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NOTE

The value of EDR2 film dosimetry in compensator-based intensity modulated radiation therapy

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Abstract

Radiographic or silver halide film is a well-established 2D dosimeter with an unquestioned spatial resolution. But its higher sensitivity to low-energy photons has to be taken into consideration. Metal compensators or physical modulators to deliver intensity modulated radiation therapy (IMRT) are known to change the beam energy spectrum and to produce scattered photons and contaminating electrons. Therefore the reliability of film dosimetry in compensator-based IMRT might be questioned. Conflicting data have been reported in the literature. This uncertainty about the validity of film dosimetry in compensator-based IMRT triggered us to conduct this study. First, the effect of MCP-96 compensators of varying thickness on the depth dose characteristics was investigated using a diamond detector which has a uniform energy response. A beam hardening effect was observed at 6 MV that resulted in a depth dose increase that remained below 2% at 20 cm depth. At 25 MV, in contrast, beam softening produced a dose decrease of up to 5% at the same depth. Second, dose was measured at depth using EDR2 film in perpendicular orientation to both 6 MV and 25 MV beams for different compensator thicknesses. A film dose underresponse of 1.1% was found for a 30 mm thick block in a 25 MV beam, which realized a transmission factor of 0.243. The effect induced by the compensators is higher than the experimental error but still within the accepted overall uncertainty of film dosimetry in clinical IMRT QA. With radiographic film as an affordable QA tool, the physical compensator remains a low threshold technique to deliver IMRT.

(Some figures in this article are in colour only in the electronic version)

1. Introduction

Physical compensators have been used for many years to produce a uniform dose at depth by compensating the variations in radiological depth. Compensators can also be used as dose optimization filters (Boyer *et al* 2001) to produce specific non-uniform intensity modulations. The use of compensators in IMRT was initially suggested by Brahme (1988). But compensators have a cumbersome and time-consuming manufacturing process and have to be changed for each gantry orientation. Since 1995, the mainstream was to replace them by MLCs. Webb (2005) described the metal compensator as 'the Cinderella of IMRT, somewhat overlooked but still with much potential'. The compensator has indeed multiple advantages, including higher resolution in the direction normal to the MLC leaf motion and no matchline nor tongue-and-groove problems. A related advantage of compensator-based IMRT is that all parts of the field are irradiated simultaneously and thus minimizing problems of patient movement. Furthermore, as long as the minimum thickness of the compensator is zero, the use of a compensator is extremely monitor-unit (MU) efficient (Williams 2003). Chang *et al* (2000) reported a higher performance of compensators in the clinic than both static and dynamic MLC techniques because of their higher and continuous intensity modulated resolution. Further pros of compensators were formulated by Sherouse (2002). Compensator-based IMRT can serve as an intermediate step, as was the case in our institution during 1993–1994, before more automated approaches to IMRT are adopted (Intensity Modulated Radiation Therapy Collaborative Working Group 2001).

Compensator-based IMRT has been clinically implemented for breast cancer (Chang *et al* 1999, Baird *et al* 2001) and head-and-neck cancer (Salz *et al* 2005, Nangia *et al* 2006). The main practical advantage of compensator-based IMRT is the short treatment delivery time, dose computation and its quality assurance procedure (Chang *et al* 1999, 2004). Radiographic film has been an important 2D dosimetric tool in the quality assurance of compensator fabrication (Baird *et al* 2001) and compensator-based IMRT (Nangia *et al* 2006). Geis *et al* (1996) used film dosimetry to compare dose distributions at a specified depth from a physical metal compensator and from the dynamic MLC that mimicked the modulation produced by the compensator. Computational methods for compensators have been validated with film dosimetry and Monte Carlo (Spezi *et al* 2001, Mejaddem *et al* 2001). Notwithstanding these positive reports, Salz *et al* (2005) and Wiezorek *et al* (2005) recently reported that film response may show deviations as high as 5% between small (3–4 mm) and large (30–35 mm) compensator thicknesses. This and other literature vaguely suggest hardening effects of the primary beam and the generation of scattered radiation and contaminating electrons as possible causes of the alleged film dosimetry artifacts. This uncertainty triggered us to start this study.

2. Material and methods

The compensator blocks were manufactured from MCP-96 alloy (15.5% tin, 52.5% bismuth, 32.0% lead and by weight, with density of 9.72 g cm^{-3}). They were mounted in both 6 MV and 25 MV photon beams from an Elekta SL25 accelerator (Elekta, Crawley, UK) on the blocking tray at 67.2 cm distance from the x-ray target. The tray holder contained a 1.5 cm and 1.2 cm thick Perspex plate downstream and upstream of the block, respectively.

The transmission factors of the 10, 20, 30 and 50 mm thick blocks were determined using a 0.6 cm^3 Farmer-type ionization chamber (TM30001, PTW) in combination with a Unidos electrometer (PTW, Freiburg, Germany). The chamber was positioned in a polystyrene (Polystyrol 495F, BASF, Germany) slab phantom (30 × 50 × 20 cm^3).

In order to assess possible effects of beam hardening, radiation scattering or electron contamination, relative depth dose curves were recorded in an automated water phantom system (MP3, PTW, Freiburg, Germany) by using a scanning diamond detector (T60003, serial no. 994582, PTW, Freiburg, Germany) for an open beam and beams containing the plain block tray, 10 mm, 20 mm, 30 mm and 50 mm thick blocks. The field size was 10 cm × 10 cm, and the SSD (source to surface distance) was 95 cm and 90 cm for 6 MV and 25 MV, respectively. The diamond detector is known to be energy independent for megavoltage photon beams. As the dose-rate dependence of the particular diamond detector was low, with a dose-rate exponent of 0.9927 in the power law that corrects for dose rate (Laub *et al* 1997), and as the objective was comparing only diamond-detector measured curves, no dose-rate correction was applied. The water phantom itself was provided with a monitor signal that was proportional to the instantaneous accelerator delivery rate, allowing us to link consecutive measurements and to compensate for fluctuations in the output rate.

Possible effects of the compensating blocks on the film response were assessed using EDR2 film (Eastman Kodak Co., Rochester, NY, USA) with a size of 30.5 cm × 25.4 cm. All films were of the same emulsion batch and all jackets were punctured at two corners to avoid air pockets. The film calibration procedure, including the third-order polynomial fit, and the film processor used are described in Gillis *et al* (2005). Both calibration films and measurement films were scanned using a VXR-12 film digitizer (Vidar Systems Corporation, Herndon, VA, USA). The film scanner was operated with a resolution of 75 dpi (0.34 mm/pixel), a coding depth of 12 bit/pixel, and a digitizing speed of 14 ms/line. To avoid the warm-up effect, the film digitizer was switched on 15–20 min beforehand (Mersseman and De Wagter 1998). Film analysis was performed using in-house written routines in the Matlab environment (The Math Works Inc., Natwick, MA, USA, Matlab 6.1). Each film response was obtained by averaging the central region of 50 × 50 pixels. Three consecutive films were taken for each measurement condition, including block thicknesses (10 mm, 20 mm, 30 mm, 50 mm), field size (5 × 5 cm, 10 × 10 cm), field offset (±5 cm, ±10 cm, ±15 cm in-plane and cross-plane) and measurement depths (15 mm, 35 mm, 50 mm, 100 mm).

Each film was placed at isocentric distance in the slab polystyrene phantom in a perpendicular geometry. In order to obtain the same exposure to each film, the chamber-measured transmission factors were applied to the MU counts so that basically the same dose was delivered to each film irrespective of the beam attenuation by the blocks. The film-measured dose was systematically divided by the dose measured by the Farmer-type ionization chamber at the same depth in order to compensate for MU truncation errors, accelerator output variations and beam hardening or softening effects.

Alternatively, dose response curves were determined using the regular film calibration procedure with and without a compensator block in a 6 MV and 25 MV (5 cm × 5 cm) beam.

To demonstrate the value of EDR2 film for compensator-based IMRT, we dosimetrically investigated a challenging modulated beam. The intended beam modulation was derived from an inverse-pyramid beam as investigated by Yeo *et al* (2004), who realized the modulation using a multileaf collimator. The compensator filter used is displayed in figure 5(a). The cross-sectional dose profile was measured at 10 cm depth using the diamond detector in the MP3 water phantom and EDR2 film in the polystyrene slab phantom. The photon beam quality was 25 MV and SSD was 90 cm.

3. Results and discussion

For the block thicknesses of 10 mm, 20 mm, 30 mm and 50 mm we obtained transmission factors 0.540, 0.347, 0.224 and 0.0943 at 6 MV, and 0.591, 0.379, 0.243 and 0.0983 at 25 MV

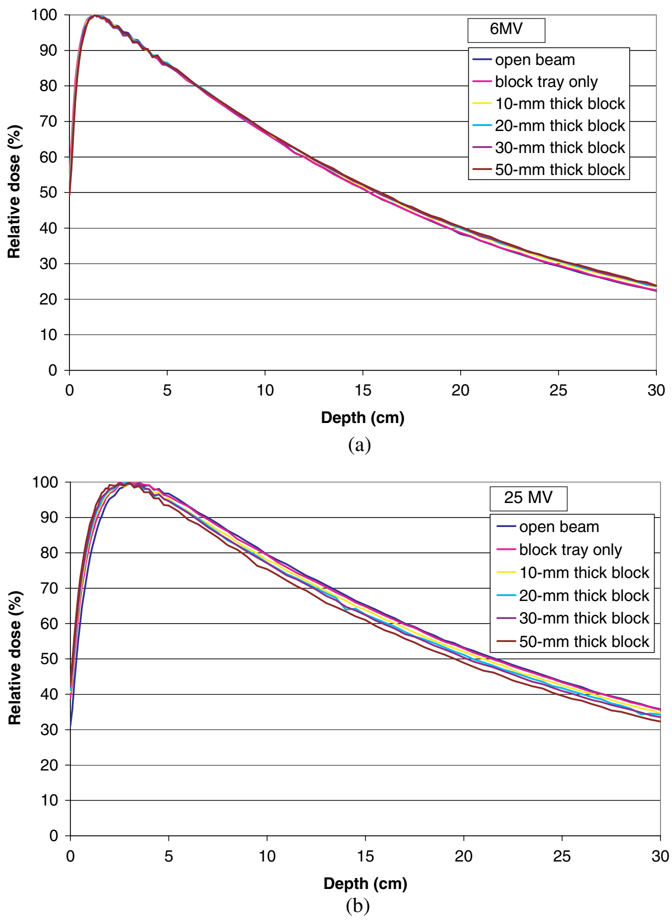


Figure 1. Percentage depth dose for various thicknesses of compensator blocks for a 6 MV (a) and 25 MV (b) (10 cm × 10 cm) field, measured using a diamond detector mounted in a water tank.

using the ionization chamber for the (10 cm × 10 cm) field, respectively. Similar values were obtained for the offset fields and the (5 cm × 5 cm) field.

Figure 1(a) displays the diamond-measured relative depth dose curves in water at 6 MV for the various thicknesses of compensator blocks. At depths higher than 10 cm, the slight separation of the curves obtained with the blocks indicates a small but clear energy hardening effect induced by the blocks. The resulting relative dose increase at 20 cm depth is 2% for the 50 mm block thickness. The depth dose curve obtained with the block tray follows the curve of the open beam. Figure 1(a) does not unveil any effect at depth of compensator scattered photons or contaminant electrons. These findings are in agreement with the conclusions drawn in Xu *et al* (2002) and Jiang and Ayyangar (1998). Jiang and Ayyangar investigated the effect of cerrobend compensators on a 6 MV beam from a Varian Clinac 1800 accelerator using Monte Carlo computations. They found that compensators significantly altered the energy spectrum without significantly affecting the per cent depth dose characteristics. Figure 1(b), in contrast, demonstrates that at 25 MV the block induces a beam softening at depth. The softening effect gradually increases with block thickness. An explanation for this softening effect is the selective absorption of higher-energy photons by pair formation in the block. The

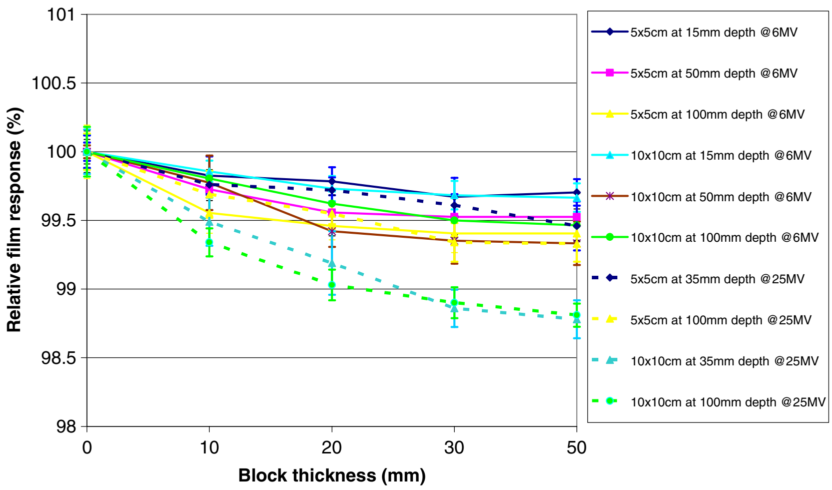


Figure 2. Percentage deviation of dose response of EDR2 film as a function of compensator block thickness for 6 MV and 25 MV and various field sizes and measurement depths. The error flags correspond to the standard errors of the mean. The linear interpolation between the dots is only to pronounce trends.

resulting relative dose decrease at 20 cm depth reaches 5% for the 50 mm block thickness. In contrast to 6 MV, the blocks and even the tray affect the dose in the build-up region suggesting the presence of compensator scattered photons or contaminant electrons in the beam. Dosimetry in the build region is beyond the scope of this note as radiographic film dosimetry is utmost complicated there and not suited for practical QA of IMRT.

Figure 2 shows the deviation of film response as a function of compensator block thickness for both 6 and 25 MV. There is a minor film underresponse as a function of block thickness, which is systematically higher for 25 MV. The underresponse at 25 MV increases with field size but is insensitive to measurement depth when outside the build-up region. The deviation is maximally 1.3% for a 50 mm thick block in a 25 MV (10 × 10 cm) beam. Behind a block of 30 mm thickness, the error is 1.1%. The observed underresponse is higher than the experimental error, as obvious in figure 2, but is still within the overall uncertainty of film dosimetry which is of the order of 3% for perpendicular orientation (Martens *et al* 2002).

Field offset also contributes to the film underresponse, as apparent from figure 3. The effect of field offset is most important, namely of the order of 1.3%, in the direction toward the gun and might be due to spectral changes related to the beam bending system.

Figure 4 compares the dose response curves of EDR2 film with and without a 20 mm thick compensator block for both 6 MV and 25 MV. As could be expected, the obtained curves unveil a systematic underresponse that remains below 2% and well below the overall uncertainty of film dosimetry. Therefore, a film calibration obtained in an open beam can be safely used at depth in (physically) compensated beams. Effects of relative film orientation, field size and measurement depth have a higher impact on the accuracy of radiographic film than the presence of a compensator block.

Laub *et al* (2001) obtained an agreement between CEA TVS EP film and diamond detector measurements within ±3%, and concluded that film measurements are sufficient to check the quality of compensators. In Xu *et al* (2002), Kodak XV2 film did not reveal a systematic deviation against computed dose profiles. The accelerator was a Varian Clinac 2300C/D and the compensator filters contained a mixture of tungsten powder and a silicon-based

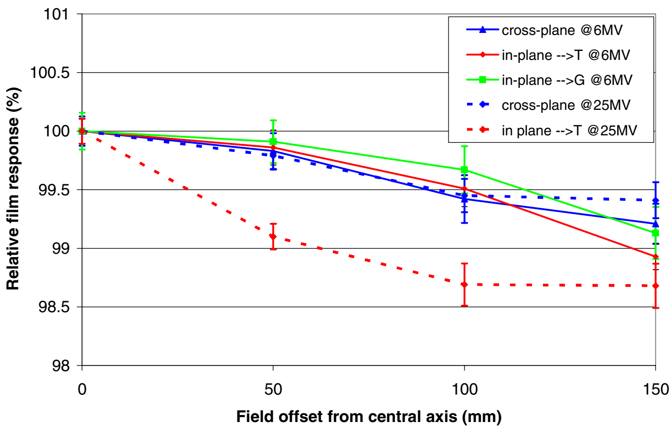


Figure 3. Percentage deviation of dose response of EDR2 film as a function of field offset for 6 MV and 25 MV and (10 cm × 10 cm) for a 30 mm thick compensator block. 'T' and 'G' stand for target and gun, respectively. The error flags correspond to the standard errors of the mean. The linear interpolation between the dots is only to pronounce trends.

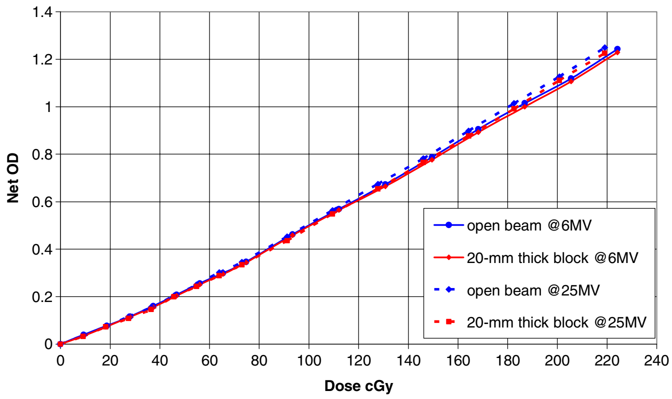
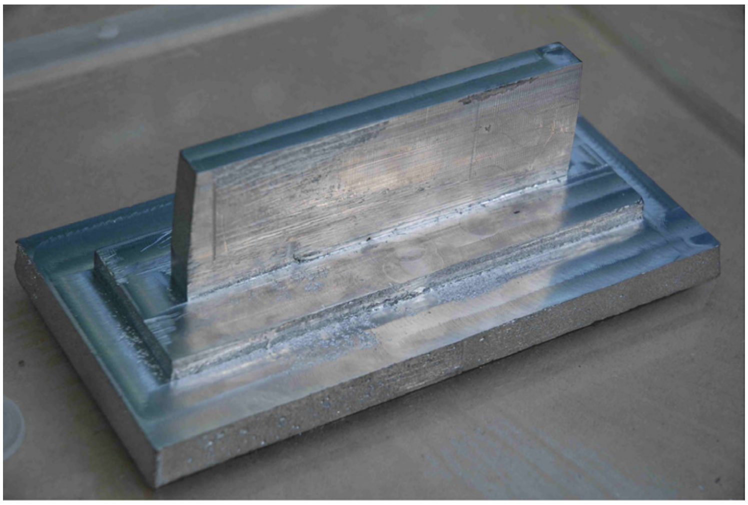
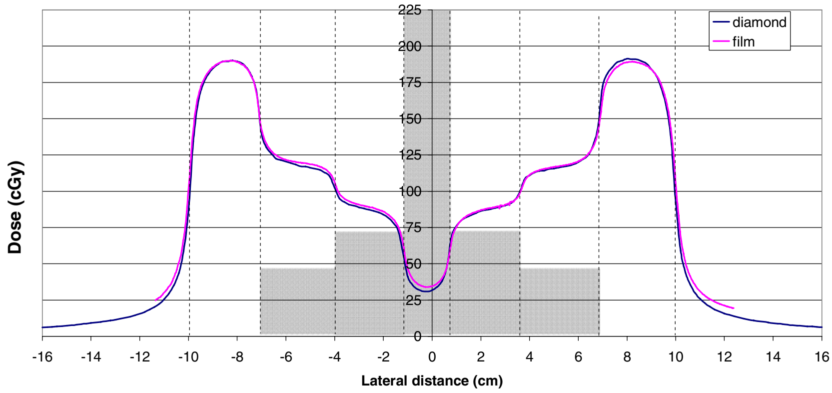


Figure 4. Dose response curves of EDR2 film with and without a compensator block in a 6 MV and 25 MV beam, at a depth of 5 cm and 10 cm, respectively. Calibration field size was (5 cm × 5 cm). Film was always at isocentric distance.

binder. Also in Xu *et al* (2004), a reasonable agreement was obtained between XV2 film-measured and computed 6 MV dose profiles obtained for a step-shaped modulator. Also the pre-IMRT era, film was considered as a reliable and intuitive tool for dosimetric QA of compensators (Evans and Schreiner 1992). Wiezorek *et al* (2005) however showed that EDR2 film features a 5% underresponse at 10 cm depth for a 32 mm thick cerrobend filter in a 15 MV photon beam from a Mevatron Primus accelerator (Siemens OCS, Erlangen, Germany). The same group reported a similar underresponse for XV2 film and MCP-96 compensators (Salz *et al* 2005). At 6 MV, the corresponding underresponse was reported to be 2%. These data are clearly contradictory to our findings that were obtained under comparable conditions. The authors pointed to contaminating electrons but it is doubtful that contamination particles from the compensator would still have an effect at a depth of 10 cm (Jursinic and Mackie 1996).



(a)



(b)

Figure 5. Photograph (a) of the MCP-96 compensator filter to realize the inverse-pyramid beam and resulting film-measured and diamond-measured cross-sectional dose profiles (b) obtained at a depth of 10 cm for 200 MU and SSD = 90 cm. The central part of the block is 63 mm thick, and the adjacent parts are 20 mm and 13 mm thick. The filter is mounted on a Perspex blocking tray. The dotted lines in (b) indicate the projected edges of the compensator steps. The field size of 20 × 20 cm creates the laterally distant unattenuated beam parts.

A special category of compensators for which film dosimetry has been used over tens of years is the physical wedges. Williamson *et al* (1981) stated that the calibration of Kodak XV2 film is unchanged by the inclusion of 60° and 45° wedge filters in the field at 4 and 10 MV. Baird *et al* (2001) compared calculated and film-measured dose distributions of 6 and 18 MV breast treatment plans that were optimized using open/wedge combinations and compensator filters. They used TVS film (CEA America Corporation, Houston, TX) and demonstrated agreement between calculations and measurements to within 3%. Novotny *et al* (1997) obtained a good agreement between the profiles measured with XV2 film and with the ionization chamber in a polystyrene phantom for wedged fields in a 6 MV and a 18 MV photon beam.

The value of EDR2 film dosimetry in compensator-based IMRT might be deduced from figure 5(b) that compares the diamond- and film-measured cross-sectional dose profiles behind the compensator block shown in figure 5(a). The film underresponse is clearly compensated by the scatter contribution in this highly modulated field, especially behind the central part of the block that is 63 mm thick and 20 mm wide (at isocentric distance). The lateral shift in both profiles points to an inaccurate centering of the block on the Perspex plate.

As radiographic film overresponses to photons from the spectrum below approximately 400 keV, we can conclude from this study that compensator blocks do not significantly change at depth that are part of the spectrum. At depth, the Compton scattered low-energy photons dominate and stimulate the film overresponse in larger fields, irrespective of the use of compensator blocks.

4. Conclusion

Compensators made of MC-96 alloy cause EDR2 film to slightly underestimate the measured dose. The underresponse grows with the compensator's thickness and is more prominent at 25 MV than at 6 MV. The maximum underresponse of 1.3% was obtained for a 50 mm thick block in a 25 MV beam. Behind a block of 30 mm thickness, which is more realistic in compensator-based IMRT, the deviation was 1.1%. An extra underresponse can be expected with field offset. These deviations are higher than the experimental error but are still within the overall uncertainty of film dosimetry which is of the order of 3% for perpendicular orientation.

Also the QA dosimetry of an IM beam achieved by a compensator block gives evidence that the response of radiographic film at depth is practically not affected by beam hardening or softening when a compensator block is mounted in the tray holder. Radiographic film can be safely used as a 2D dose detector in compensator-based IMRT. This information is of interest to hospitals in developing countries that intend to upgrade to compensator modulation.

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