conditions, film developer, and scanner variations. The daily production of a sensitometric curve requires a quick way to accurately generate different known exposures on film so that labour costs can be minimized. The high reproducibility, low error, quick delivery time and ease of use of the calibration method show that the single film calibration method is superior to previous procedures. It allows fast daily calibrations of films for highly accurate IMRT verification. It is further recommended that EDR2 film can be used clinically due to its near tissue equivalent response to low-energy photons.

Conflict of interest

No conflict of interest.

Financial disclosure

The funding sources had no involvement for the conduct of the research and/or preparation of the article, analysis and interpretation of data.

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