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NOTE

Rounded end multi-leaf penumbral measurements with radiochromic film

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Abstract

Multi-leaf penumbral doses have been investigated for 6 MV x-rays and a Varian millennium multi-leaf collimator (MLC) using Gafchromic MD-55-2, radiochromic film and X-omat V radiographic film. An advantage of Gafchromic film for multi-leaf penumbral dose measurement is the relatively low energy dependence of the film. A comparison of penumbral dose measurements has also ascertained the effects of energy response on radiographic film in this region. Similar 80%/20% penumbral doses have been measured with both types of films. Thus there is a relatively low energy effect on penumbral dose measurements in film dosimetry. The 80%/20% dose penumbral distances for rounded leaf end multi-leafs for a 10 cm × 10 cm field at D_{max} were found to be 4.6 mm and 4.3 mm for radiochromic and radiographic film respectively. This is compared to 2.6 mm and 2.6 mm for the leaf edge penumbra. Radiochromic film also measured leaf end/interleaf leakage doses in the penumbral region, which was shown to produce approximately 4% of maximum dose wave across the penumbral region with maximum doses delivered at the MLC leaf interfaces.

1. Introduction

Gafchromic film, due to its relatively low energy dependence compared to radiographic film, has become a significant dosimetry tool in high-energy radiotherapy (Klassen *et al* 1997, Niroomand-Rad *et al* 1998, McLaughlin *et al* 1991). The relative energy independent nature of Gafchromic film is a useful tool for testing the effects of energy spectral changes on radiographic film dosimetry. Areas such as the penumbral region of a multi-leaf collimated beam may have changed energy spectral components of the beam compared to that at the central axis. The effects of this change may significantly influence doses measured in these regions with radiographic film. The aim of this short paper is to investigate the ability of radiochromic film to measure doses in the penumbral region of a multi-leaf collimated beam and compare the result to radiographic film. Radiochromic film will also be used to measure variations in dose along the penumbral region of a MLC beam caused by interleaf leakage.

2. Materials and methods

Measurements were performed on a Varian 2100C accelerator for 6 MV photon beams in a RMI 30 × 30 cm^2 solid water (Constanitinou *et al* 1982) slab phantom at 100 cm source to surface distance. The millennium 120Leaf MLC was utilized. The isocentric projected leaf widths for the inner 40 leaves are 0.5 cm at 100 cm SSD and 1 cm for the outer leaves. The film used was Gafchromic MD-55-2 with batch number 970116. Precautions in handling radiochromic film outlined in TG-55 were used which included minimizing scratching and handling the film with the use of gloves and a paper tag attached to one side of each film piece for manipulation. During experiments and film analysis the film was kept at temperatures of 22 °C ± 2 °C thus reducing the effects of time and temperature dependent evolution and read-out (Meigooni *et al* 1996) of the absorption spectra of the film. The film is only removed from a light tight envelope during irradiation and readout to reduce the effects of ambient light (Butson *et al* 1998). The film was analysed with a VIDAR VXR-12 scanner that produces images in 12 bit levels of grey. It has a minimum pixel size of 85 μm and can also be scanned at 169, 339 and 423 μm. During image capture, the film is passed over a fluorescent light and the image is focused on a 5000 element CCD array through a focusing lens. Optical density range is quoted by the manufacturer as 0–2.6 OD. This digitizer has been shown to be an adequate densitometer for radiographic film analysis by Mersseman and De Wagter (1998) and by Cheung *et al* (2002) for radiochromic film analysis. The radiochromic film strips (due to their small size) were attached with tape to radiographic film sheets during analysis to aid in their entry into the scanner. The film was then analysed for optical density results using OSIRIS[3] version 4.13 software. The film was cut into strips of various sizes to cover the penumbral regions of MLC fields at various field sizes ranging from 5 cm × 5 cm up to 20 cm × 20 cm. In all cases the primary collimators were moved out to an isocentric projected field size of 40 cm × 40 cm. The film was exposed to 60 Gy applied dose at central axis. The radiochromic film dose calibration is performed using a multiple step process. Firstly a calibration set is irradiated using a 10 cm × 10 cm field size at 100 cm SSD at $D_{\max}$ to doses up to 60 Gy in 5 Gy intervals. The net optical density of each film piece is measured by subtracting the original background OD. A second order polynomial function was used to fit the calibration curve. The experimental film pieces were firstly given a 5 Gy dose to measure their response uniformity. This is delivered at the central axis in a single fraction using a 20 cm × 20 cm field size at $D_{\max}$. This produces a uniform dose within 2% over the irradiated area. The net OD is calculated by subtracting the background OD from results. This removes variations associated with results with background non-uniformity and also acts as a check for the film response uniformity. Less than 3% variation was seen in response across films used. The films are then given their experimental doses. Final results are found by subtracting the 5 Gy initial results from final measured doses compared to the calibration curve. 24 h time delay is used between each of these steps.

Measurements were made to analyse the dose delivered in the penumbral region along the edges parallel to the leaf direction. This was tested to measure the effects of rounded leaf ends and any interleaf end leakage. Similar experiments were performed with Kodak

[3] OSIRIS version 4.13: University Hospital of Geneva, Switzerland.

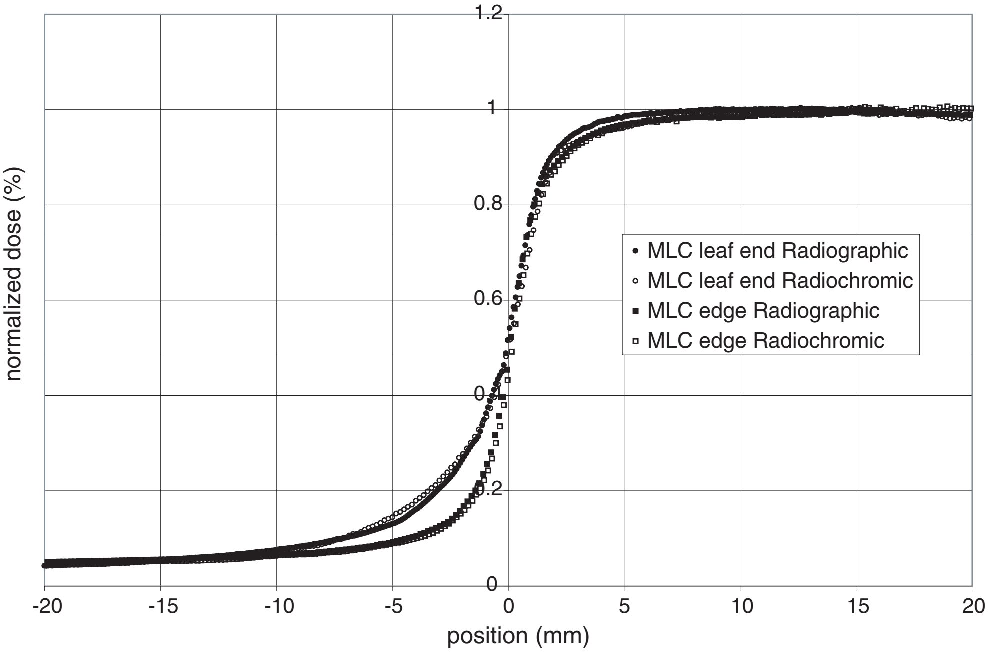

Figure 1. Measurements using radiochromic and radiographic films for multi-leaf collimator edge and end penumbra for a 10 cm × 10 cm field using 6 MV x-rays. Larger penumbras are seen for end leaf penumbra. Radiochromic and radiographic film results are in close agreement.

X-Omat V radiographic film for comparison at appropriate dose levels. For dose calibration of Kodak X-Omat V radiographic film, the calibration films were positioned in a solid water (Constanitinou *et al* 1982) phantom of dimensions 30 cm × 30 cm × 30 cm. The phantom was placed on a Varian 2100C linear accelerator treatment couch with the upper surface at the isocentre (100 cm). The film was positioned at a depth of D_{max}, 1.5 cm for 6 MV x-rays and doses ranging from 0 cGy to 50 cGy in 10 cGy intervals were given with the film perpendicular to the central axis of the beam. The film was processed in a Kodak M35 X-Omat processor in a single batch, then digitized and analysed with the same hardware/software as the Gafchromic film.

3. Results and discussion

Figure 1 shows the averaged penumbral dose for a 10 cm × 10 cm MLC field at D_{max} measured by radiochromic and radiographic films. The film penumbra was averaged over a 2 cm wide profile, which incorporated four MLC leaf widths in the leaf end direction and at the central axis of the MLC in the direction perpendicular to the MLC leafs. That is, the measured penumbral incorporates the measured MLC leaf end leakage for the given penumbra. For this field size the 80%/20% penumbra width is calculated to be 4.6 ± 0.3 mm for Gafchromic and 4.3 ± 0.2 mm for radiographic films in the leaf end direction. Table 1 shows results for penumbra width with different field sizes and with the MLC leafs moved off axis. For off axis measurements, a 10 cm × 10 cm field was used with the quoted position being the centre of the field distance from isocentre. Results show that no significant difference in measured 80%/20% penumbra exists between radiographic and radiochromic films. Our results have also shown no systematic variation in penumbral width with variation in offset distance.

Table 1. 80%/20% penumbra widths for various beam configurations.

Field size	Off-axis distance (cm)	Radiochromic film	Radiographic film
5 cm × 5 cm	0	4.3 ± 0.3	4.4 ± 0.2
10 cm × 10 cm	0	4.6 ± 0.3	4.3 ± 0.2
20 cm × 20 cm	0	4.5 ± 0.3	4.4 ± 0.3
30 cm × 30 cm	0	4.5 ± 0.3	4.5 ± 0.2
10 cm × 10 cm	5	4.2 ± 0.3	4.5 ± 0.2
10 cm × 10 cm	10	4.4 ± 0.3	4.4 ± 0.2
10 cm × 10 cm	15	4.4 ± 0.3	4.3 ± 0.2

That is, the 80%/20% penumbra for a 10 cm × 10 cm field is 4.6 mm at central axis and 4.4 mm with a 15 cm offset. Results by Huq *et al* (2002) show a small variation in penumbra with a reduction in width from approximately 4.4 mm down to approximately 4 mm with the same offsets. This is more consistent with the rounded leaf end design. Our results did not show this trend specifically; however, this may have been hidden by the size of errors in our data analysis. As highlighted in figure 1, the rounded leaf end penumbra in general is larger than the leaf edge penumbra. This is mainly due to increased dose at lower levels (i.e. the 20% dose level). Due to the accuracy and reproducibility of both radiographic and radiochromic film measurements, the 80%/20% penumbra widths have a relatively high error estimation. However, both film types agree within the error limits. Neither film produced a consistently larger penumbra measurement for all field sizes and configurations tested. As such there seems to be no significant energy dependence effect on penumbra measurements for radiographic or radiochromic film. The leaf edge penumbra was found to be 2.6 ± 0.2 mm and 2.6 ± 0.2 mm for radiochromic and radiographic films using a 10 cm × 10 cm field size. Results have shown that the rounded leaf end penumbra is larger that the edge penumbral which is expected due to the physical shape of the Varian multi-leaf ends. Results did however show a close agreement for radiochromic and radiographic films, with the largest variation being 0.3 mm penumbral width difference, which is equal to a variation of less than ±2% of maximum dose in both penumbral cases. This implies that the energy dependent nature of radiographic film is not a major concern for measurement of dose in the penumbral region of multi-leaf beams at this chosen energy. Thus, we would recommend that radiographic film is suitable for measurements in the penumbral regions of multi-leaf collimated beams and that the energy dependent nature of the silver halide film is not a major issue.

A noticeable effect of the millennium MLC collimator is the interleaf end leakage points whereby higher exposure is observed on the film. Huq *et al* (2002) and Killoran *et al* (2002) have studied various multi-leaf collimators previously and showed effects of end leaf penumbra and interleaf leakage using just radiographic film. Our results differ from their results in that we have compared with radiochromic film and we have studied the leakage at the leaf ends. Using the Gafchromic MD-55-2 film, a profile measurement was made across the penumbral region of the MLC beam to assess the size of the leakage in the penumbral region. Figure 2 shows results for average dose recorded along a profile taken within the 80%/20% penumbral region. The profile measurement was made normal to the beam penumbral direction, thus showing a wave of dose along the MLC edge. The higher doses recorded correspond to the projected MLC leaf edges where the leakage occurs. Results show that an average percentage of maximum dose change of approximately 4% occurs within the 80%/20% penumbral region as measured by Gafchromic film with the average dose over the 80%/20% penumbra being approximately 42–46% of maximum. Of interest in this figure is a mismatch in the physical

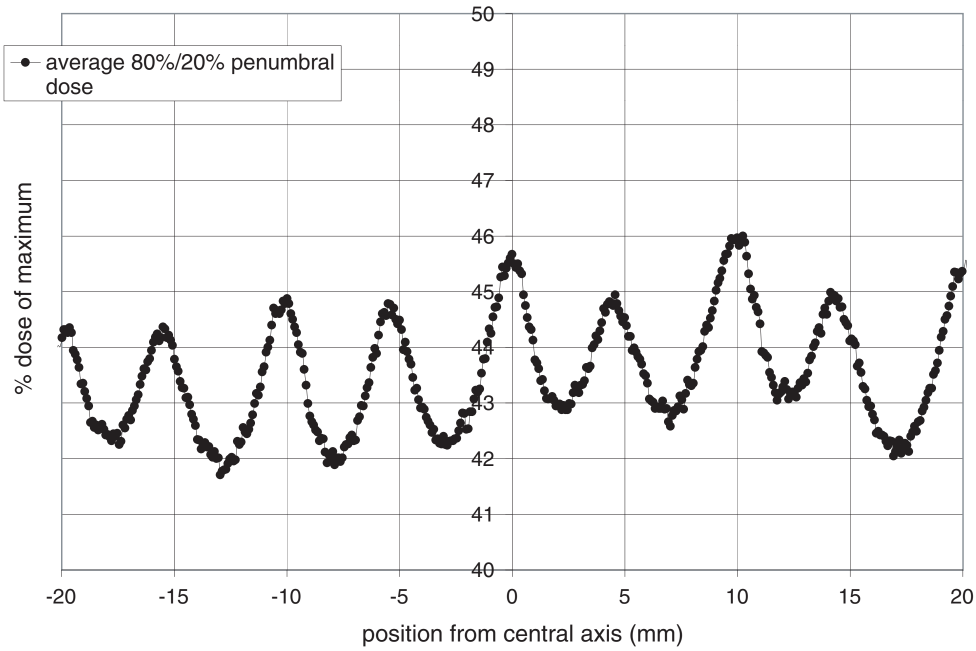

Figure 2. The dose 'wave' produced in the penumbral region which results in interleaf and end leaf leakage.

position of maximum dose in every second dose peak. This is assumed to be possibly caused by the tongue and groove system of the Varian MLCs.

4. Conclusion

Gafchromic film is an ideal dosimeter for measuring doses where a high level of spatial resolution is required and a relatively energy independent response may be required such as near the edge of a multi-leaf collimator. Results have also shown that radiographic film is also capable of measuring dose in this region. Gafchromic film has measured the 80%/20% penumbral edge of a round leaf end MLC as in the range of 4.2–4.6 mm in various field configurations. Gafchromic film has also adequately measured the variation in dose delivered in the penumbral region produced by interleaf leakage at the ends of the rounded leaf end MLC and showed a leakage dose of approximately 4% of maximum producing a wave pattern across the edge of the MLC collimator.

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