SCIENTIFIC NOTE

Evaluation of the magnitude of EBT Gafchromic film polarization effects

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Abstract

Gafchromic EBT film, has become a main dosimetric tools for quantitative evaluation of radiation doses in radiation therapy application. One aspect of variability using EBT Gafchromic film is the magnitude of the orientation effect when analysing the film in landscape or portrait mode. This work has utilized a >99% plane polarized light source and a non-polarized diffuse light source to investigate the absolute magnitude of EBT Gafchromic films polarization or orientation effects. Results have shown that using a non-polarized light source produces a negligible orientation effect for EBT Gafchromic film and thus the angle of orientation is not important. However, the film exhibits a significant variation in transmitted optical density with angle of orientation to polarized light producing more than 100% increase, or over a doubling of measured OD for films irradiated with x-rays up to dose levels of 5 Gy. The maximum optical density was found to be in a plane at an angle of 14 ° ± 7 ° (2SD) when the polarizing sheet is turned clockwise with respect to the film. As the magnitude of the orientation effect follows a sinusoidal shape it becomes more critical for alignment accuracy of the film with respect to the polarizing direction in the anticlockwise direction as this will place the alignment of the polarizing axes on the steeper gradient section of the sinusoidal pattern. An average change of 4.5 % per 5 ° is seen for an anticlockwise polarizer rotation where as the effect is 1.2 % per 5 ° for an clockwise polarizer rotation. This may have consequences to the positional accuracy of placement of the EBT Gafchromic film on a scanner as even a 1 ° alignment error can cause an approximate 1 % error in analysis. The magnitude of the orientation effect is therefore dependant on the degree of polarization of the scanning light source and can range from negligible (diffuse LED light source) through to more than 100 % or doubling of OD variation with a fully linear polarized light source.

Key words Gafchromic, EBT , Radiochromic film, densitometry, orientation

Introduction

Radiochromic films have become a significant tool for radiation dosimetry in medical radiation applications over the last 10 years [1-6]. Specifically EBT Gafchromic has been utilized for high energy and low energy radiotherapy / diagnostic dosimetry[7-14]. Some of its characteristics which have defined its usefulness include high spatial resolution[15] and near energy independence[16]. Combining this with automatic development[17], relative insensitivity to fluorescent and incandescent room light sources and the ability to measure dose over a 2 dimensional map provides a dosimeter suited to most radiotherapy dosimetric applications. The most common method of analysis for EBT Gafchromic film is with the use of a flat bed scanner[18-23]. This is due to, the ease of use and the high accuracy achievable with a relatively inexpensive scanner model.

One important aspect of EBT Gafchromic dosimetry is the known orientation effect whereby a difference in measured optical density (or scanner density units) is seen with film orientation to the scanning direction. ISP specifically states this is a known effect and recommends scanning take place in the landscape direction (i.e. the scanning plane parallel to the long axis of the film pieces). Butson et al's original work[22] found variations of 4 % - 15 % with a standard desktop scanner. Other authors have quantified this effect on their scanner with quite varying results. Lynch et al[20] found variations of the order of 8 % to 12 %. Saur et al [18] found similar values, whereas Zeidan et al [19] found up to 50% variations with different scanner types. These differences highlight the fact that the magnitude of this variation is scanner-specific and are most likely due to the level of light polarization that occurs during the scanning process. Klassen[24] showed how polarized light effected MD-55-2 film optical density. Similar work was performed by Butson et al[25]. A small component was found to be due to the MD-55-2 active layer whilst a larger component was found to be due to the films Mylar protective coating.

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Both the crystal structure and the protective coatings of EBT Gafchromic have changed from the MD-55-2 film type as shown by Rink et al[26]. These changes still allow effects of polarized light to produce variations in transmitted light. This work aims to quantify the best and worst case scenarios for the magnitude of the polarization effects with film orientation, thus defining the maximum and minimum variations that can be seen and accounted for.

Materials and methods

Experiments were performed with radiochromic film type Gafchromic EBT Lot No. 47277-06I (ISP Corp, Wayne NJ, USA) to analyse the magnitude of the light source polarization effect on transmitted optical density. EBT film is constructed with a multi-layer approach consisting of the active layer along with polyester protective coatings which allows the film to be easily handled and minimizes effects from ultraviolet exposure[27]. The effective atomic number of the EBT film is $Z_{eff} = 6.98$ compared to water $Z_{eff} = 7.42$. More detailed descriptions of the EBT film construction and properties are available in Butson[16]. To measure the variation in transmitted optical density of EBT Gafchromic film with polarized light, a greater than 99 % linear polarized light source was utilized within a dedicated built clam shell densitometer. The polarizer used was a linear polarized Kodak sheet (10 cm x 20 cm), which produced a reduction in transmitted light of 99.8 % when two pieces are positioned normal to each others axis of polarization. The clam shell densitometer was constructed using a 635 nm, 20 nm FWHM band pass diffused non – polarized Light Emitting Diode (LED) so as to allow analysis of the EBT near the peak absorption wavelength[17]. The transmitted intensity was measured using a non-polarized photo diode. Both devices were imbedded into the clam shell construction spot densitometer. This allowed the film to be measured over a 5 mm square area as a point dosimeter. Analysis was performed on the EBT Gafchromic films for absorbed doses ranging from 0 Gy to 5Gy. The films were analysed 1 day after irradiation to minimize post irradiated coloration effects[28]. The films were cut into 5 cm x 5 cm squares with the analysis performed at the centre of each film piece to avoid effects from pressure induced OD change [29]. The films were positions in the clam shell densitometer for analysis. The films were analysed with the diffused LED light source as well as with the linear polarizer between the light source and the EBT film to act like a linear polarized light source[25,30]. Measurements were made for optical density over a 360 ° rotation of the film in incremental steps of 10 °. More accurate measurements (within 2 °) were performed to measure the position of the maxima / minima optical density of the EBT film with the polarizer in place. The films orientation was defined as 0 ° when the long edge of the film is perpendicular to the direction of linear polarization of the sheet. A positive rotation occurs when the linear polarizer is turned clockwise with respect to the film. The angle of polarization for multiple films was measured and no significant variations were found within the films tested. From measured data, absorbed dose response curves and angular response curves have been produced. Errors were calculated using 10 sets of measurements on the same film pieces and shown on the figures as 1 standard deviation of the mean.

Results and discussion

Figure 1a shows the change in measured net optical density for various EBT films exposed to dose levels of 0cGy, 100 cGy, 200 cGy, 300 cGy and 500 cGy (as examples) as the angle of orientation is varied using a diffuse 635nm LED light source. As can be seen negligible variations are seen in the measured optical density of the film with angle. Although EBT film may act as a polarizing plate to some degree, if the initial light source is non polarized the intensity of the light transmitted will not be dependant on the angle of orientation of the film. On the other hand, figure 1b shows the same film pieces analysed with the fully linear polarized light source. A significant variation in measured optical density is seen. The maxima / minima values for 100 cGy and 500 cGy optical density values were 0.509 / 0.209 and 1.376 / 0.760 respectively. That is, when compared to the minimum optical density, a percentage increases of 143 % and 81 % exists with a 90 ° rotational change in the position of the polarizer. Similar values were found with other dose levels as shown in figure 1. The angular position of the maximum optical density was found not to exist at the 0° position of alignment but at approximately 14 ° ± 7 ° (2SD) when the polarizer is rotated clockwise with respect to the film. A comparison of the OD at the 0 ° and maximum position produces an average percentage difference in measured OD of approximately 2.5 %. The fact that the maximum OD value is positioned at a small angle off perpendicular polarizing position gives rise to a phenomena whereby a small misalignment in angular position in one direction will give rise to a much larger error or change in measured OD than would be the case for a similar sized misalignment in the other direction. This is specifically due to the zero degree position being near the cusp of the sinusoidal nature of the optical density polarization effect. Being an approximate 14 ° offset, the rate of change of the sinusoidal polarity function is an average of 1.2 % change for 5 ° OD rotation clockwise of the polarizer to film, as opposed to an average 4.5 % change for 5 ° rotation in the anticlockwise direction polarizer to film. Thus the direction of misalignment when using a polarized light source can produce a significantly different effect on measured optical density results. Although a 5 ° rotational offset may be visibly noticeable on a desktop scanner a 1 ° or 2 ° may not and this could introduce an extra 2 % uncertainty into the analysis.

Rink et al[26] shows an inverted light microscope image of the EBT active polymer layer. Shown, was the needle like layers of the film with the polymer chain being approximately 25 micrometers long and a few micrometers wide. Klassen et al[24] investigated the polarization effects of MD-55 film in the presence of polarized light and found

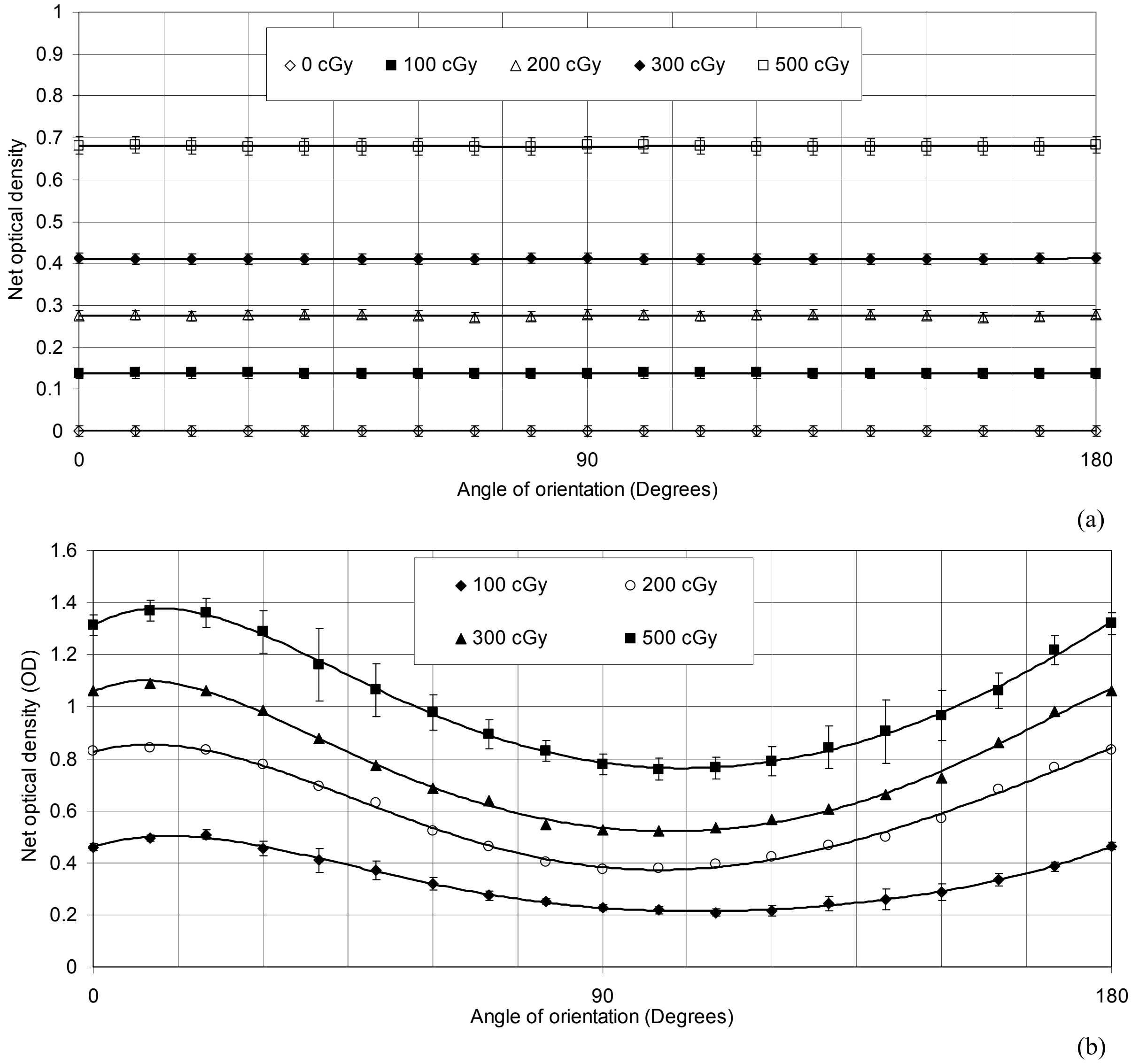

Figure 1. *(a) Angular response of net optical density for EBT Gafchromic film analysed with a non-polarized light source. (b) Orientation effect on net optical density of the EBT film analysed with a linearly polarized light source.*

significant variation in measured OD with changing angle of orientation which was attributed to the characteristics of the middle Mylar layer. Aside from the differences in the active layer, the EBT film utilizes a similar construction technique and materials as MD-55. In summary, the crystalline shape along with the aligned nature of the particles produces a diffraction grating effect whereby it will only allow light of certain electromagnetic orientation to pass through. This magnifies any polarization effects on measured optical density as seen with this film type.

When using a desktop scanner, in reflection or transmission mode a degree of polarization occurs as the light source is either reflected or transmitted through a glass plate or the like. This produces a degree of linear polarization which will be dependant on the type of glass and its construction as well as the light source initially used. This explains the large variation in orientation effects noted in the literature from multiple authors. It is a known effect and the manufacturers recommend using the film in the landscape scanning orientation. This is specifically due to the film providing a higher sensitivity in OD change per dose in this orientation. This work highlights however the actual extent of this polarization and the significance of the angular offset in optical density response if the light source is polarized to some degree.

Using a polarized light source thus can provide differences in measured optical density of the same film piece at different angles of orientation with respect to the polarization axis of the light source. Figure 2 shows the measured dose response curves at various angles of film orientation to the polarized light source, compared to OD when the diffused non-polarized light source is used. As can be seen, the sensitivity of the films response can be changed as a result of the films orientation, to a maximum variation of approximately 100 % using a > 99 % linear polarized light source. Similar but smaller variations will be

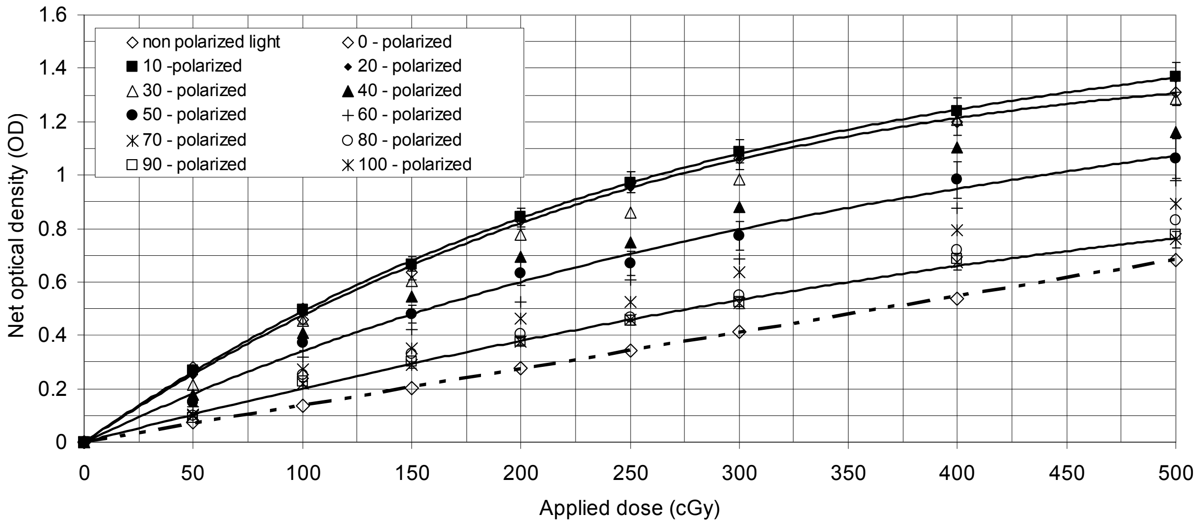

Figure 2. *Dose response curves for the EBT film analysed at various orientations with respect to a linear polarized light source.*

seen for desktop scanners which have semi polarized light sources. Thus the degree of dose sensitivity can become a function of the light source linear polarization and angle of incidence of the film.

Conclusion

This work has quantified the variation in measured optical density for EBT Gafchromic film in the presence of linear polarized light sources. Results have shown that a significant variation of more than 100 % in OD values occur with changing angle of orientation of the EBT Gafchromic film compared to the axis of polarization when polarized light is used. These effects can then either decrease or increase the sensitivity of the dose response of the film. The maximum OD value is offset from the 0° direction of the film by approximately 14 ° ± 7 ° (2SD) rotation. The result means that a small shift or set up error in one direction for the film produces a much larger error than the same size shift or error in the other direction. Results highlight the need to accurately set up the film in a reproducible orientation for any scanner or light source that is in some way polarized as is the case for most desktop scanners.

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