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SCIENTIFIC NOTE

Scanner uniformity improvements for radiochromic film analysis with matt reflectance backing

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Abstract A simple and reproducible method for increasing desktop scanner uniformity for the analysis of radiochromic films is presented. Scanner uniformity, especially in the non-scan direction, for transmission scanning is well known to be problematic for radiochromic film analysis and normally corrections need to be applied. These corrections are dependant on scanner coordinates and dose level applied which complicates dosimetry procedures. This study has highlighted that using reflectance scanning in combination with a matt, white backing material instead of the conventional gloss scanner finish, substantial increases in the scanner uniformity can be achieved within 90% of the scanning area. Uniformity within ±1% over the scanning area for our epsonV700 scanner tested was found. This is compared to within ±3% for reflection scanning with the gloss backing material and within ±4% for transmission scanning. The matt backing material used was simply 5 layers of standard quality white printing paper (80 g/m^2). It was found that 5 layers was the optimal result for backing material however most of the improvements were seen with a minimum of 3 layers. Above 5 layers, no extra benefit was seen. This may eliminate the need to perform scanner corrections for position on the desktop scanners for radiochromic film dosimetry.

Keywords Radiochromic film · Gafchromic · Dosimetry · Scanner uniformity · X-ray · Radiotherapy

Introduction

Radiochromic film is a two dimensional dosimetry medium which can be used for many applications for dosimetry in radiotherapy and medical imaging. The low X-ray energy dependence of radiochromic films [1, 2] make them clinically useful in both kilovoltage X-ray applications [3–7] and high energy X-ray applications [8–11]. Radiochromic films that are commonly used in these applications include Gafchromic EBT and EBT2 films. As these films produce a visible colour change upon irradiation, they are suited for analysis using a common computer desktop scanner [12, 13] as well as other more specific densitometry and spectroscopy equipment. It is well known however that desktop scanners have an intrinsic scanner non uniformity when scanning is performed in transmission mode especially in the non-scanning direction [14–16]. In this note we use the terms ‘portrait mode’ and “landscape mode” as defined by Saur et al. [16]. Menegotti et al. [15] measured a variation in normalised pixel value of up to 19% whereas Saur et al. [16] found differences of the order of 800 pixel value units, in transmission scans of EBT film. While the variations seen appear to be scanner specific, all scanners exhibit some effect which if not corrected for, can affect

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dosimetric accuracy for 2 dimensional dose assessment for procedures like IMRT dose verification. Because EBT film is not rendered completely opaque by irradiation, both reflectance and transmission scanning can be performed. Kalef-erza et al. (2008) [17] compared these two scanning techniques and assessed reflection mode to be superior for accuracy especially at lower doses. However, both transmission scanning and reflectance scanning still produce a non-uniformity in scanner response which appears to be due to scattering of light within the scanner, especially at the scanning edges. This study has investigated the effects on scanner uniformity response for an Epson V700 desktop scanner and devised a simple method using matt white backing paper to improve the scanner uniformity in reflection mode analysis compared to traditional transmission mode analysis.

It is also acknowledged that both EBT and EBT2 film have intrinsic non-uniformity in their responses that produce local changes in measured OD over the entire film piece. Saur et al. [16] showed this effect to be up to 4% (2 standard deviations) for EBT film, apparently due to manufacturing effects and uneven distribution of the active layer. While these effects are an intrinsic part of Gafchromic film dosimetry, this study aims at evaluating and minimizing the scanner produced variations in radiochromic film dosimetry.

Materials and methods

Gafchromic EBT, radiochromic film (Lot no. 47277-06I) (expiry date May 2010) has been utilized for the measurement of scanner uniformity response in two dimensional radiation dosimetry. While EBT2 film is now the commercially available film type, results were performed using EBT as it provides superior film uniformity compared to currently available versions of EBT2. Thus potential effects on this study from film non-uniformity are minimised. The results obtained for EBT film could be applied to EBT2 film analysis.

Films were exposed to solar ultraviolet to produce a "X-ray radiation dose equivalent" darkness of approximately 2 Gy (6 MV X-rays) and 5 Gy (6 MV X-rays). Solar radiation was used as it provides a uniform exposure of the entire film piece. These values for reflected optical density were 0.42 and 0.69 OD, respectively. During analysis no corrections were made for intra-film non-uniformity. However, the films were scanned in the same position and orientation, each time, so that any variations would be at a constant position and so that differences caused by film polarisation effects [18, 19] could be avoided. All films were scanned in portrait mode. Previous study by Saur et al. 2008 [16] has shown that film uniformity has been found to be within 4% (2SD) for EBT film.

Experiments were performed to evaluate if the scanning method may affect dose assessment in regions where a sharp dose change may occur such as a junction region for a segmented treatment field. EBT2 film was irradiated to 100 and 110 cGy using a 2 step method to produce a segmented junction edge for evaluation. A 20 × 20 cm field was used to deliver 100 cGy dose to the film followed by a 10 × 10 cm field of 10 cGy inside this field. This way a junction edge was created and evaluated for the measurement of dose at this region to compare the different scanning methods. In this process, any differences in calculated dose caused by the scanning methods could be evaluated.

All films were analysed using a PC desktop scanner and Image J software on a PC workstation at least 24 h after irradiation to maximise the stability of post irradiation colouration [20]. The films were kept in a light proof container when not being analysed, to reduce coloration from ambient light and UV sources [10]. The scanner used for quantitative analysis of uniformity was an Epson Perfection V700 photo, dual lens system desktop scanner using a scanning resolution of 50 pixels per inch. The images produced were 48 bit RGB colour images and analysis was performed using the red component of the data. The films were examined in both transmission and reflectance modes. When scanning in reflectance mode, scans were performed in various configurations. These included the use of the normal gloss white scanning background as well as the use of various layers of pure white 80 g/m^2 matt paper ("Reflex white", Reflex, Vic, Australia). The white sheets were placed behind the EBT film during the scan process in thicknesses ranging from 1 (0.1 mm) up to 10 (1 mm) layers. In reflectance mode, reflective optical density (ROD's) for all films were calculated to evaluate uniformity response in landscape and portrait directions. ROD is defined as Eq. 1:

$$\mathrm{ROD} = \log(65536/P_t) \quad (1)$$

Where P_t is the pixel value of the reflected intensity through the EBT film. Similar scanner properties were used for transmission scanning with the software changed to transmission mode and the transmission light source used for analysis. For data analysis the outer 1 cm edge of the scanned film results was removed. This was performed to minimize any effects on scanner results from film edges or cutting damage [21]. Results given are the average for 5 scans of each film piece with a 2 cm wide profile in either the landscape or portrait direction. Experiments were repeated five times for analysis using different films with results shown as the average of 5 scans for each film piece.

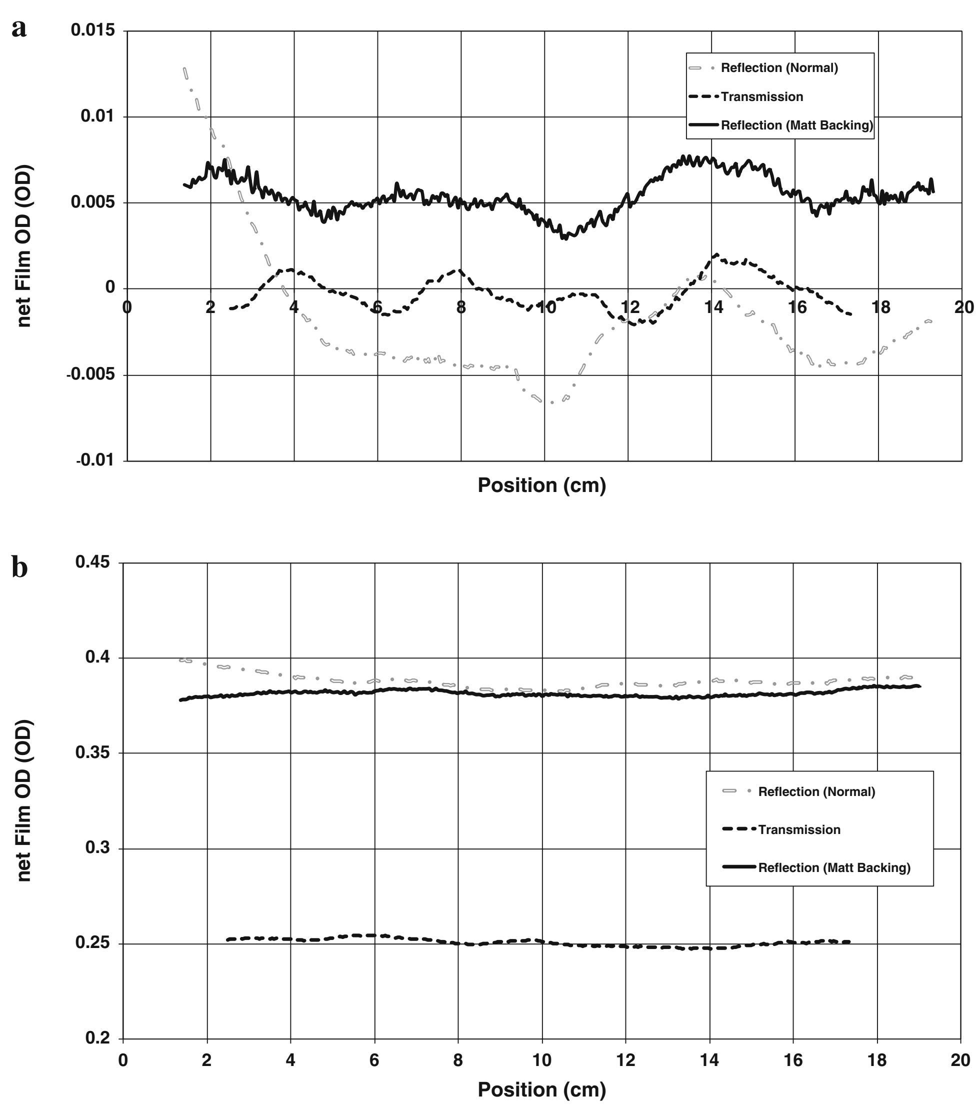
No substantial variation in uncertainty or results were seen over the 5 experiments performed.

Results and discussion

Figure 1 a shows the optical density profiles in the landscape direction (parallel to the scanning direction) for an EBT radiochromic film which has not been irradiated, where there is minimal scanner non-uniformity for transmission mode and reflection mode with 5 layers of matt white sheet backing (approximately within ±1%) for the entire length. In reflection mode with the scanner's reflective white backing (normal mode), there is a larger (up to 5%) increase in OD near the beginning of the film scan. Figure 1b shows similar results for profiles in the landscape direction along an exposed film (approximately 2 Gy equivalent). These results also show low level variations along the scan plan with the transmission and matt backing reflection methods producing less than ±1% variation and normal reflection mode with an approximate 1.5% variation at the beginning of the scan and less than 1% elsewhere. These results are similar to other researchers (Menegotti et al. 2008 [15], Saur et al. 2008 [16]) whereby a relatively uniform response is seen in landscape mode or along the scan plan direction.

Figure 2 shows the profile results for a profile obtained in the portrait direction (in the non-scanning direction) for a non-irradiated sheet of EBT film when analysis is performed in reflection and transmission mode. If transmission mode is used, a substantial variation across the profile is seen with a variation of up to 7% seen on this film. The largest OD values (or darkest scan results) were seen at the edges. A similar trend is seen in the profiles obtained using reflection mode with the normal glass white backing material, but the amplitude of the variation is reduced to

Fig. 1 Variation in normalised OD in landscape (along scan direction) axis for non irradiated (**a**) and an exposed (2 Gy equivalent darkening) (**b**) EBT Gafchromic film pieces in transmission, normal reflection and matt backing reflection mode



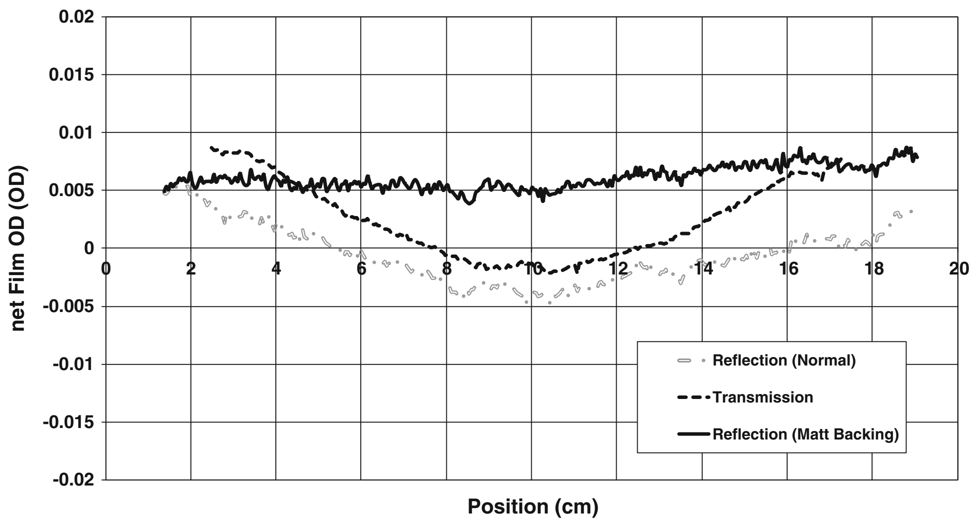


Fig. 2 Variation in normalised OD in portrait mode (across scan direction) for non irradiated EBT Gafchromic film pieces in transmission, normal reflection and matt backing reflection mode

4%. When the film is scanned with a matt white backing material, the variation is reduced to less than 2% across the film piece.

Figure 3 shows the effect of reflectance scanning with varying thickness of white paper behind the EBT film. Results shown are profiles in the portrait direction with 0 sheets (normal) 1, 3 and 5 sheets backing. Up to 10 sheets in multiples of 1 were tested. As shown in Fig. 3, there is a substantial improvement in uniformity by using 1 sheet of backing paper over the normal gloss backing. Further improvements are seen for 3 sheets. It was found that 5 sheets provided the most uniform response across the film profile and that by adding more sheets of white backing paper, no further increase in uniformity was achieved. For this experiment, the standard deviation of results across the portrait profile for the normal gloss background, 1, 3 and 5 sheets were found to be 0.0113, 0.0047, 0.0041 and 0.0040, respectively. This shows that 3 to 5 sheets of matt white backing paper placed behind the EBT film and scanning in reflection mode increases the uniformity of scanner response. Similar effects were seen for irradiated films.

Figure 4a shows the results for a film irradiated with solar UV to reach a darkness of approximately equivalent to 2 Gy X-rays at 6 MV energy. Figure 4b for a darkness equivalent of 5 Gy. Results show that the scanner uniformity for the matt backing reflection mode scan is improved compared to the normal reflection scan and to transmission scan mode. In each case, the uniformity across the film in portrait mode was found to be within ±1% as compared to variations of up to 7% for transmission mode.

The improvement in uniformity achieved with the use of the matt backing may be caused by the minimization of both reflections within the scanner and other sources of scattered light which can form a substantial part of the signal for transmission mode and for reflectance mode scanning with the high gloss white backing normally

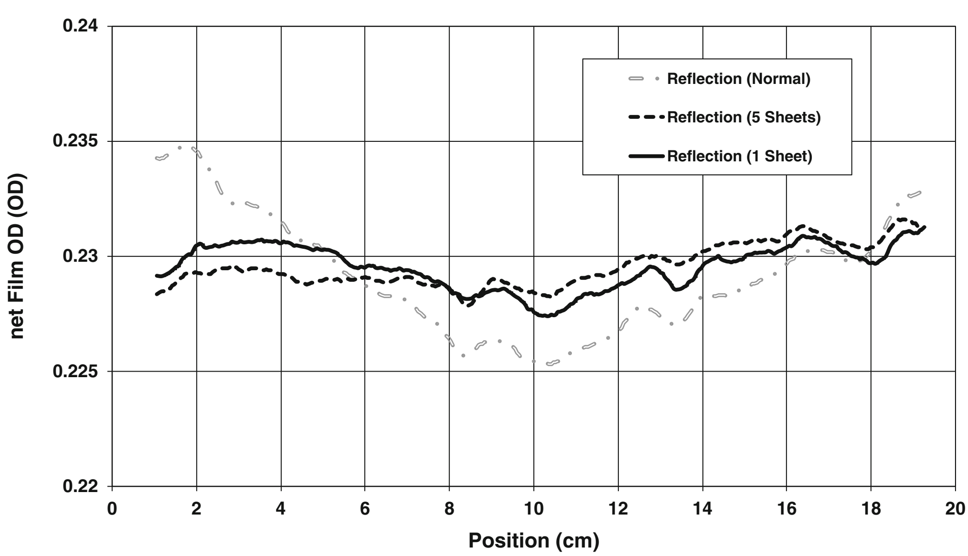


Fig. 3 Effects of the layers of matt backing material on the uniformity of reflection mode scanning in portrait mode

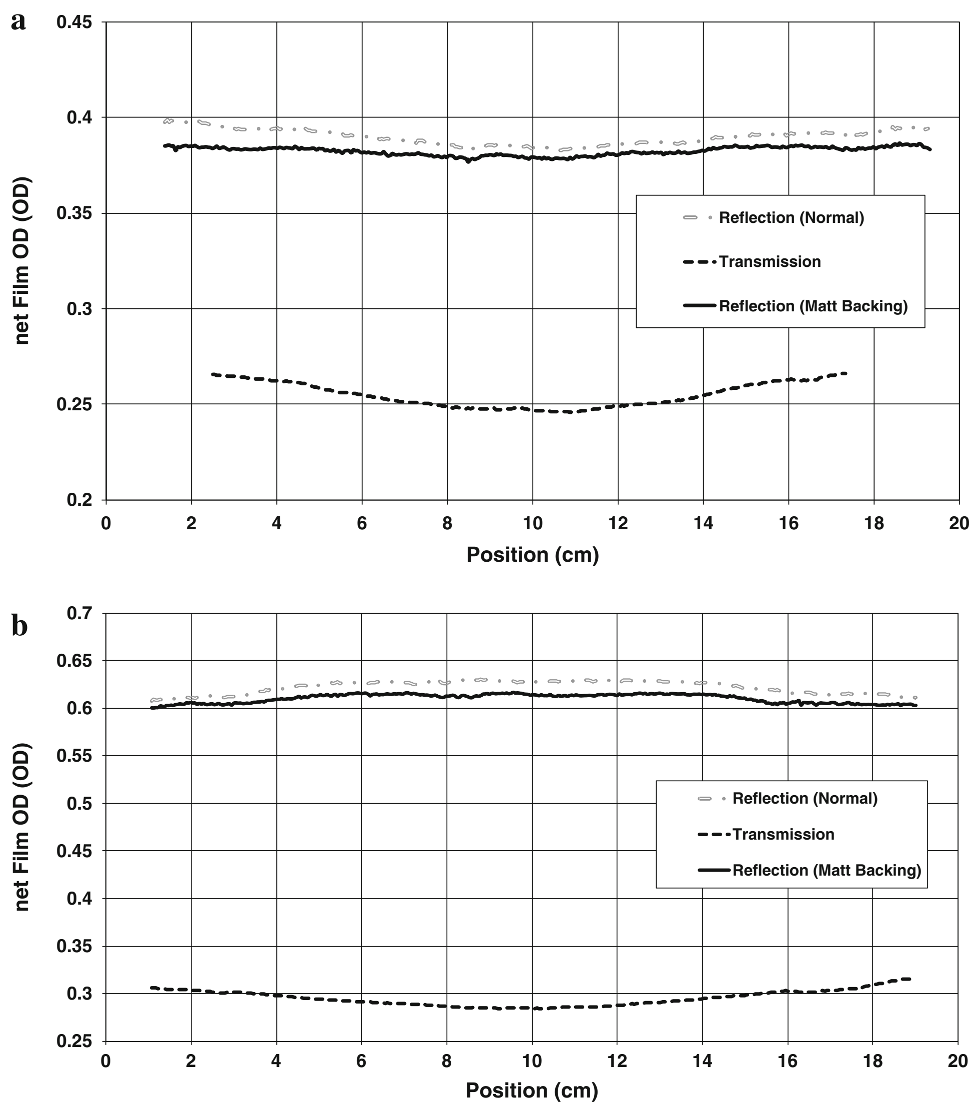


Fig. 4 Variation in normalised OD in portrait mode (across scan direction) for EBT films irradiated by uniform solar UV radiation to equivalent darkening levels of 2 Gy (**a**) and 5 Gy (**b**) in transmission, normal reflection and matt backing reflection mode

provided with the scanner. By utilizing a matt white backing, we reduce the reflected or scatter light to a level which obviously provides a much more uniform response in both the scanning and non-scanning direction.

The use of the matt backing material has appeared to minimize the scanner non uniformity to a level which could be acceptable for dosimetry purposes thus eliminating the need to perform scanner non-uniformity corrections.

One concern here could be that this method is also reducing or removing genuine OD variations caused by dose variations as would be the case for IMRT or segmented fields. Figure 5 shows a dose profile of the junction region using an EBT2 film irradiated to a stepped dose field of 100 and 110 cGy using the normal reflection, matt backing reflection and transmission mode scanning methods. As can be seen, the variation in dose at the junction is relatively similar for all three methods when the scan is performed in the central part of the desktop scanner. Thus the use of the matt backing material has had a minimal impact on real dose variations on Gafchromic film dosimetry whilst minimizing scanner induced non-uniformity.

As reflection mode scanning is normally much quicker to perform, the use of reflection mode and the matt backing material would certainly increase the speed of analysis whilst retaining a high level of accuracy for film dosimetry. Results have of course only been performed on our Epson V700 scanner and others would need to assess their own desktop scanner for this level of uniformity before adopting this procedure into clinical practice.

Conclusion

The study has shown that by using a matt white backing material for reflection scanning of radiochromic EBT

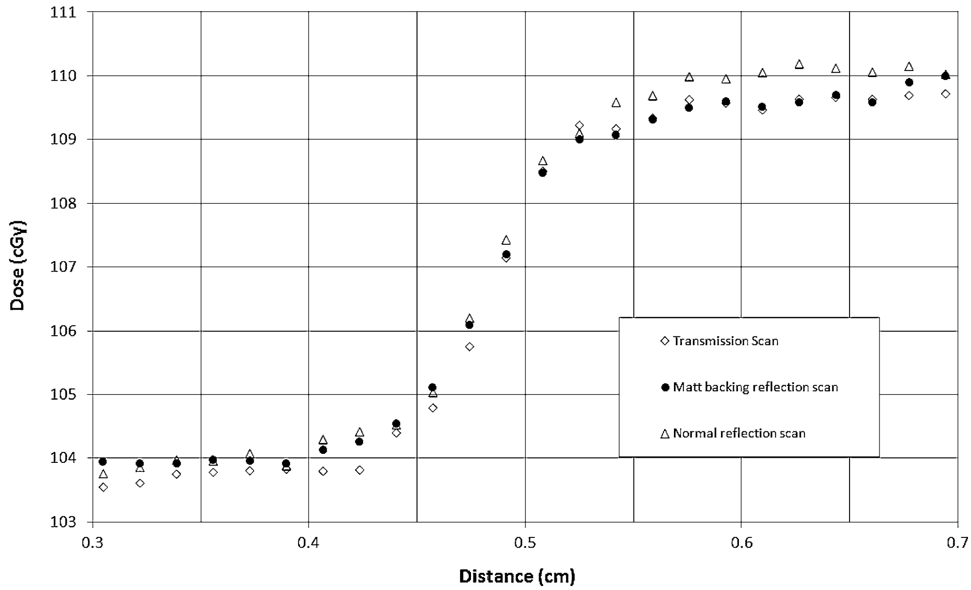


Fig. 5 Effects of actual dose variations from the matt backing scan method compared to normal reflection mode and transmission mode when the EBT2 film is irradiated with a 100–110 cGy step dose using a 6 MV X-ray beam produced by a linear accelerator

Gafchromic film, the non uniformity of scanner results in the portrait direction can be minimized to a level within ±1% using an Epson V700 desktop scanner without accounting for Gafchromic film non-uniformity. This provides an improvement over reflection scanning with the gloss white background normally supplied with the scanner as well as over transmission scanning where up to 7% variations were seen over the same scan area. Matt backing, reflection scanning may be used to eliminate the need for scanner non uniformity corrections which need to be applied for transmission mode scanning when high accuracy dosimetry is required. The level of uncertainty in film scanning can be reduced using this method, however, non-uniform film response will still remain unchanged.

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