SCIENTIFIC NOTE

Radiochromic film for verification of superficial x-ray backscatter factors

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Abstract

Accurate calculation and knowledge of backscatter factors (BSF) in superficial x-ray radiotherapy is required to perform accurate absorbed dose determination. These measurements have been performed historically with small thin parallel plate ionisation chambers and Thermoluminescent Dosimeters (TLD's). This note investigates the use of a low energy dependence radiochromic thin film (GAFCHROMIC™ EBT) for measurement and verification of backscatter factors. A single layer film and an extrapolation method with multiple films have been investigated. 50kVp to 150kVp beams were analysed and results for BSF were measured and compared to IPEMB (Institution of Physics and Engineering in Medicine and Biology UK) derived results. Agreement within 2% (1 SD) was found using both the single layer and extrapolation techniques with IPEMB derived results at 30cm SSD and equivalent photon energies. A 150kVp beam was found to have BSF of 1.12 ± 0.02 (2cm circle) , 1.24 ± 0.01 (5cm circle), 1.36 ± 0.02 (10cm circle) respectively compared to 1.11, 1.23 and 1.36 for IPEMB derived results. In summary a single layer film provided an accurate measurement and verification of BSF and was found to be within 2% of derived IPEMB results in all cases. The extrapolation method in general provided a slightly closer match to IPEMB results (<1%) but with no extra discernable accuracy than the single layer film most likely due to the already small thickness (0.3mm) of one film piece. GAFCHROMIC™ EBT, Radiochromic film provides a very simple and easy method for measurement and verification of BSF for x-ray energies commonly used for superficial x-ray therapy.

Key words

Introduction

Backscatter factors in radiotherapy are utilized for the calculation of absorbed dose in water through the measurement of exposure in air using the IPEMB protocol [1,2]. Using this method, Backscatter factors are defined as the tissue kerma ratio's, with and without backscatter material (water) present. It is well known that backscatter factors are dependant on many parameters such as beam energy, field size and source skin distance (SSD). Factors have been measured experimentally, previously by a number of authors. Klevenhagen [3,4] in particular developed a series of ionisation chambers specifically designed for measurement of backscatter factors using low atomic number material, plane parallel design and a phantom zero thickness extrapolation technique. Others (Coudin and Morunetto [5] and Podgorsak et al [6]) have used thermoluminescent dosimeters, TLD's with success for these measurements. Another approach which has provided data for backscatter factors is theoretical calculations using Monte Carlo techniques. The most recent and widely used data was performed by Grosswendt [7] and Knight in 1992 (cited in IPEMB 1996 [1]) and is the basis for backscatter factors used in the IPEMB along with experimental measurements performed by Klevenhagen [4].

In essence, to properly and accurately measure backscatter factors the dosimeter of choice requires a minimal thickness or at least the ability to extrapolate to a zero thickness to remove photon scatter contributions to measurements from any dosimetry material, as well as a low atomic number for water equivalence. The GAFCHROMIC™ EBT film is a radiochromic film model with the above mentioned characteristics. Its optical density to absorbed dose response differs by less than 3-5% over the energy range 50kVp to 150kVp [8], is only approximately 0.3 mm thick and could be easily used in a layered method to extrapolate to zero thickness. This film would also be useful for measurement of doses in x-ray guided interventional procedures due to its low energy dependence [9]. Using these characteristics, this note investigates the ability of GAFCHROMIC™ EBT film model to measure BSF's for x-ray qualities typically used for superficial radiotherapy.

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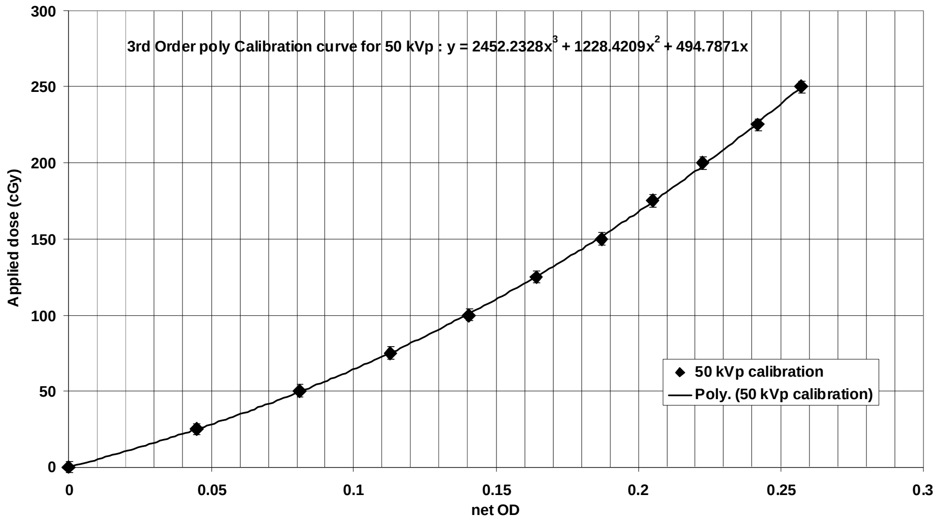

Figure 1. *Example calibration curve for a 50 kVp x-ray beam irradiation using GAFCHROMIC™ EBT film. From results, a 3rd order polynomial function was found to accurately match experimental data for conversion of experimental OD to absorbed dose.*

Material and methods

Backscatter factors are measured using a comparison between measured colour change for GAFCHROMIC™ EBT film in superficial x-ray beams when exposed with or without backscatter material present utilising experimentally verified optical density to absorbed dose calibration curves. GAFCHROMIC™ EBT 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 [10,11]. The effective atomic number of the EBT film is Z_{eff} = 6.98 [12] compared to water Z_{eff} = 7.3, a comparatively close match compared to other radiochromic film types and radiographic film. It provides a low energy dependence [7] and has an overall water equivalent thickness of approximately 300 µm. I.e. Ten times thinner than Klevenhagen's parallel plate ionisation chamber.

A Gulmay D3300 orthovoltage machine was used to deliver x-ray exposures ranging from 50kVp to 150kVp energy. Exposures from 0 Gy to 2.5 Gy were used. Radiation beam qualities used were 50kVp (HVL : 1.4mm Al), 75 kVp (HVL : 2.475mm Al), 100 kVp (HVL : 3.72mm Al) and 150 kVp (HVL : 0.627mm Cu). 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 [1]. The phantom material used was a RMI solid water phantom [13] of dimensions 30cm × 30cm × 30cm. Hill et al [14] examined the radiation absorption equivalency of RMI solid water to water and found a match to within 1% over the energy range 75kVp to 300kVp. As such we have examined our BSF's using RMI solid water with no corrections applied to our results. To perform the full backscatter material measurements, the GAFCHROMIC™ EBT film was placed on top of the solid water phantom during irradiations in full scatter conditions. For air measurements the film was held in the radiation beam at the required SSD using a thin (0.05mm) plastic sheet which was stretched across two support beams located 50cm away on each side from the measurement site. Thus no scatter material (except the 0.05mm plastic sheet) was within 50cm of the GAFCHROMIC™ EBT film during air irradiations. All exposures were performed at 30cm SSD with various clinical applicators producing field sizes ranging from 2cm to 10cm diameter circles.

Two experimental arrangements were tested, single layer and stack layer experiments. For the single layer experiment, a single sheet of GAFCHROMIC™ EBT film, 2cm × 2cm was irradiated in both the air and full scatter conditions. The choice of a 2cm × 2cm size was arbitrarily based on an easily handled film size which would produce a reproducible scan and not significantly provide extra scattering material for the experimental procedure. A film size of 10cm × 10cm was tested and found to produce negligible difference in the measured results due to the scattering conditions introduced. A film stack technique whereby 3 films, 2cm × 2cm were placed on top of each other during irradiation was also tested. As such each film piece would have a different amount of backscatter material present providing a method for extrapolation to zero thickness. The first layer s effective point of measurement was at 0.15mm, the second at 0.45mm and the third at 0.75mm which is the central position of each film layer scaled to physical density [15]. Utilizing these results, a linear extrapolation was performed to zero thickness and thus zero backscatter material

To calibrate the GAFCHROMIC™ EBT film optical density to absorbed dose conversion equations, a calibration curve was produced by irradiating GAFCHROMIC™ EBT film to known doses from 0 Gy to 2.5 Gy in 25 cGy steps as shown in figure 1. This was performed in a solid water

Table 1. *Measurement and calculated Backscatter Factors for a 50 kVp (1.4 mm Al HVL) superficial photon beam.*

Field diameter (cm)	Single layer	Extrapolation Method	IPEMB Derived	% Difference (single / IPEMB)	% Difference (Extrap / IPEMB)
2	1.12 ± 0.01	1.11 ± 0.02	1.10	1.7	0.9
3	1.14 ± 0.02	1.13 ± 0.02	1.12	1.3	1.0
5	1.17 ± 0.02	1.16 ± 0.02	1.16	1.4	0.5
10	1.21 ± 0.02	1.19 ± 0.02	1.20	0.7	0.6

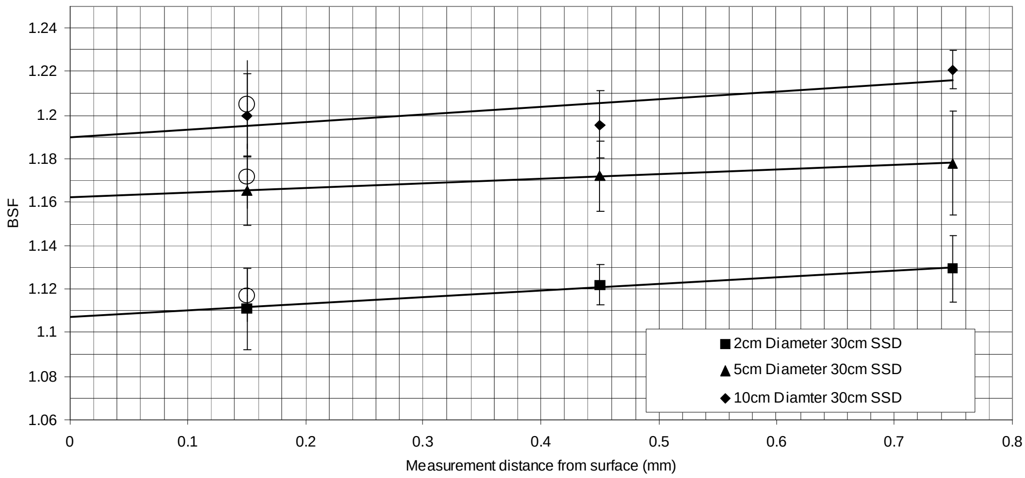

Figure 2. *Example linear extrapolation of Backscatter factors for a 50 kVp beam field sizes 2 cm, 5 cm and 10 cm circle. The BSF values measured with a single film layer are shown as well (open circles). The solid lines represent the linear function fitted through the measured values that were used to extrapolate to zero thickness.*

phantom. The net OD 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. 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. The scanner used was an Epson perfection V700 photo, dual lens system desktop scanner. This scanner uses a matrix CCD with a micro lens system which is capable of producing scanner resolutions of up to 9600 pixels per inch. It has a maximum measurable optical dentistry of 4.0 and uses a white cold cathode fluorescent lamp. Each film was analysed using the central 1.5 cm × 1.5 cm area with a scanning resolution of 150 pixels per inch using Image J software. Results used were the average values recorded within this area. Over this area and scanning resolution a standard deviation in average value was found to be approximately 1% (1SD of net OD) of the given value for most cases.

Results and discussion

Table 1 shows the results for measured backscatter factors for a 50 kVp x-ray beam as measured with the single layer film and the extrapolated technique. Also shown for comparison are the interpolated backscatter factors from the IPEMB data using equivalent HVL, field size and SSD data. Field sizes of 2 cm, 3 cm , 5 cm and 10 cm are quoted. As can be seen both the single layer film and extrapolation technique films produce results which are within 1.7% (1SD) to the IPEMB results for all field sizes from 2 cm to 10 cm at 30 cm SSD. Figure 2 shows the averaged results for 10 extrapolation measurements for a 2 cm, 5 cm and 10 cm diameter field at 50 kVp. The error bars show the standard deviation of the ten measurements taken for each point. These values highlight that the GAFCHROMIC^{TM} EBT film's use is subject to some uncertainty and that multiple measurements are required to improve the accuracy of the BSF value. By comparison of the extrapolated BSF to the IPEMB values the extrapolation method does produce a slightly closer match than the single layer film but not substantially. This is probably expected, due to the fact that the single layer film, being only 0.3 mm thick provides a very small amount of scatter material in the

Table 2. *Measurement and calculated Backscatter Factors for a 75kVp (2.475mm Al HVL) superficial photon beam.*

Field diameter (cm)	Single layer	Extrapolation Method	IPEMB Derived	% Difference (single / IPEMB)	% Difference (Extrap / IPEMB)
2	1.12 ± 0.017	1.12 ± 0.01	1.12	0.5	0.4
3	1.17 ± 0.021	1.16 ± 0.02	1.15	1.5	1.2
5	1.22 ± 0.016	1.21 ± 0.02	1.20	1.75	1.2
10	1.28 ± 0.013	1.28 ± 0.02	1.27	1.0	1.2

Table 3. *Measurement and calculated Backscatter Factors for a 100 kVp (3.72 mm Al HVL) superficial photon beam.*

Field diameter (cm)	Single layer	Extrapolation Method	IPEMB Derived	% Difference (single / IPEMB)	% Difference (Extrap / IPEMB)
2	1.12 ± 0.021	1.13 ± 0.02	1.12	0.2	0.3
3	1.18 ± 0.018	1.17 ± 0.01	1.16	1.2	0.5
5	1.24 ± 0.012	1.24 ± 0.02	1.23	1.1	0.7
10	1.34 ± 0.016	1.33 ± 0.02	1.32	1.8	1.1

Table 4. *Measurement and calculated Backscatter Factors for a 150 kVp (0.627 mm Cu HVL) superficial photon beam.*

Field diameter (cm)	Single layer	Extrapolation Method	IPEMB Derived	% Difference (single / IPEMB)	% Difference (Extrap / IPEMB)
2	1.12 ± 0.016	1.12 ± 0.02	1.11	1.2	1.4
3	1.17 ± 0.021	1.16 ± 0.02	1.15	1.4	1.0
5	1.24 ± 0.014	1.24 ± 0.02	1.23	1.1	0.6
10	1.36 ± 0.018	1.35 ± 0.02	1.36	0.3	0.4

first place and results would not change significantly with the increase of another 0.3 mm to 0.6 mm. We felt that the apparent increase in accuracy using the 3 layer technique (apparent as the results were closer to the IPEMB values) is not warranted due to the small gains found with significantly more detailed and laborious process required. Smith [16] performed experiments on the effects of front plate thickness on BSF for closed applicators at orthovoltage energies and found that an approximate increase in BSF of 1% per mm of materials would occur. Similar differences could be expected here.

Tables 2, 3 and 4 provide results for 75 kVp, 100 kVp and 150 kVp x-ray energies respectively with the single layer and extrapolation technique. The IPEMB results are also shown for comparison. In all cases, good matches to BSF were found within 2% with our measured results being in general slightly higher in value. Each superficial x-ray beam is slightly different and although a match for first HVL is found, there still maybe a slight variation in the spectral distributions of the beam utilised. As such, the energy spectral distribution for our beams (eg 50 kVp 1.4 mm HVL) may be different to the IPEMB (eg. 1.4mm) results. This may account for the difference in BSF's measured compared to the derived IPEMB values.

Using this measuring technique provides a simple method for analysis and measurement of BSF's in superficial radiotherapy. The GAFCHROMIC^{TM} EBT film is easily handled and is a cost and time effective way to measure backscatter factors. Other film characteristics might allow GAFCHROMIC^{TM} EBT to provide greater flexibility in measurement of backscattered dose in superficial radiotherapy. GAFCHROMIC^{TM} EBT has a high spatial resolution which could allow for measurement of backscatter in areas of heterogeneity. It is also flexible so may be suitable for measurement of BSF for irregular shaped areas such as around eyes, ears of other non flat surfaces. In summary the single film piece was found to accurately measure BSF for superficial x-rays with an easy experimental set up and analysis. Results compare well with those found in IPEMB within the expected uncertainties of values associated with differences in spectral contributions for the beams tested. Due to its low energy dependence and thin film design, GAFCHROMIC^{TM} EBT is a suitable detector for measurement of backscatter radiation in superficial radiotherapy applications.

Conclusions

Measurement of BSF's are required for calculation of absorbed dose determination in superficial x-ray radiotherapy. GAFCHROMIC™ EBT film has been shown to be a useful and accurate dosimetry for measurement and verification of Backscatter radiation. Results compared well with the IMEMB standards within the uncertainties of measurements. An extrapolation technique provided only slightly improved comparison of results to the IPEMB values (<1%) compared to a single layer film probably due to the already thin (0.3 mm) design of the film itself. As such a single piece of GAFCHROMIC™ EBT film can adequately measure and verify backscatter factors for a given superficial beam.

Acknowledgements

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