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NOTE

Polarization effects on a high-sensitivity radiochromic film

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Abstract

A new high-sensitivity radiochromic film has been tested for its polarization properties. Gafchromic HS film has been shown to produce a relatively small (less than 3%) variation in the optical density measured at 660 nm wavelength when the light source is fully linear polarized and the film is rotated through a 360° angle. Similar variations are seen when the detector is linearly polarized. If both the light source and the detector are linearly polarized, variations in the measured optical density can reach 15% when the film is rotated through a 360° angle. This seems to be due to a phase shift in polarized light caused by the radiochromic film resulting in the polarized light source becoming out of phase with the polarized detector. Gafchromic HS radiochromic film produces a minimal polarization response with varying angle of rotation; however, we recommend that a polarization test be performed on a densitometry system to establish the extent of its polarization properties before accuracy dosimetry is performed with radiochromic HS film.

1. Introduction

Gafchromic film has become a significant dosimetry tool in radiotherapy due to properties such as its relatively low energy dependence and automatic colouration (Klassen *et al* 1997, Niroomand-Rad *et al* 1998, McLaughlin *et al* 1991). Many radiochromic films are produced with various layers in their construction. As an example, Gafchromic MD-55-2 film is produced with multiple layers of Mylar protective coatings, radiosensitive gels and glue, whereas Gafchromic HS film is produced with a single active layer within two Mylar protective coatings. These types of constructions can produce effects based on the polarization qualities of the construction materials as well as the readout light sources or detectors used for optical density evaluation. Some analysing light sources are polarized to some degree

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whereas some are not. Light source diffraction grating photo spectrometers produce polarized light sources due to the nature of grating. He–Ne lasers can produce two orthogonally polarized modes in their densitometry light sources (Demspey *et al* 2000). Most top quality densitometers/scanners use polarization filter in their systems as it eliminates optical density measurement variations for reflectance measurements between glossy and matte images (Gretag Macbeth 2002). Klassen *et al* (1997) studied the polarization properties of the MD-55 Gafchromic film and found significant variations in the measured optical density with film rotation using polarized light sources and detectors. Variations larger than 50% were seen. As HS Gafchromic film has a different physical structure, it was considered that the polarization properties might also differ. In this short note we investigate the effects of polarized light sources and polarized detectors on dosimetry using relatively new high-sensitivity Gafchromic HS radiochromic film.

2. Materials and methods

Measurements to assess the effects of polarized light sources and detectors have been taken using a custom built densitometer. The densitometer was constructed using a 660 nm peak wavelength ultra bright light emitting diode source and a visible (red peaked) photo diode. The light source and detectors were placed approximately 0.5 cm apart, which allowed enough room for radiochromic film and two sheets of linear polarizer to be placed within the measurement area. The densitometer was constructed to allow the polarizer and radiochromic film to have 360° of rotation for the analysis. The polarization properties of the light source and detector were tested using a linear polarized sheet and producing optical density measurements through the 360° rotation. Results showed that the light source and detector had no measurable polarization properties with no systematic variation in measured optical density recorded with polarizer rotation. This densitometer was used as a base for the polarization property analysis.

The film used was Gafchromic HS batch number K0223HS. It was cut into 4 cm diameter circles for the analysis and doses from 0 Gy to 20 Gy were applied using a Varian 2100C accelerators at a photon energy of 6 MV in a RMI 30×30 cm^2 solid water (Constanitinou *et al* 1982) slab phantom at 100 cm source to surface distance for the analysis. Precautions in handling of radiochromic film outlined in TG-55 were taken, which included minimizing scratching and handling of the film with the use of gloves and a paper tag attached to the side of each film piece for manipulation. During experiments and analysis, the films were kept at temperatures of 22 ± 2 °C, thus reducing the effects of time- and temperature-dependent evolution and readout (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). Each film circle was attached to a calibrated set square which could easily rotate 360° within the constructed densitometer. The polarizers used were Coherent Scientific linear polarized sheets of size 10 cm $\times$ 10 cm. When the two sheets were placed together and rotated to a minimum transmission, approximately 0.2% transmission was observed using the 660 nm light source densitometer created for this research.

To test the polarization properties of the Gafchromic HS film, four tests were performed, which were (1) effects of film rotation with unpolarized lights and detectors, (2) effects on film dosimetry with a polarized light source, (3) effects of a polarized detector and (4) effects of both polarized light source and detector. Test 1 was performed by rotating the HS Gafchromic film through the 360° rotation and measuring the optical density results in 10° intervals. Test 2 was performed by fixing a linear polarized sheet to the LED, thus producing a linear polarized light source with unpolarized detector. The film was then rotated through 360° and the optical density was measured in 10° steps. Test 3 was performed by fixing the linear polarized

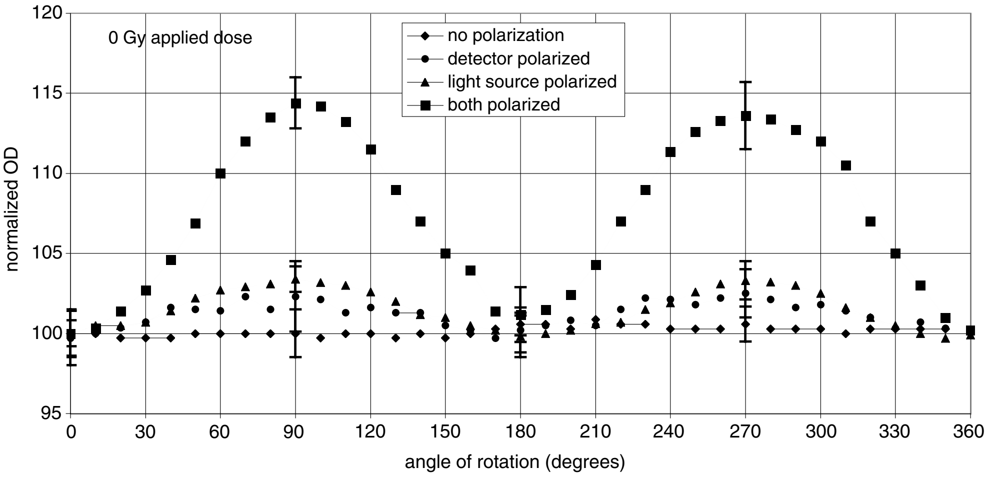

Figure 1. Variations in optical density as a function of the angle of rotation of the film for an unirradiated film. Results are for unpolarized densitometer, polarized light source, polarized detector and both polarized light source and detector.

sheet to the detector, thus producing a linear polarized detector with unpolarized light source. Again the Gafchromic film was inserted and the optical density was measured through 360° of rotation in 10° intervals. Test 4 was performed by attaching linear polarized sheets to both the light source and the detector. The orientation of the polarizers was made to produce a maximum intensity output, thus the linear polarization was in the same plane for the two sheets. The Gafchromic film was then inserted between the polarizers and the optical density was measured for the 360° rotation.

3. Results and discussion

Figure 1 shows the effects of polarized light sources, polarized detectors and both polarized light sources and detectors for unirradiated HS Gafchromic films. The initial absolute optical density for the film was approximately 0.15 at the 0° position. We have defined the 0° position as the position for minimum intensity output from the film when polarized conditions are applied. Error bars are only shown at 90° intervals to improve the clarity of the figures; however, they are representative of all measurements and are one standard deviation for five measurements over two pieces of film in each case. The results show that a small polarization effect occurs when only the light source or the detector is polarized. A maximum variation of 3% in the measured optical density (OD) was observed. This seems to be independent of whether the light source or the detector is polarized. When both the light source and the detector were polarized, a larger variation in the OD was observed with an approximate variation of 15%. Similar normalized results were seen for irradiated HS film as shown in figure 2. The results show the same configuration of polarized sources and detectors and both for a film exposed to the 15 Gy applied dose. Absolute optical density results for the film at the centre was found to be approximately 1.2OD for the 15 Gy applied dose at the 0° position. The results also show that an approximate 2.5% variation in the optical density is seen with polarized light source and polarized detectors separately and approximately 15% is seen with both linearly polarized. These results are similar for all measured doses between 0 Gy and 20 Gy. The variation in the measured OD for polarization experiments did not significantly

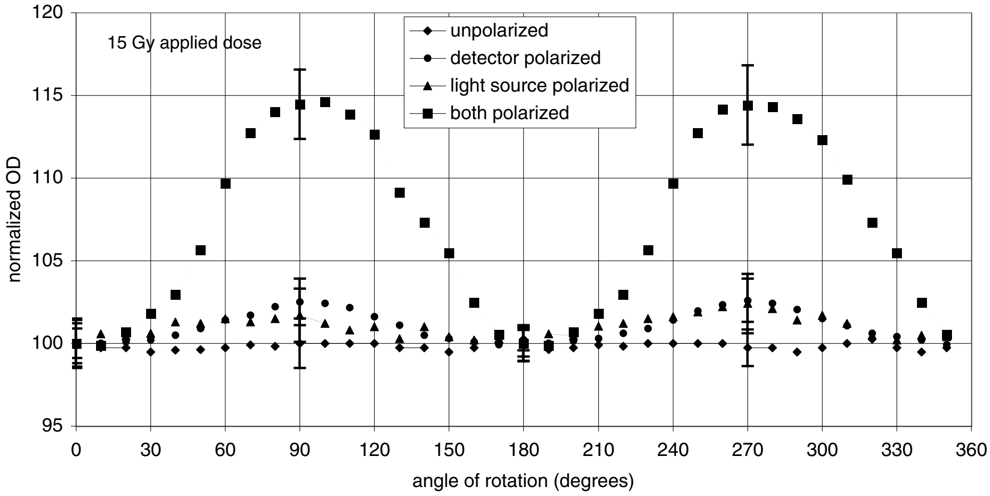

Figure 2. Variations in optical density as a function of the angle of rotation of a film irradiated to 15 Gy. Results are for unpolarized densitometer, polarized light source, polarized detector and both polarized light source and detector.

vary with various film pieces within the one film batch and they did not significantly differ with spatial movements across a film piece. From these results we can assume that the Gafchromic HS film is only slightly polarizing itself. Using either a polarized light source or a polarized detector, the degree of polarization within the HS film can be measured, which shows an approximate 2–3% peak-to-peak variation in normalized OD. The larger variation seen with the angle of rotation in both data sets presented is a result of a phase shift produced by the Gafchromic film in between the linearly polarized light source and detector as would be the case for many plastic-based thin films. That is the film shifts the phase of the light passing through, which is analogous to the polarizers being rotated to an out of phase position.

These results differ from those reported by Klassen *et al* (1997), who studied the Gafchromic MD-55-2 film. They found larger polarization effects produced by the MD-55 Gafchromic film. The HS film has a physical structure different from the MD-55-2 one and as such this may have improved the non-polarization properties of the film. The importance of the polarization properties of HS Gafchromic radiochromic film depends on the properties of the densitometry system you are using. Some densitometers or photo spectrometers may have polarized light sources or detector systems. The extent of the polarization properties of the light source and detector will in turn affect the quantity of the variations in the OD seen with angular rotation of the film. Thus we would recommend that a test for polarization with a polarized film should be used to assess this property for your densitometer before the film analysis is performed to improve the accuracy of dosimetry with HS Gafchromic film. If the degree of polarization is seen in the densitometers used, care must be taken when scanning the films to reproduce the same angle of orientation for each film piece analysed, including experimental and calibration films to eliminate any variation in measured optical density recorded.

4. Conclusion

Gafchromic HS radiochromic film has been tested for polarization properties and found to be minimally polarized. This in effect produces a small variation in the measured optical density as a function of the angle of rotation if a polarized light source or polarized detector system was used. If, however, a densitometer system has both polarized light source and detector, the Gafchromic HS film can significantly (up to 15%) change the measured optical density by producing a phase shift in the transmitted light as a function of the angle of rotation of the film. The polarization properties of a densitometer light source and detector should be tested before quantitative dosimetry is performed with HS radiochromic film to improve the accuracy of the dosimetry film. If the densitometer used has polarization properties, care must be taken to align all films used to the same angle of rotation to eliminate variations in measured OD caused by polarization and phase shifting properties.

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