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TECHNICAL NOTE

Measurement of radiotherapy superficial X-ray dose under eye shields with radiochromic film

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Abstract Accurate measurement and knowledge of dose delivered under eye shield during superficial X-ray radiotherapy is required for patient peripheral dose assessment. Critical structures can include the cornea, lens and retina. Measurement of dose under eye shields has been historically performed with Thermoluminescent Dosimeters (TLD's) due to their small size and design. Restrictions include the energy dependence and the fact that they only provide a point dose assessment. This note investigates the use of a low energy dependence radiochromic thin film for measurement of dose under eye shields in a phantom and compares results to theoretical calculation of dose. Results have shown a good match between predicted and experimentally measured results at the centre of an eye shield irradiated with 50 kVp and 150 kVp beams. The added advantage of radiochromic film compared to TLD measurements is the two dimensional dose map which is recorded for the assessment of dose providing not only an assessment at the site of the cornea, lens and retina in a phantom but in other areas as well. Radiochromic film has been found to accurately measure dose under eye shield in phantom treatments.

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Introduction

Eye shields are used in superficial radiotherapy of the periorbital region to reduce the dose delivered to critical structures beneath the area requiring treatment. Treatment areas often include the nasal bridge, medical canthus and the eye lids [1,14]. As such, a treatment field can be close to or over an eye. During this procedure the eye is shielded using

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a small high density (normally tungsten or lead) eye shield which is placed between the eye lid and the eye. Some areas requiring protection are the cornea, normally situated within the first 1 mm of tissue, lens, conjunctiva and the retina. All normally lay within the first 20 mm of depth. Baker et al. [3] produced empirical models to estimate absorbed dose behind eye shields. This theory produces a simple yet effective tool for estimation of dose under an eye shield. In essence the ratio of dose under an eye shield is given by

$$\frac{D_s}{D_u} \approx \frac{\mathrm{BSF(f)} - \mathrm{BSF(s)}}{1 + \mathrm{BSF(f)} - \mathrm{BSF(s)}} \qquad (1)$$

where D_s is the dose under the shield, D_u is the dose without the shield and BSF (f) and (s) are the back scatter factors for the open (non-shielded) field and shielded field size, respectively.

However, if more information is required to describe dose at a particular depth or a particular position under the shield, dosimetry must be performed. Historically, this has been performed using TLD (Coudin et al., 1997; [10]) where by dose assessment can be performed on a phantom or invivo. Advantages of the TLD's are their small size making measurements possible in such a small and tight geometric configuration. Their disadvantages, however, include energy dependence to a degree and they only provide a point dose measurement. The read out process is also relatively laborious. Although TLD's are small, they can produce discomfort to the patient during in-vivo use as they sometimes press against the eye and the cornea in particular. Radiochromic film in contrast provides a more energy independent assessment of dose and also provides a high spatial resolution with the ability to measure a two dimensional map of dose under an eye shield. This short note investigates the ability of EBT Gafchromic film to measure dose under eye shields in phantoms and compares results to prediction models.

Material and methods

The dosimetry under the eye shield was assessed using EBT Gafchromic, radiochromic film and compared to empirical models and (LiF) Thermoluminescent dosimeters. EBT Gafchromic film is constructed with a multi-layer approach consisting of the active polymer along with polyester protective coatings which allows the film to be easily handled and minimizes effects from ultraviolet exposure [4,5]. The effective atomic number of the EBT film is $Z_{\mathrm{eff}} = 6.98$ compared to water $Z_{\mathrm{eff}} = 7.3$, a comparatively close match compared to other radiochromic film types and radiographic film. It provides a low energy dependence (Butrson et al., 2006; [8]) and has an overall water equivalent thickness of approximately 300 μm. This construction and design allows the film to be relatively flexible compared to other film types and can curve around a cylindrical shape when required. This factor is utilised when measuring profile doses under an eye shield.

A Gulmay D3300 orthovoltage machine was used to deliver X-ray exposures, at 50 kVp (HVL: 1.4 mm Al), and 150 kVp (HVL: 0.627 mm Cu) energy. The given radiation exposure levels are based on absorbed dose to water calibrations performed with a Farmer thimble-type ionization chamber according to the IPEMB protocol for kilovoltage X-rays [2,12]. The phantom material used was RMI solid water phantom [9] of dimensions 30 cm × 30 cm × 30 cm. Hill et al. [11] examined the radiation absorption equivalency of RMI solid water to water and found a match within 1% over the energy range 75 kVp—300 kVp. To perform assessment of dose under an eye shield a 2.5 mm diameter lead eye shield (thickness 2 mm) is placed on top of a flat 30 cm × 30 cm × 30 cm phantom. To simulate the eye within the shield a wax insert was made and inserted under the eye shield in the shape of an eye. Radiochromic film strips were used to measure dose at depths of surface (0 mm), 5 mm and 20 mm in the flat solid water phantom. The film for the surface dose measurement was designed to curve up under the eye shield to simulate dose delivered to the eye surface. No visible damage was caused to the radiochromic film during this procedure. Due to the geometry of the eye phantom, an off set of 3 mm at the centre of the phantom was produced which accounts for the shape of the eye. That is, the measurement performed at 5 mm depth would measure dose at an approximate depth of 8 mm at the centre of the eye. These films were placed perpendicular to the beam direction and no curvature was made within the phantom at depth. Doses ranging from 2 Gy to 3 Gy were delivered during experimental procedures with field sizes ranging from 5 cm to 10 cm diameter circles. Results are quoted as a percentage of delivered dose if no eye shield was present. Lithium Fluoride, Thermoluminescent dosimeters (TLD) were also used in this study as a comparative dosimeter. TLD's were placed under the eye shield at its centre. These measurements were performed at the surface (0 mm) and at the 5 mm depth position. Standard readout and calibration techniques were used for these dosimeters producing an uncertainty in measurement accuracy of ±6% (2SD).

All films were analysed using a PC desktop scanner and Image J software on a PC workstation at least 24 h after irradiation to minimize effects from post irradiation colouration [7] which can be up to 9% over the first 12 h before becoming stable. The scanner used was an Epson perfection V700 photo, dual lens system desktop scanner using a scanning resolution of 150 pixels per inch. The uniformity response of this scanner was found to be within 1% over the central 80% of the scanning area. As such this area is always used for analysis. The images produced were 16 bit RGB colour images. These images were analysed with the full RGB components [6]. The net OD of films was calculated by subtraction of the fog optical density from the measured optical density of each irradiated film piece. From these results a 3rd order polynomial fit was produced using excel to produce an adequate fit as shown in Fig. 1. The polynomial function was then applied to measured net OD from experimental films to calculate exposure for each film. This was performed for every beam energy used in this work. To avoid problems associated with scanner homogeneity, the film pieces were each scanned in the same position at the centre of the scanner together with a control film.

Results and discussion

Fig. 2 shows the measured percentage dose profile across a 10 cm diameter field with a 2.5 cm radius eye shield in place (approx. at the field centre) at the surface, 5 mm

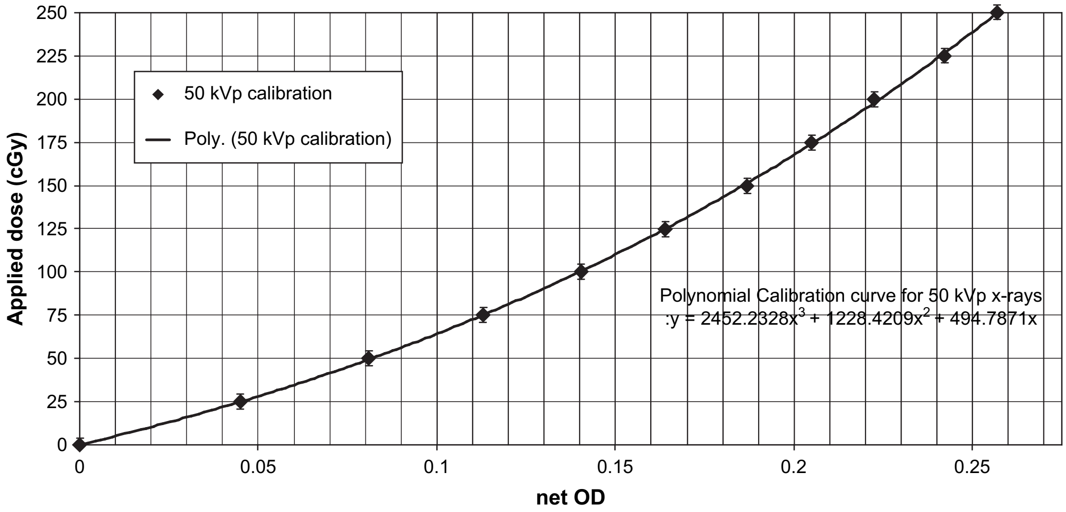

Figure 1 Calibration curve for EBTY Gafchromic film used for assessment of dose under eye shields in superficial X-ray radiotherapy.

and 20 mm depth for a 50 kVp X-ray beam. The surface dose profile film curves up underneath the eye shield to measure the dose delivered along the region simulating the sclera, conjunctiva and cornea. The other films were perpendicular to the beam direction and relate to the depths in the flat solid water phantom outside the eye shield. Results show that an average percentage dose under the shield (80% of geometric shield size) was 8.5%, 10% and 11.5% for the depths 0 mm, 5 mm and 20 mm, respectively. The predicted dose under the eye shield which was 7.5% using Eq. (1). Also shown on the figure are the point dose measurements using TLD's. Similar results are found within the uncertainty of dosimeter accuracy showing agreement between the detector measurements. Fig. 3 shows similar results at 150 kVp. Measured and predicted dose under the eye shields were 19% (surface), 20% (5 mm), 25% (20 mm) and 19% predicted by Eq. (1), again showing an adequate match using radiochromic film. Results shown in Figs. 2 and 3 are from one film each and give an example of the profile dose assessment. Experiments were repeated five times and variations in relative % dose were found to be within ±4% (2SD) under the shields area. This produces a slightly lower uncertainty than TLD's in measured results.

The TLD's used were 1 mm thus produced an effective depth of measurement of around 0.5—0.7 mm. This is compared to the approximate effective depth of measurement for EBT Gafchromic of 0.15 mm. This may be an issue in regards to measurement of low energy electrons produced near the lead surfaces from superficial X-ray backscatter, however no noticeable effects were seen with the EBT film measurements. It was assumed that the low density protective layer covering the inside of the eye shield absorbs any low energy electrons produced which have been backscattered. However, it may be more appropriate to use thin TLD's like 0.3 mm thickness for these measurements instead of 1 mm thick if EBT film is not available.

The percentage contribution to dose under the eye shield relative to maximum delivered dose ($D_{\max}$) was observed to increase with depth within the phantom. This is expected due to the increased contribution from scattered dose under the eye shield as depth increases. It is well known that at kilovoltage energies ranging from 50 kVp to

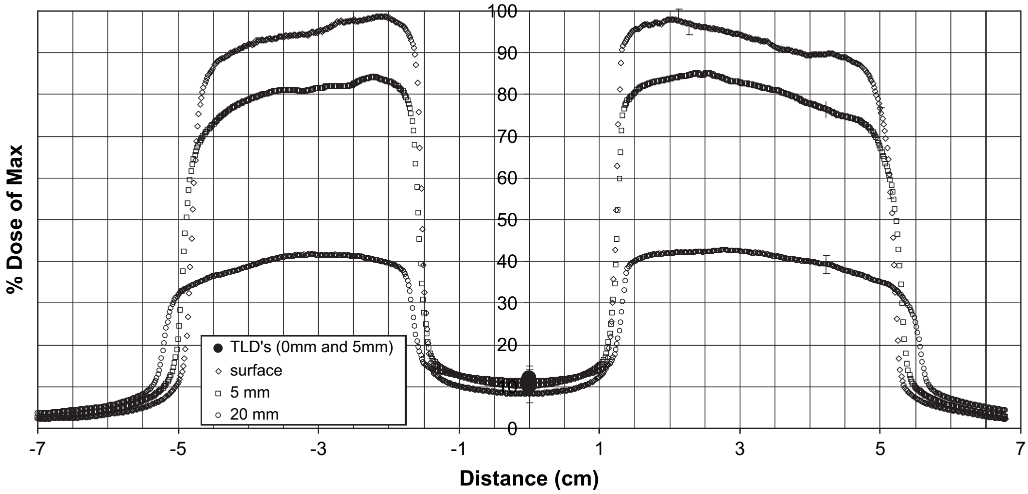

Figure 2 Representative percentage dose profile measured across a 50 kVp X-ray beam using an eye shield.

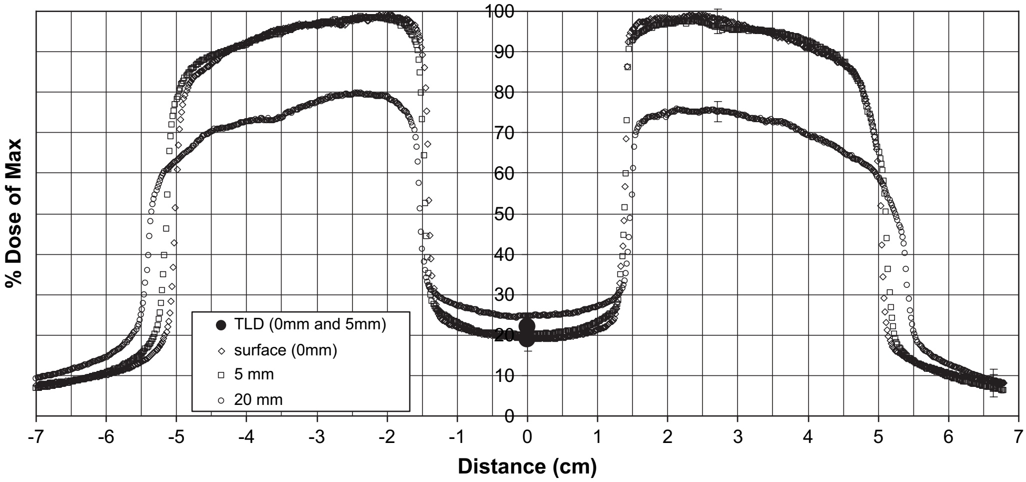

Figure 3 Representative percentage dose profile measured across a 150 kVp X-ray beam using an eye shield.

150 kVp, only minimal dose under eye shields is caused by primary beams photons (<1% in our case). As such, the back scatter contributions are the primary interaction for dose delivered at this site. Smith [13] showed that for orthovoltage beam energies that the back scatter factor increases by approximately 1%/mm of attenuating material in the beams path for full scatter conditions. This was analysed through the interaction of front plate material used in orthovoltage cones. A similar type of variation can be seen here. The dose under the shield is proportional to the backscatter factors for the given beam arrangements.

Gafchromic film is not only an accurate tool for the measurement of dose under eye shields, which matches well with theory for point dose assessment, but also allows the user to produce two dimensional dose assessment in the use of eye shields. This may be useful in areas where shielding edges are close to critical structures such as the conjunctiva which are normally just covered by shields. This area also highlights the importance of the ability to use two dimensional dosimeters where by dose assessment over the entire treatment field and peripheral regions can be performed providing substantially more data than a single point dosimeter. It is also useful for assessing dose in areas where contours occur as the film can bend around irregular geometries without producing optical effects. If the film if placed under too much pressure or acute angle damage can occur, however the user must be careful in placement and bending of the film to provide the optimal result. Damage is easily visibly identified so the user is aware if damage has occurred before irradiation begins. Whilst these results are performed on the phantom studied, results will be adaptable to in-vivo results. In-vivo measurement of dose under an eye shield is complicated mostly by the sensitivity of the cornea. Normally a few millimeter gap is present between the shield and the cornea as the shield sits directly on the sclera and its shape allows this small gap to occur for the cornea. This would allow a TLD or a small piece of Gafchromic film to be inserted in the centre of the shield without effecting patient comfort. The thin film (0.3 mm) would most certainly have less effect on patient comfort than a 1 mm thick TLD chip in other areas in contact with the patient eye.

Conclusions

EBT Gafchromic, radiochromic film has been shown to adequately measure radiation doses delivered under eye shields using phantom results and can be used for estimation of dose to critical structures such as the cornea, lens and retina during periorbital radiotherapy whilst using eye shields for patients. Results have shown that the EBT Gafchromic film measured dose was within 2% of predicted dose (at the surface) and provides the added advantage of being able to produce a two dimensional dose map of the shielded area. This may be of significance for areas which are just covered by the shield such as the conjunctiva.

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