Physica Medica (2010) **26**, 216–219

available at www.sciencedirect.com

ScienceDirect

journal homepage: http://intl.elsevierhealth.com/journals/ejmp

ORIGINAL PAPER

Scanning orientation and polarization effects for XRQA radiochromic film

Hani Alnawaf [c], **Martin J. Butson** [a,b,c,*], **Tsang Cheung** [a], **Peter K.N. Yu** [a]

[a] *City University of Hong Kong, Dept. of Physics and Materials Science, Kowloon Tong, Hong Kong*
[b] *Illawarra Cancer Care Centre, Department of Medical Physics, Crown St., Wollongong, NSW 2500, Australia*
[c] *Centre for Medical Radiation Physics, University of Wollongong, Northfields Ave., Gwynneville, NSW, Australia*

Received 25 March 2009; received in revised form 11 December 2009; accepted 14 January 2010
Available online 10 February 2010

KEYWORDS
Gafchromic XRQA;
Radiochromic film;
Densitometry;
Orientation

Abstract Gafchromic XRQA radiochromic film, is an effective tool for quality assurance and dose assessment in kilovoltage radiotherapy and diagnostic applications. Like other Gafchromic film products, XRQA film exhibits a variation in dose to reflected optical density response with angle of rotation when analysed with a light source that is partially or fully polarised such as a desktop scanner. Although warnings are not given on manufacturers specifications, this can affect dosimetry accuracy and we recommend that it is essential to scan all XRQA films in the same orientation. The effect is not as pronounced as EBT Gafchromic film. The magnitude of this variation has been measured and shown to be up to $16 \pm 2\%$ (1SD) using a fully linear polarised light source was seen with a 90° angle rotation. This would be the maximum variation seen on a desktop scanner with a fully polarised light source. For our standard desktop scanner (Epson v700) a mean variation of $2 \pm 1\%$ from 0 cGy to 20 cGy applied dose was measured as compared to $8 \pm 2\%$ for EBT Gafchromic. We recommend that to decrease uncertainty in dose measurement, accurate alignment of the calibration films to experimental films be performed on a regular basis. This is especially important if your desktop scanner has a high degree of polarization of its light source.

Introduction

For 2-dimensional quality assurance procedures and dosimetry analysis in diagnostic and therapeutic applications, radiochromic film has become an effective tool. As these films are automatically developing they remove the need for darkrooms and any form of processing post-irradiation. The most common method of analysis for

* Corresponding author. Dept. of Medical Physics, P.O. Box 1798, Wollongong, 2500 NSW, Australia. Fax: +61 2 42265397.
E-mail address: martin.butson@sesiahs.health.nsw.gov.au (M.J. Butson).

1120-1797/$ - see front matter © 2010 Associazione Italiana di Fisica Medica. Published by Elsevier Ltd. All rights reserved.
doi:10.1016/j.ejmp.2010.01.003

radiochromic films is with the use of a flat bed scanner [1–4]. This is due to, the ease of use and the high accuracy achievable with a relatively inexpensive scanner model. Many authors have investigated various effects and uncertainties which are introduced with the use of such scanners. One aspect is the fact that most desktop scanners due to their intrinsic design with either reflected or transmitted light sources through glass plates, produce a partially polarised light source. Authors have investigated these effects on films such as EBT Gafchromic and MD-55-2 Gafchromic films and have measured differing levels of variation in measured reflected optical density with angle of orientation of the film with the scanner plate. Variations up to 50% have been measured with fully polarised light sources and EBT Gafchromic film [2,5]. The differing quantity of variation quoted in the literature is most likely due to the degree of polarization occurring with the different types scanners. XRQA film is a type of reflectance dosimetry film which has been developed for analysis at low kilovoltage energies and low applied dose levels [6–9]. Examples where low applied dose measurements are of importance include estimation of doses to the eye lens behind eye shields or doses behind nasal shields in superficial facial radiotherapy. The films physical design is different from the transmission style films in that an opaque backing material is used so that the film can only be analysed in a reflective type manner. The film also incorporates a yellow coloured filter to aid in visual recognition of colour change at small doses. The aim of this study is to examine the effects on measured reflected optical density of scanner orientation for this film with semi-polarised and polarised light sources to examine if variations occur in measured reflected optical density with angle of orientation in order to improve accuracy of XRQA radiation dosimetry.

Materials and methods

Experiments were performed with radiochromic film type Gafchromic XRQA Lot# 36124-002 (ISP Corp, Wayne NJ, USA) to analyse the effects of film to scanner orientation with semi-polarised and polarised light sources. Gafchromic XRQA film is constructed with a multi-layer approach consisting of the active polymer along with polyester protective coatings which are utilized for a few features. The base coat polyester is a white opaque coating which is used to reflect the active layer colour change for visual inspection. The top polyester coating is a transparent yellow coloured filter which acts to protect the active layer and provide an enhanced visible colour change for the film upon radiation for qualitative QA procedures. As the base coat is opaque, the film can only be analysed using a reflective mode of analysis. This can be most easily performed using a desktop scanner.

To measure the variation in reflected optical density with respect to angle of film orientation of XRQA Gafchromic film with polarised light, a greater than 99% linear polarised light source was utilized. The polariser used was a linear polarised Kodak sheet (10 cm × 20 cm) and produced a reduction in transmitted light of 99.8% when two pieces are positions normal to each other's axis of polarization. Measurements were also made without the linear polarizing sheet to ascertain the effect caused by just the scanner alone. The linear polariser sheets when used were positioned parallel to the scanning axis within $\pm 1^{\circ}$. The films were analysed 1 day after irradiation to minimize post-irradiated coloration effects [10]. The films were cut into 10 cm × 10 cm squares using sharp scissors with the analysis performed at the centre of each film piece to avoid any optical damage which may occur due to the cutting process [11]. Measurements were made for reflected optical density over a 360° rotation of the film in incremental steps of 10°. The films orientation was defined as 0° when the film piece was in "landscape mode" and with the upper surface of the film, when removed from the commercial packaging, remaining the upper surface for analysis. The scanner used was an Epson V700 desktop scanner in reflective mode.

For dose delivery, the films were positioned in a solid water [12] phantom of dimensions 30 cm × 30 cm × 30 cm. The phantom was placed on a Gulmay (Gulmay Limited, Chertsey, Surrey, KT16 9EH, United Kingdom) D3300 orthovoltage machine using a 10 cm diameter circular field and films were given absorbed doses from 0 cGy to 20 cGy. Irradiations were performed at the surface, position of Dmax for the 100 kVp beam. All films were analysed using a PC desktop scanner and ImageJ [13,14] software on a PC workstation. The scanner used for quantitative analysis was an Epson Perfection V700 photo, dual lens system desktop scanner using a scanning resolution of 50 pixels per inch in reflection mode [15]. The images produced were 48 bit RGB colour images. An area of 3 cm × 3 cm was used to analyse the pixel values of the film. No filters or correction functions were applied to raw pixel value results. These images were analysed using the red component. Net Reflective optical density (ROD) for all films was calculated to evaluate energy and dose responses. Net ROD is defined as Eq. (1):

$$\text{Net ROD} = \log(P_u/P_t) \tag{1}$$

where P_u is the pixel value of the reflected intensity through an unexposed film at an orientation whereby the maximum pixel value is found and P_t is the pixel value of the reflected intensity at any other film orientation or irradiation level. Ohuchi [16] produced a similar definition for reflected optical density. For RXQA film this was found to be at approximately -10° (80°). The errors and uncertainties of results are the average of five film pieces used at each data point and measured five times each for average pixel value. Results are quoted to 1SD of the mean.

Results and discussion

Fig. 1 shows the variation in normalised net reflected optical density of XRQA film at various absorbed radiation doses (0 cGy, 10 cGy and 20 cGy) when analysed using a Epson V700 desktop scanner in normal scanning mode. Results are normalised to 1 at the maximum net reflected optical density measured for each film dose level. The absolute values for net reflected OD values were 0.205, 0.505, 0.785 at -10° orientation for 0 cGy, 10 cGy and 20 cGy respectively. As can be seen there is a small but

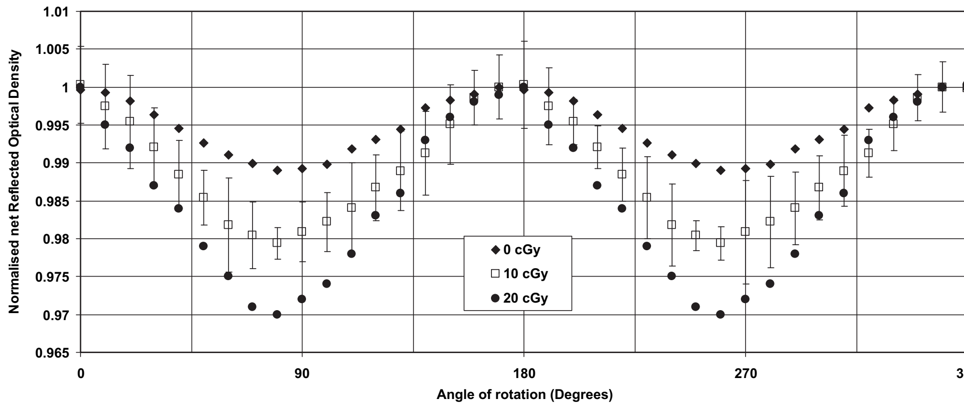

Figure 1 Variations in normalised reflected optical density for XRQA film when analysed on a Epson v700 desktop scanner in reflection mode.

measurable orientation effect when the film is rotated through 360° with respect to the desktop scanner position. The maximum variation seen is 3% at the dose level of 20 cGy. The net reflected OD to dose calibration curve produces a slightly non-linear 2nd order polynomial function. The non-linearity from 0 cGy to 20 cGy is less than 5%, i.e. the OD variation which would overestimate dose if a linear response was assumed would be less than 5% of the values quoted. Although the variation in measured reflected optical density is small for these film types they are both measurable and reproducible and can reduce the accuracy of dose measurement for this film type if orientation of scanning is not taken into account. Various authors have investigated similar orientation effects using EBT Gafchromic and found significantly different degrees of variation. It is assumed that a cause may be due to the degree of polarization which is present in different desktop scanners due to their own intrinsic physical characteristics. As such we have also investigated the magnitude of the orientation effect for XRQA film with a fully linear polarised light source.

Fig. 2 shows the effects of angle of orientation of the film to the scanner position using a fully linear polarised light source. As can be seen a much more significant variation is seen with angle of rotation with up to 16% variation in normalised reflective optical density occurring for a 20 cGy irradiated film piece. It is interesting to note that whilst the percentage variation for fully polarised light is significantly larger than for the partial polarised desktop scanner light source, the overall variation for the 3 given dose levels is relatively the same (i.e. approximately 3% variation in net reflected OD at each specific angle of orientation). It may be the case that the polarization effects are caused mainly by the films substrate and over-laminate rather than the XRQA films active layer. Fig. 2's results would represent the maximum variation which could occur for this film type due to polarization effects at this dose level. ISP Corp, the films manufacturers do not provide warning advice on their product sheet specifications or packaging of this effect as is the case for EBT Gafchromic film. Although the effect is not as large it is essential that film orientation is taken into consideration when dosimetry is being performed with this film type. Fig. 3 shows a comparison between the magnitude of the orientation effects of XRQA and EBT Gafchromic film [5] using the same scanner and polarised light sources. The EBT film was analysed using the same reflectance technique as the XRQA film. This shows that the orientation effect on EBT film can be approximately 4 times greater. So although orientation induced reflected optical density variations are much smaller for Gafchromic XRQA than those measured using Gafchromic EBT film, they could produce a significant uncertainty or error in measurement if they were not taken

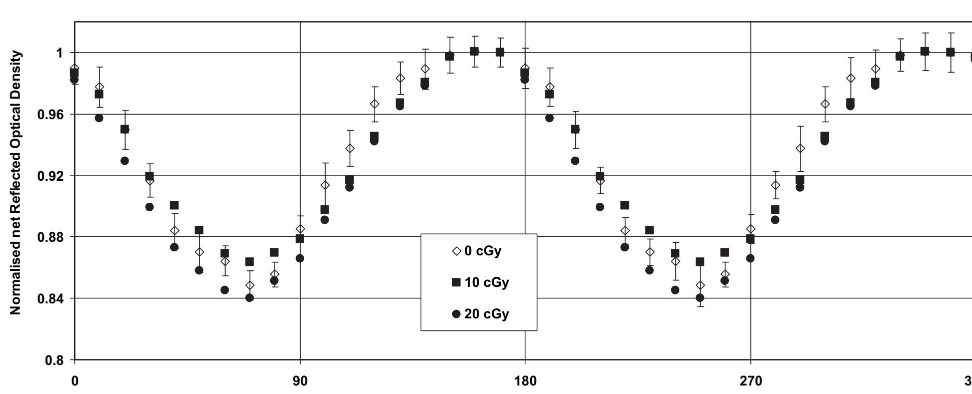

Figure 2 Variations in normalised reflected optical density for XRQA film when analysed with a fully linear polarised light source on a desktop scanner in reflection mode.

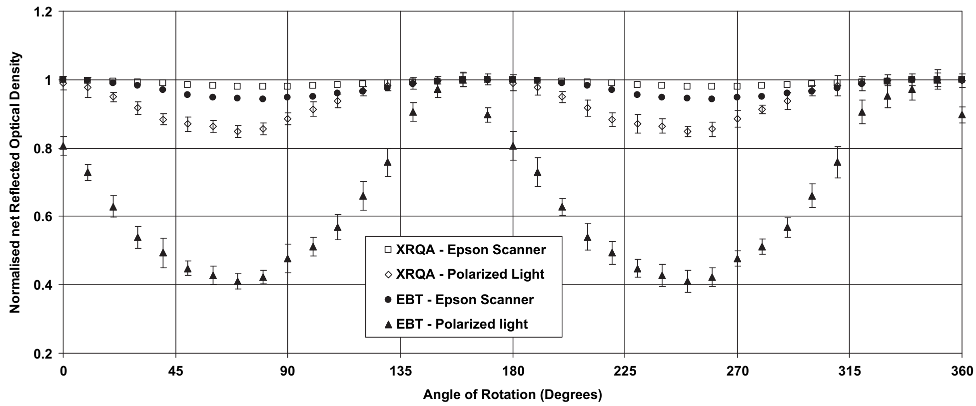

Figure 3 Comparison of the magnitude of orientation effects of XRQA film with conventional EBT Gafchromic film.

into account when a largely polarised light source is used for analysis.

Conclusion

This work has quantified the absolute variation in measured reflected optical density for XRQA Gafchromic film in the presence of linear polarised light sources and desktop scanners. Results have shown that variation occurs for net reflected OD values for changing angle of orientation for the XRQA Gafchromic film compared to the scanning plane when polarised light sources are used. This effect was small but measurable with our Epsom v700 desktop scanner but became more significant with up to $16 \pm 2\%$ (1SD) variation seen when a fully polarised light source was used. As such it is recommended that a same angle of orientation be used for XRQA film analysis compared to the scanner orientation for accurate film dosimetry, similar to the conditions that apply for Gafchromic EBT film.

Acknowledgements

This work has been fully supported by a grant from the Research Grants Council of HKSAR, China (Project No. 112108). Hani Alnawaf has been supported by a grant from the Saudi Arabian Government.

References

[1] Saur S, Frengen J. GafChromic EBT film dosimetry with flatbed CCD scanner: a novel background correction method and full dose uncertainty analysis. Med Phys 2008;35:3094—101.

[2] Zeidan OA, Stephenson SA, Meeks SL, Wagner TH, Willoughby TR, Kupelian PA, et al. Characterization and use of EBT radiochromic film for IMRT dose verification. Med Phys 2006;33:4064—72.

[3] Lynch BD, Kozelka J, Ranade MK, Li JG, Simon WE, Dempsey JF. Important considerations for radiochromic film dosimetry with flatbed CCD scanners and EBT GAFCHROMIC film. Med Phys 2006;33:4551—6.

[4] Dini SA, Koona RA, Ashburn JR, Meigooni AS. Dosimetric evaluation of GAFCHROMIC XR type T and XR type R films. J Appl Clin Med Phys 2005;6:114—34.

[5] Butson MJ, Cheung T, Yu PKN. Scanning orientation effects on Gafchromic EBT film dosimetry. Australas Phys Eng Sci Med 2006;29:281—4.

[6] Alnawaf H, Cheung T, Butson MJ, Yu PKN. Absorption spectra response of XR-QA Radiochromic film to x-ray radiation. Radiat Meas, in press, doi:10.1016/j.radmeas.2009.10.058.

[7] Chu RY, Lam T, Liang Y. GafChromic XR-QA film in testing panoramic dental radiography. J Appl Clin Med Phys 2007 Apr 19;8(2):110—3.

[8] Rampado O, Garelli E, Deagostini S, Ropolo R. Dose and energy dependence of response of Gafchromic XR-QA film for kilovoltage X-ray beams. Phys Med Biol 2006 Jun 7;51(11): 2871—81.

[9] Chiu-Tsao ST, Ho Y, Shankar R, Wang L, Harrison LB. Energy dependence of response of new high sensitivity radiochromic films for megavoltage and kilovoltage radiation energies. Med Phys 2005 Nov;32(11):3350—4.

[10] Cheung T, Butson MJ, Yu KN. Post irradiation coloration of Gafchromic EBT radiochromic film. Phys Med Biol 2005;50: N281—5.

[11] Yu PK, Butson M, Cheung T. Does mechanical pressure on radiochromic film affect optical absorption and dosimetry? Australas Phys Eng Sci Med 2006;29:285—7.

[12] Constanitinou C, Attix F, Paliwal B. A solid water phantom material for radiotherapy X-ray and gamma ray beam ray calculations. Med Phys 1982;9:436—41.

[13] Butson MJ, Cheung T, Yu PKN. Evaluation of the magnitude of EBT Gafchromic film polarization effects. Australas Phys Eng Sci Med 2009 Mar;32(1):21—5.

[14] http://rsbweb.nih.gov/ij/links.html [accessed June 2009].

[15] Thomas G, Li Y, Chu RY, Cheung JY, Maqbool F, Rabe F, et al. Measurement of dose-area product with GafChromic XR type R film. J Appl Clin Med Phys 2005 Summer;6(3):122—32.

[16] Ohuchi H. High sensitivity radiochromic film dosimetry using an optical common-mode rejection and a reflective-mode flatbed color scanner. Med Phys 2007 Nov;34(11): 4207—12.