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Measurement of the sensitometric curves of Kodak EDR2 and X-Omat V films using Enhanced Dynamic Wedges and Dynamic Multileaf Collimators

Krzysztof Chełmiński, Joanna Rostkowska, Małgorzata Kania, Wojciech Bulski, Barbara Gwiazdowska

Department of Medical Physics, Maria Skłodowska-Curie Memorial Cancer Centre and Institute of Oncology, Warsaw, Poland

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Summary

Background Modern linear accelerators, used in oncological radiotherapy, are often equipped with a dynamic wedge option and dynamic multileaf collimators. For linacs having these options, measurements of absorbed dose distribution require complete movement of the jaw, or of the dynamic multileaf collimator, for each measurement point. In conformal radiotherapy, three or more beams, modified by dynamic accessories, are combined to produce a summarized dose distribution.

Aim This study is an investigation of the use of film as a detector of dose distribution produced by a single beam, or by a pair of beams modified by dynamic accessories, in phantoms.

Materials/Methods Measurements of the sensitometric curve of the recently introduced EDR2 (extended dose range) and extensively used X-Omat V radiographic films were performed. Films were irradiated using a Clinac 2300 C/D Varian™ accelerator, equipped with dMLC (dynamic multileaf collimator) and EDW (enhanced dynamic wedge) options. The recorded wedge dose distribution created by the EDW and by programmed dMLC movement were used to obtain response curves of the films. Solid Water™ 457 blocks, manufactured by Gammex RMI, were used as phantoms, in which the films were irradiated.

Results Measurement and verification of dose distributions created by beams modified by dynamic accessories can be performed using both EDR2 and X-Omat V radiographic films. The EDR2 low sensitivity films are suitable for measurements of total dose distribution, as created by a number of dynamically modulated beams. High sensitivity X-Omat V films are more suited to verification of energy flow, or of the dose distribution generated by single fields, modified by dynamic accessories.

Conclusions The presented methods for the measurement of sensitometric curves may be applied in the routine calibration of film dosimetry chains for IMRT plan verification.

Key words **film dosimetry • dynamic multileaf collimator • Enhanced Dynamic Wedges • EDR2 film • X-Omat V film**

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Author's address: Krzysztof Chełmiński, Department of Medical Physics, Maria Skłodowska-Curie Memorial Cancer Centre and Institute of Oncology, Roentgena 5 Str., 02-781 Warsaw, Poland, e-mail: kchelm@rth.coi.waw.pl

Background

The use of radiation fields modulated by dynamic multileaf collimators (dMLC) is a current technology in radiotherapy. There are associated problems with the dosimetric verification of fields and plans when the radiation dose is distributed through time. The role of ionization chambers and other point dose detectors is thus reduced. Dosimetry films appear to be useful tools for the measurement of dose distributions in beams created by dynamic wedges (DW) or by dMLC.

A number of studies have been performed investigating the sensitometric curves of Kodak X-Omat V and EDR2 films. As reported by Danciu et al. [1] many groups have focused on studying the influence of different parameters on the sensitometric curve; such as the delivered dose, the proton beam energy, film plane orientation relative to the beam axis, depth in the phantom etc. Methods for measurement of the sensitometric curve were based on irradiating several films with single open square fields [1–5]. Ju et al. [6] measured the sensitometric curve using this method of film dosimetry for step-and-shoot IMRT. Much work was required to irradiate the films and to process them. For IMRT QA, Olch [7] proposed a method for irradiating the calibration film with four open square fields positioned at each corner of the film. As he reported, each measured dose has to be corrected for dose contributions from the irradiation of each of the corners. In IMRT verification, Nathan et al. [8] used step-and-shoot programmed MLC fields in order to deliver eight squares of differing doses to a single film. True dose measurements were performed by positioning an ion chamber at each individual square.

Aim

The aim of this paper was to investigate the use of films as a detector of dose distribution produced by a single beam, or by pair of beams modified by dynamic accesories in phantoms. The method for measurement of sensitometric curves proposed in this paper was evaluated and tested for plan verification in intensity modulated radiotherapy (IMRT).

Materials and Methods

Linear accelerator

A Clinac 2300 C/D linear accelerator from Varian Medical Systems, Inc. Paolo Alto, California, with two photon energy modes (6MV and 15MV) was used as a beam generator for the irradiation of films. The Source-Axis Distance (SAD) of the accelerator was 100 cm.

The Enhanced Dynamic Wedge (EDW) option for photon beams was enabled on the accelerator. There were 7 angles of 10°, 15°, 20°, 25°, 30°, 45° and 60° available on the Clinac 2300 C/D unit. The accelerator was equipped with a Varian Millennium dynamic multileaf collimator consisting of 40 leaf pairs. The physical width of a single leaf pair and the distance between the upper MLC surface and the beam source were correlated, in order to obtain a beam shadow 1 cm in width at the SAD, due to divergence of the beam. The movement of each leaf pair in the dMLC collimator could be programmed separately.

Enhanced Dynamic Wedge

An Enhanced Dynamic Wedge with a maximum wedge angle value of 60° was used to achieve the largest possible range for the dose deposited in the film during a single radiation shot. For a 15MV photon beam, modified with a 60° EDW, a continuous dose range of 10%–100% of the maximum dose detected under the slender "thin" end of the wedge was achieved. For a 6MV photon beam, the range was 13%–100% of the maximum dose. The EDW was established by moving the jaw of the collimator. Therefore, there is no beam hardening effect. Variation of the dark-level, owing to possible energy dependence of the sensitivity of the film, was thus avoided.

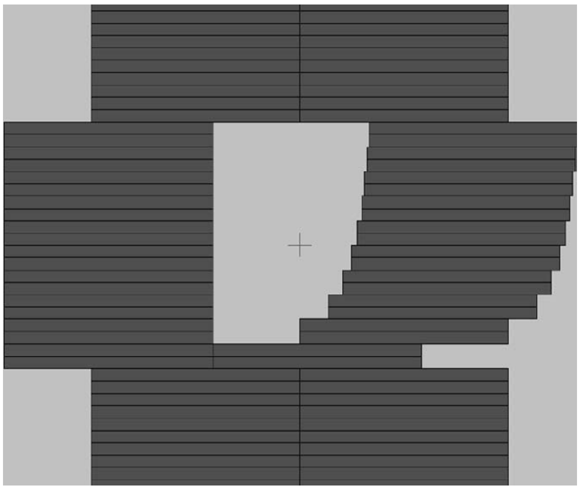

Figure 1. The Shaper software allows for the programming of dMLC motion. This image presents an example position of leaf pairs from a total of 21 positions programmed for a dMLC step wedge with a field size of 15×20 cm^2.

Step wedge

The dMLC step wedge was programmed and saved to a file using Varian MLC Shaper software. The programmed dMLC sequence (Figure 1) allowed the attainment of several grey levels (Figure 2) on a single film irradiated by a single radiation shot. Programmed dMLC motion was imported from the file by Clinac MLC Millennium Workstation control software. During delivery of the radiation, the leaf pairs were moved according to the programmed sequence, affecting the beam flow. The programmed movement of the leaves was intended to achieve dynamic intensity modulation, giving 10 dose levels. Each dose level was created by the movement of 2 leaf pairs. Hence, a step wedge dose distribution was recorded on films placed between Solid Water slabs, perpendicular to the beam axis.

Films

Two dosimetry film types were investigated – the widely used Kodak X-Omat V film and the newly available Kodak EDR2 low sensitivity dosimetric film. The films were available in factory envelopes and could therefore be placed into phantoms without use of a dark room. X-Omat V high sensitivity films are frequently used in the verification of patient positioning for radiotherapy. The intended use of the films is to obtain images depicting the position of the patient and the positions of internal organs and bones relative to the beam axis and field shape at the time of irradiation. For this purpose, high sensitivity is required in order to minimize the dose received by the patient during

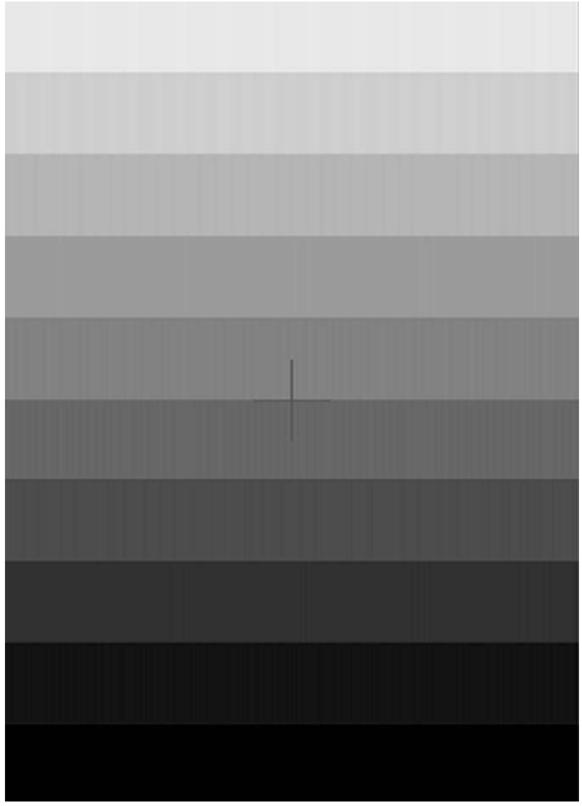

Figure 2. Simulated image of a film with 10 discrete OD levels. The image was generated by MLC Shaper software for a field of size 15×20 cm^2 modulated by a programmed dMLC step wedge.

position verification. This is important because verification is frequently performed using fields which are different from the therapeutic fields. Kodak EDR2 films, on the contrary, are used as dosimetric verification tools. In this case, low sensitivity is required in order to record the dose distribution in a phantom gained from superimposition of several fields. Figure 3 depicts the measured sensitometric curves for chosen films.

Solid Water phantom

Slabs of Solid Water™457 (Gammex RMI) material 20×20×5 cm^3 in size were used as a phantom. The thickness of the slabs allowed for irradiation of the films at a depth of 5 cm or of 10 cm. Full scatter conditions were assured by 5 cm of PMMA material, which was placed under the film.

Film processor

The irradiated films were processed in a Protec 45 Compact film processor. The processor features automatic regeneration of developing and fixing solutions. After processing a few square meters of a film, a small amount of fresh developer and

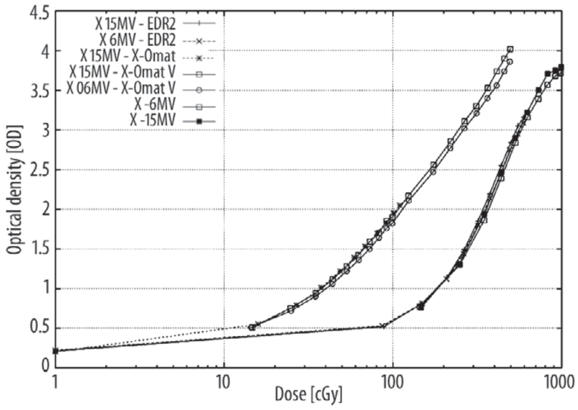

Figure 3. In this plot, absolute OD versus absorbed dose is presented. The symbols represent measured data for discreet levels along the lines, representing linear interpolation. The measurement data were obtained by modulation of a 16×20 cm^2 field with a dMLC step wedge.

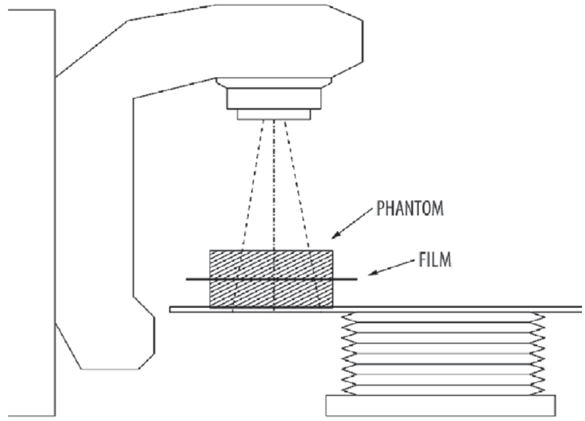

Figure 4. The film was placed between Solid Water slabs placed on the therapeutic table, perpendicular to the beam axis.

fixer is added to replenish used reagents. The processor is routinely used for the processing of check films. Thus, the temperature of chemical reagents and the times for developing and fixing were set to optimal conditions for diagnostics films. The processor was filled with Agfa G138i developer and Agfa G334i fixer.

Film digitizer

For digital processing and analysis of film images, scanning and digitization was required. A Vidar VXR-16 Dosimetry Pro digitizer was used. The scanner enables the storage of digital image data in the Tagged Image File Format (TIFF) with 8 or 16 bit resolution, giving 2^8 or 2^{16} grey levels respectively. The higher bit resolution was chosen for scanning and processing in order to achieve the highest possible precision of the readout. The scanner can digitize with a spatial resolution of 72,150, and 300 dots per inch (dpi). Only the lowest spatial resolution mode was used in order to smooth and minimize fluctuations in the readout and to maximize the signal-to-noise ratio (SNR) [9].

Densitometer

A Victoreen Nuclear Association Model 07–443 densitometer was used to measure the absolute optical density (OD) of the irradiated and developed films. The densitometer was calibrated against the factory Quality Control Step Tablet – a step wedge of known absolute optical density.

Water phantom

Relative and absolute measurements of the dose were performed in a commercially available water phantom (type MP3 – PTW–Freiburg). The water tank was equipped with a fixing frame to which an ionization chamber or an array of chambers was mounted. The set of step engines moving the frame allowed for precise and reproducible positioning of the detectors.

Ionization chamber

For absolute dose measurements, a graphite ionization chamber (type NE–2571 NE–Technology) with a sensitivity volume of 0.6 ccm was selected.

Array of ionization chambers

For accurate determination of relative dose distributions created by dynamically modulated fields, an LA48 ionization chamber linear array (PTW–Freiburg) was used. LA48 consists of 48 ionization chambers set one by one along an aluminium bar. Neighbouring chambers are spaced about 8 mm apart. The off-axis profiles were collected by an LA48 submerged in the water phantom. A measurement resolution of 2 mm was achieved by applying computer-controlled movement of the frame to which the array was mounted. The measuring geometry range was also extended by shifting the array during the measurement session. The data from all chambers was acquired

Figure 5. An example image of EDR2 film with 10 discrete OD levels. The film was irradiated using a single X-15MV field of size 15×20 cm² modulated with a programmed dMLC step wedge.

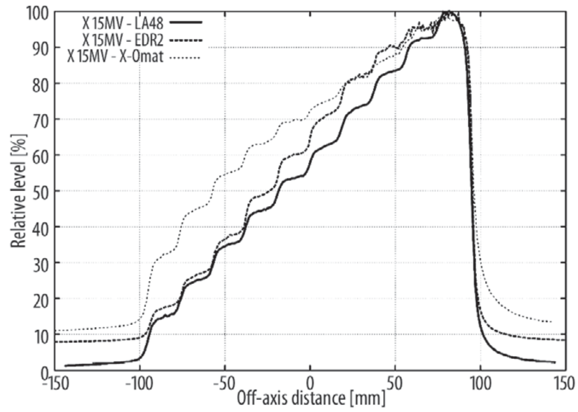

Figure 6. An example of off-axis relative profiles for 15MV X-ray beams, obtained from the EDR2 and X-Omat films and measured by an LA48 array. A field size of 15×20 cm² was modulated using a step wedge dMLC. The detectors were placed 100 cm from the beam source at a depth of 5 cm.

simultaneously while the beam was on. Prior to measurement, each ionization chamber from the linear array was calibrated using a reference ionization chamber (see Section Ionization chamber).

Geometry of the measurements

Both films and ionization chambers were irradiated using the same geometrical parameters. The source to phantom surface distance was set to SPD=90 cm while the collimator and the gantry rotation angle were set to 0°. The film was placed under the Solid Water slabs, perpendicular to the beam axis (Figure 4). The depth at which the film was placed depended on the thickness of Solid Water slabs. Hence, measurements using the film were performed at two fixed depths, that is d_1=5 cm for the dMLC step wedge and d_2=10 cm for the EDW. Each film was placed on a 5 cm thick layer of the PMMA material to provide for the dose from back-scattered photons. Since each film was packed in a factory envelope which was not transparent to visible light, geometric settings and film positioning were possible using room lighting. Irradiation of the film, parallel to the beam axis, was made possible by rotating the gantry to a 90° position. Gravity assured sufficient pressure of the phantom slabs and removed air from the film-phantom gaps.

The position of the field axis was reconstructed from marks on the film. Marks (small black dots) – appeared after film processing in places where small holes had been made in the envelopes with a sharp needle.

The measurements of dosage at selected points were performed using the same geometry as for the relative measurements of the off-axis profiles using the LA-48 array. The geometrical position of the chamber was determined on the off-axis profiles; the absolute dose profile was thus obtained.

Post-processing – obtaining the sensitometric curve

The sensitometric curve of the recently introduced EDR2 (extended dose range) and extensively used X-Omat V radiographic films were examined. In order to read the pixel values from the scanned images, FilmCall and Mefysto software (PTW-Freiburg) were used. FilmCall software allowed for the probing of a set of pixel values at selected points and for assigning the probed values to measured dose levels. The pixel values for selected grey levels were relative and dependent on the bit resolution set on the scanner. In this study, a set of 10 points was probed from the image (Figure 5) produced by irradiating the film with a beam modulated by dMLC. The Mefysto software allowed for the probing of relative point dose levels from the dose profiles measured by the LA48 array, in the direction perpendicular to the moving leaf pairs. In our study, a set of 10 point dose

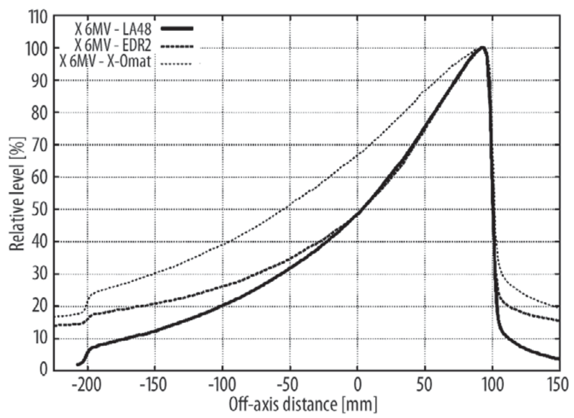

Figure 7. An example of off-axis relative profiles for 15MV X-ray beams, obtained from the EDR2 and X-Omat films and measured by an LA48 array. An asymmetric field of size 15×30 cm^2 was modified by the EDW. The detectors were placed 100 cm from the beam source at a depth of 10 cm.

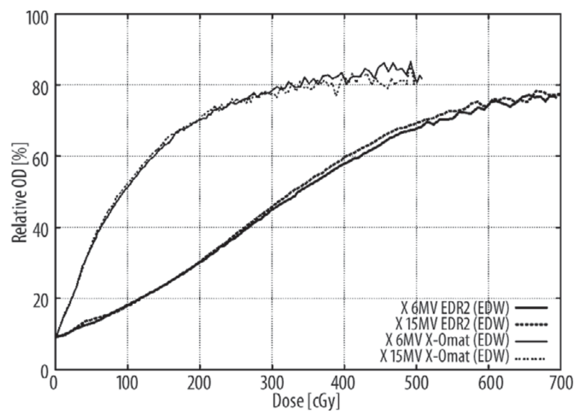

Figure 9. In this plot, relative OD versus absorbed dose is presented. The solid and dotted lines represent semi-continuous data obtained by modulation of the [Trial mode] field with the EDW for X6 MV and X15 MV beams, respectively. The thick lines show the sensitometric curves for the EDR2 film while the thin lines represents data obtained for the X-Omat V film.

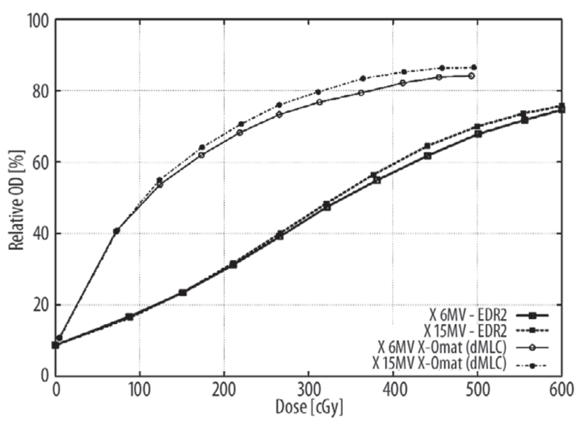

Figure 8. In this plot, relative OD versus absorbed dose is presented. The symbols represent measured data for discreet levels along the lines representing linear interpolation. The measuring data were obtained by modulation of a 16×20 cm^2 field with a dMLC step wedge.

levels was probed from the measured relative step wedge profile (Figure 6). The absolute dose values for probed points were calculated from a single measurement of the absolute dose, performed using a reference ionization chamber placed at the centre of one of the selected dose levels. Absolute measurement was performed using the same geometry as the relative measurement.

In the case of film irradiated with a beam modified by EDW, a single central grey level was probed, from the point where the beam axis crossed the film layer. This point was easy to locate thanks to marks made on the film during positioning. Subsequently, the off-axis profile (parallel to the direction of jaw movement) was read by the Mefysto software, from the scanned image, with the probing step set to 2 mm. After normalization and multiplication by a single central grey level, the grey level profile was calculated using values from the range set by FilmCall. The sensitometric curves of the films were reconstructed from the film grey-level profile and from the measured dose profile (Figure 7). The dose profile points were related to the film profile points by their spatial positions.

Results

Sensitometric curves were obtained from the dose and film profiles generated either by use of the dMLC step wedge or EDW.

The discrete sensitometric characteristics presented in Figure 8 were obtained using films irradiated by the dMLC step wedge. Single point doses and the corresponding OD values were probed for each of 10 dose levels (Figures 5,6). The symbols represent data measured at two energies with EDR-2 (rectangles) and X-Omat V (circles). The linear interpolation between the measured data is depicted with solid and dotted lines.

In Figure 9, thick and thin lines represent semi-continuous sensitometric curves obtained using

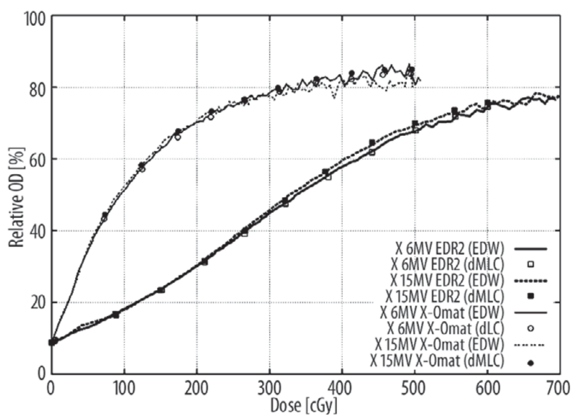

Figure 10. In this plot, relative OD versus absorbed dose is presented. The symbols represent measured data for discreet levels obtained by modulation of the [Trial mode] field with a dMLC step wedge. The lines represent semi-continuous data obtained by modulation of the [Trial mode] field with the EDW.

the EDW for EDR-2 and X-Omat V respectively. For EDW fields the dose levels and the film OD were measured with a spatial resolution of 2 mm. Hence, for the 60° EDW, the dose data (horizontal scale) were obtained with a resolution of around 2cGy and for the OD data (vertical scale) with a resolution of approximately 0.3%.

A total of 2^{16} (65536) grey levels, as separated by a 16 bit resolution scanner, was assumed to be a normalization factor of relative OD for the vertical coordinates in Figures 8–10.

In Figure 10, compatibility may be seen between the characteristics obtained using the dMLC step wedge method and the method with the EDW (see Sections: Enhanced Dynamic Wedge, Step wedge).

It was observed that for higher OD recorded on the film, the Vidar digitizer introduces noise which significantly affects the pixel value readout above 65% of the 16 bit range (see Figure 10).

Discussion

It is important to note that the sensitometric curves which have been assessed with the proposed methods are not absolute. The shape of the curves may vary due to the use of different chemical reagents or the use of different types of film processors. Also, the type and model of the scanner used in the examination may affect the final shape of the characteristics curve. The characteristics may also vary if the condition of the film processor changes or the scanner light source wears out. Because of these factors, the measurement of the sensitometric curve has to be done each time the dosimetric verification of IMRT plans is performed. Both of the proposed methods require irradiating and developing a single calibration film together with films irradiated in an IMRT verification phantom. Absolute measurements of the true dose in water under the dMLC step wedge or the EDW may be performed only once. For future correction of the true dose profiles, only the output of the accelerator has to be checked when the films are irradiated.

The experiences gained during verification showed that the calibration of film dosimetry procedures requires adds to the workload and that this must be included in the overall time required for dose distribution measurements. Therefore, a rapid and simple film calibration method is required. Also, the number of films used during assessment of the sensitometric curve needs to be minimized.

The significant noise introduced by the Vidar digitizer above the OD=2 value was also reported by Merseeman and De Wagter [9]. It may be clearly seen from Figure 10 that the influence of the digitization noise can be detected using the measurement method from which the high resolution data are obtained.

Conclusions

The results show that the proposed methods for the measurement of sensitometric curves are proper for the films tested. The calibration of the film dosimetry chain, including the film itself, the film processor, the scanner and the image analysis software may be achieved in this way. Hence, errors due to changes in the film dosimetry chain are eliminated. This ensures that the highest possible accuracy is achieved from the equipment. On this basis, a reliable verification of IMRT plans is possible with film processors used for developing routine position check films in Radiotherapy Departments. For the scanning of films, a bit resolution of 12 or 16 bits is advised. The higher the bit resolution, the more grey levels the scanner can separate, leading to higher accuracy of the calibration and of the dose assessment. It is important to evaluate the digitizer SNR for different OD. The discussed method, using the EDW, can be applied in the assessment of the level of the noise introduced by digitizers and for selecting the OD range for which the introduced noise level is acceptable. The method using the EDW clearly shows the range of doses (approximately below 450cGy for EDR2 and 150cGy for X-Omat V) for which the Vidar digitizer can be used. The noise influence is hardly detectable when measuring the sensitometric curve using the dMLC method.

Measurements and verifications of dose distributions created by beams modified by dynamic accessories can be performed using both EDR2 and X-Omat V radiographic films. The EDR2 low sensitivity films are suitable for measurements of total dose distribution created by a number of dynamically modulated beams. High sensitivity X-Omat V films are better suited to the verification of the energy flow or of the dose distribution generated by single fields, modified by dynamic accessories.

The results shows that the tested film calibration methods can be applied for both EDR2 and X-Omat V films.

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