Measuring Solar Ultraviolet Exposure Dose on EBT3 Film Through the Application of Visible Absorbance Spectroscopy

Mohd Amirul Tajuddin and Ahmad Fairuz Omar

Abstract External Beam Therapy 3 (EBT3) film is the latest model of the EBT film that has been designed to overcome Newton's Rings artifact and the orientation problem of film during scanned process that occur in radiotherapy procedure. The original colour of the film (light green) will become darken (dark green) depending on the cumulative energy received on the film. This paper examined the applicability of EBT3 film in measuring solar ultraviolet (UV) exposure dose. The solar UV energy obtained through conventional UV meter was correlated with the colour changes of EBT3 film. The colour changes of the films were analyzed using visible absorbance spectroscopy technique. The 5 best wavelengths ($A_{506.77\text{ nm}}$, $A_{604.68\text{ nm}}$, $A_{658.17\text{ nm}}$, $A_{692.99\text{ nm}}$, $A_{699.83\text{ nm}}$) in the experiment produce calibration result with $R^2 = 98.5\ \%$ and RMSEC = 301.59 mJ/cm^2; and predicted result with $R^2 = 98.3\ \%$ and RMSEP = 381.92 mJ/cm^2, which mean high correlation between UV irradiance with colour changes of EBT3 film. The EBT3 film gave a good response toward UV dose with the increases in the absorbance of the film with the exposed dose. This means that the measurement of UV dose can be performed using EBT3 film.

Keywords Colour · EBT3 film · Spectroscopy · UV dose

1 Introduction

Ultraviolet (UV) ray is a component in electromagnetic spectrum. The primary source of UV ray is sunlight [1]. UV ray is formed by UVA (315–400 nm), UVB (280–315 nm) and UVC (100–280 nm). Only UVA and UVB reach the earth

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M.A. Tajuddin (✉) · A.F. Omar (✉)
School of Physics, Universiti Sains Malaysia, 11800 George Town,
Penang, Malaysia
e-mail: mahabbahsalam@gmail.com

A.F. Omar
e-mail: fairuz_omar@usm.my

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surface because the UVC is blocked from reaching the Earth's surface by the ozone layer. Although UV ray is important in stimulating the production of vitamin D in human body, but the excessive amount of UV dose received will result adverse effect to the body. UVA can cause the aging of the skin, UVB can cause sunburn [2], and UVC can cause cancer. Excessive UV radiation also can cause adverse effects to immune function and eye [3]. Furthermore the thinning of ozone layer will increase the possibility of UVC, the most dangerous portion among UV section, to reach the earth surface. Therefore it is important to measure the amount of UV dose received to make sure the risk of getting adverse effect can be decreased.

The level of UV dose can be measured by pyranometer [4], pyrheliometer [5] and UV meter [6]. Pyranometer are used for global solar UV irradiance measurement. Pyrheliometer measures direct beam solar UV irradiance. UV meter can detect UV irradiance on a wide range of sensitivities. Previous research showed that EBT and EBT2 film can be used for solar UV dose measurement. The films are known sensitive to x-ray radiation [7–9] however the contribution from other radiation was considered negligible. For instance, Butson et al. [10] had performed a study to measure solar UV radiation with EBT film and their experimental results show that the film changes from a clear colour to blue colour when exposed to UV. The colour change is reproducible within 10 % at 5 kJ m^{-2} UV exposures under various conditions of solar radiation [10]. In another related research, Butson et al. [11] studied the response of EBT2 film toward solar UV radiation and their results showing a reproducibility of measurement to within +7 % (1 SD) when compared to calibrated UV meters. This means that solar UV dosimetry can be performed using EBT2 film utilizing the underside of the film for dosimetry [11].

EBT3 is the latest model of EBT film that has been released for clinical dosimetry purpose [12]. The differences between EBT3 with its predecessor EBT2 are in term of the improvement of film symmetry and the elimination of Newton ring artifact [13]. The other aspects of the film are still same like its predecessor. So the response of EBT3 film toward UV ray is expected as same as its predecessor. Hence, this study is designed to investigate the ability of EBT3 to quantify solar UV (A and B) dose (mJ/cm^2). The calibration algorithm for the measurement of UV dose was constructed using visible spectroscopy spectra data that was used to interpret the colour changes of the films in relation to the different quantity of accumulated UV dose. The developed calibration algorithm was then used to predict the UV dose on a different sunny day, in determining the stability and reliability of developed technique in measuring solar UV dose.

2 Materials and Methods

The experiment used EBT3 film, with dimension of 8" × 10", manufactured by International Speciality Products (ISP) Technologies, Wayne, New Jersey, USA. Figure 1 show the configuration of EBT3 film. The film was cut into 48 small pieces with size 3 cm × 2 cm.

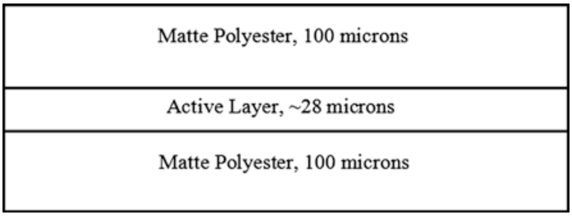

Fig. 1 The configuration of EBT3 film (ISP Technologies, Wayne, New Jersey, USA)

UV meter YK-35UV is used in this study. The UV meter is designed to detect UVA and UVB. The UV detector spectrum is from 290 to 390 nm. The UV meter has two ranges: 2 mW/cm^2 (1.999 mW/cm^2 × 0.001 mW/cm^2) and 20 mW/cm^2 (19.99 mW/cm2 × 0.01 mW/cm^2). The spectrometer used in this study is Jaz Spectrometer from Ocean Optics. Jaz Spectrometer has two channels. Channel 0 is for 200–850 nm while Channel 1 is for 650–1100 nm. Channel 0 had been chosen for absorbance measurement because it covered the wavelength of visible light. Tungsten halogen lamp, HL-2000 with spectral emission between 360 and 2000 nm and colour temperature of 2960 K has been used as illumination light source.

The experiment had been conducted from 11.45 am–12.33 pm at the rooftop of School of Physics, Universiti Sains Malaysia. The building's rooftop was chosen as the experimental location to ensure the maximum exposure of sun irradiance towards the surface of the films. During the experiment, the weather was hot with on and off appearance of clouds. 48 EBT3 films (size 3 cm × 2 cm) were placed on mahjong paper to make sure they do not have direct contact with the surface of the cement. The UV meter and the thermometer were placed exactly next to the EBT3 films during the measurement. For every one minute, one film was taken away from the paper. The exposed film was placed in the black envelope to make sure that it does not further exposed to any possible source of radiation. The reading of UV meter (mW/cm^2) and the thermometer (°C) were recorded. The same experiment had been conducted at different day from 11.43 am until 12.31 pm at the rooftop of School of Physics. The experiment follows the same setting of previous experiment. The purpose of the second experiment (prediction dataset) is to validate the results from earlier experiment (calibration dataset) and to ensure the repeatability of the proposed research setup (Table 1).

The film absorbance measurement was performed in Engineering Physics lab at School of Physics, Universiti Sains Malaysia using Jaz spectrometer with spectral

Table 1 Sampling characteristics

Sample	Irradiance (mW/cm^2)		Temperature (°C)		Time	
	Minimum	Maximum	Minimum	Maximum	From (am)	To (pm)
Calibration	1.47	4.87	33.6	42.0	11.45	12.33
Prediction	2.73	3.95	33.1	41.8	11.43	12.31

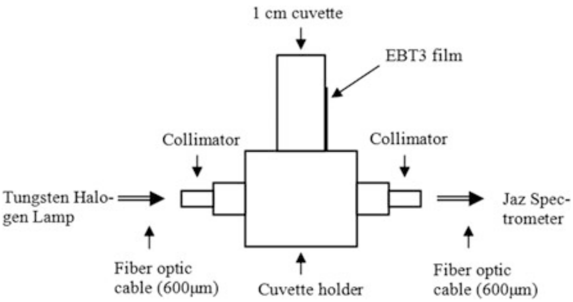

Fig. 2 Experimental set up for absorbance measurement

sensitivity within visible range of wavelengths (400–700 nm). Jaz spectrometer was connected to Tungsten Halogen Lamp via CUV 1 cm Cuvette Holder by optical fiber cables with core diameter of 600 μm. SpectraSuite software is a spectroscopy program which is used to capture and analyze spectral data from the experiment. An unexposed EBT3 film was used as a reference. In this absorbance spectroscopy experimental setup, the EBT3 film was placed in CUV 1 cm Cuvette Holder as illustrated in Fig. 2.

5 values of wavelengths were selected between 500.13 and 700.16 nm. The wavelengths were processed using Minitab (Version 17) software. The wavelengths were selected based on the performance of 3 variables. The first variable is the S-value (Root Mean Square of Error—RMSE). The wavelengths that can generate the lowest value of RMSE were selected. The second variable is the R^2-value (coefficient of determination). Wavelengths that give the highest percentage of R^2 were selected. The last variable is the P-value. The wavelengths with the lowest value of P that approximately (or preferably) less than 0.05 were selected. Figure 3 shows the absorbance spectra for EBT3 films with 3 different cumulative dose.

The performance of the calibration models and the accuracy of prediction result were evaluated using coefficient of determination, R^2 and root mean square of error, RMSE (calibration: RMSEC and prediction: RMSEP) which were calculated using Minitab (Version 17) software through the Eqs. 1 and 2:

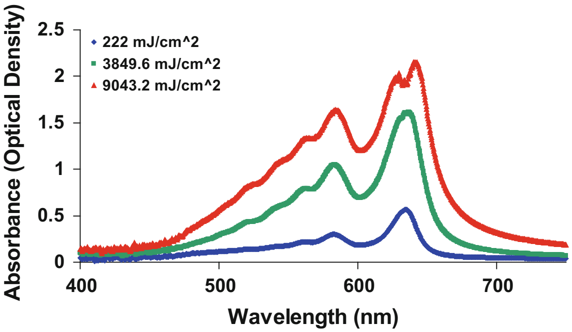

Fig. 3 Absorbance (optical density) versus wavelength (nm) for EBT3 films at 3 different cumulative dose

$$R^2 = \frac{\left[n\Sigma xy\ -\ (\Sigma x)(\Sigma y)\right]^2}{\left[n\Sigma x^2 - (\Sigma x)^2\right]\left[n\Sigma y^2 - (\Sigma y)^2\right]}. \tag{1}$$

$$\mathrm{RMSE} = \frac{\sqrt{\Sigma (y - Y)^2}}{n - 1} \tag{2}$$

3 Results and Discussion

The first experiment (for calibration dataset) was conducted from 11.45 am to 12.33 pm at the rooftop of School of Physics. 48 EBT3 films were used for this measurement. The weather is hot with average temperature throughout experiment was 36.7 °C. However the clear sky turned cloudy at certain period during experiment. As a result, some drastic fall of irradiance value at can be observed. The repetition experiment (for prediction dataset) was conducted on the next day from 11.43 am until 12.31 pm. Another 48 EBT3 films were used for this measurement. The weather during the second experiment was also hot with average temperature throughout experiment was 36.5 °C. Unlike the first experiment, for the second experiment, the sky is mostly clear throughout the period of experiment. This can be observed from the graphs illustrated in Fig. 4a and c.

Figure 4a shows the graph of irradiance versus time during the measurement of calibration set of data. The initial reading of solar UV irradiance is 4.26 mW/cm^2.

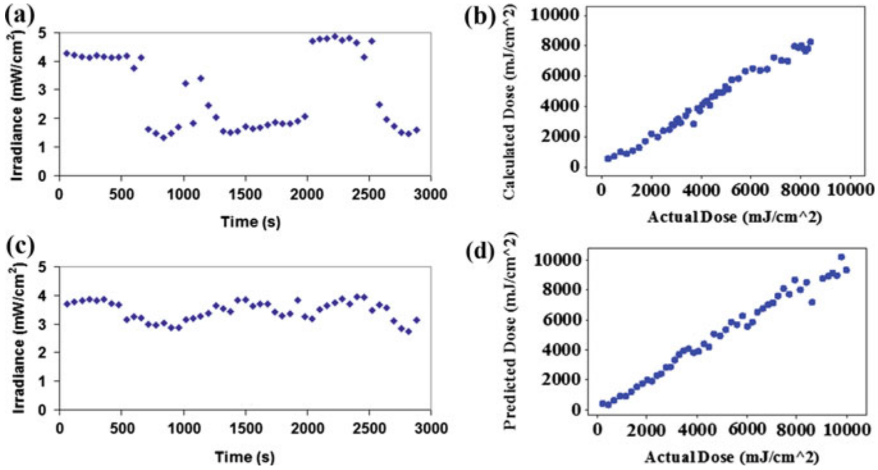

Fig. 4 Graphical representation of the measurement results. **a** Irradiance versus time for calibration dataset. **b** Calculated dose versus actual dose for the 5 best wavelengths ($A_{506.77\ \mathrm{nm}}$, $A_{604.68\ \mathrm{nm}}$, $A_{658.17\ \mathrm{nm}}$, $A_{692.99\ \mathrm{nm}}$, $A_{699.83\ \mathrm{nm}}$) for calibration dataset. **c** Irradiance versus time for prediction dataset. **d** Predicted dose versus actual dose for the 5 best wavelengths ($A_{506.77\ \mathrm{nm}}$, $A_{604.68\ \mathrm{nm}}$, $A_{658.17\ \mathrm{nm}}$, $A_{692.99\ \mathrm{nm}}$, $A_{699.83\ \mathrm{nm}}$) for prediction dataset

The irradiance readings were quite consistent until at 720 s (11.57 am) where the irradiance reading drops drastically to 1.62 mW/cm^2. This happen because at this moment there are clouds that minimizes solar UV irradiance penetration to the ground. The irradiance reading begins to increase when the sky turned clear again. The minimum irradiance reading was recorded at 1.47 mW/cm^2 and the maximum irradiance reading was recorded at 4.87 mW/cm^2. The cumulative dose for this experiment is 8389.2 mJ/cm^2. Figure 4b shows the graph of calculated dose versus actual dose for 5 best wavelengths ($A_{506.77\ nm}$, $A_{604.68\ nm}$, $A_{658.17\ nm}$, $A_{692.99\ nm}$, $A_{699.83\ nm}$) developed using calibration dataset. The calibration algorithm generated is given by Eq. 3:

$$\begin{aligned} \text{UV Dose}\left(\text{mJ/cm}^2\right) &= 689 + 15183(A_{506.77\ nm}) - 5547(A_{604.68\ nm}) + 18306(A_{658.17\ nm}) \\ &\quad - 42291(A_{692.99\ nm}) + 7537(A_{699.83\ nm}) \\ R^2(\text{calibration}) &= 98.5\ \%;\ \text{RMSEC} = 301.59\ \text{mJ/cm}^2 \end{aligned} \tag{3}$$

Figure 4c shows the graph of irradiance versus time during the measurement of prediction set of data. The initial reading of irradiance value is 3.70 mW/cm^2. The irradiance readings were quite consistent throughout the experiment because in average the sky throughout the experiment is clear. The minimum irradiance reading is 2.73 mW/cm^2 and the maximum irradiance reading is 3.95 mW/cm^2. The cumulative dose for this experiment is 9968.4 mJ/cm^2. Figure 4d shows the graph of predicted dose versus actual dose for the 5 best wavelengths ($A_{506.77\ nm}$, $A_{604.68\ nm}$, $A_{658.17\ nm}$, $A_{692.99\ nm}$, $A_{699.83\ nm}$). This graph was obtained by substituting the films' absorbance obtained from the prediction dataset (Fig. 4c) into the calibration algorithm defined by Eq. 3. The resultant prediction values of UV dose produced a high measurement accuracy with R^2 = 98.3 % and RMSEP = 381.92 mJ/cm^2.

Table 2 shows the comparative results obtained when several other combination of wavelengths were used in producing calibration and prediction results for the

Table 2 The values of parameters that being evaluated in the selection of 5 best wavelengths

	Wavelength (nm)	Calibration		Prediction	
		RMSEC (mJ/cm^2)	R^2 (%)	RMSEP (mJ/cm^2)	R^2 (%)
1	506.77, 604.68, 658.17, 692.99, 699.83	301.59	98.5	381.92	98.3
2	550.11, 604.68, 629.89, 658.17, 699.83	274.44	98.7	439.42	97.7
3	550.11, 604.68, 658.17, 692.99, 699.83	273.29	98.7	443.00	97.7
4	550.11, 604.68, 630.22, 658.17, 699.83	268.60	98.8	460.24	97.5
5	550.11, 604.68, 630.56, 658.17, 699.83	251.70	98.9	523.70	96.8

measurement of solar UV dose. These selected wavelengths are capable of producing relatively high calibration accuracy. However, despite able to produce high calibration accuracy, certain combination of wavelengths might result in lower prediction accuracy. For instance, the fifth series of wavelengths produced lower prediction accuracy with R^2 of 96.8 % and RMSEP of 523.7 mJ/cm^2 despite has generated high calibration accuracy with R^2 of 98.9 % and RMSEC of 251.7 mJ/cm^2. The first series of wavelengths are considered the best results for this study as has been presented in Fig. 4. Wavelengths 604.68 and 699.83 nm are considered the most important wavelengths in determining the colour changes of EBT3 films due the solar UV dose.

4 Conclusion

The EBT3 film gave a good response with the increase in the absorbance of the film with the exposed UV dose. In other words, solar UV dosimetry can be performed using EBT3 film because the colour changes of EBT3 film is highly correlated with the UV dose that is accumulated by the film. Additionally, in the application of visible absorbance spectroscopy technique in determining the colour changes of the films, the wavelengths selection is an essential part of the process in generating a higher prediction accuracy of the UV dose. Throughout the experiment, the highest irradiance obtained was 4.87 mW/cm^2 at 12.22 pm while the highest cumulative exposure dose on film was measured at 9968.4 mJ/cm^2. In this study, the 5 best wavelength selected ($A_{506.77\ nm}$, $A_{604.68\ nm}$, $A_{658.17\ nm}$, $A_{692.99\ nm}$, $A_{699.83\ nm}$) produce calibration result with $R^2 = 98.5$ % and RMSEC = 301.59 mJ/cm^2 and predicted result with $R^2 = 98.3$ % and RMSEP = 381.92 mJ/cm^2.

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References

1. Zeman G (2011) Ultraviolet radiation. Health Phys Soc. Accessed from. http://hps.org/hpspublications/articles/uv.html
2. Matsumura Y, Ananthaswamy HN (2003) Toxic effects of ultraviolet radiation on the skin. Toxicol Appl Pharmacol 195:298–308
3. World Health Organization, and International Commission on Non-Ionizing Radiation Protection (2002) Global solar UV index: a practical guide
4. Martinez MA, Andujar JM, Enrique JM (2009) A new and inexpensive pyranometer for the visible spectral range. Sensors 9:4615–4634
5. Eltbaakh YA, Ruslan MH, Alghoul MA, Othman MY, Sopian K, Fadhel MI (2011) Measurement of total spectral solar irradiance: overview of existing research. Renew Sustain Energy Rev 15:1403–1426

6. Ellis J, Harris B (2014) July 5 UV meter. http://www.wisegeek.com/what-is-a-uv-meter.htm. Accessed 2 July 2014
7. Butson M, Yu P, Metcalfe P (1998) Effects of readout light sources and ambient light on radiochromic film. Phys Med Biol 43:2407–2412
8. Butson MJ, Yu P, Metcalfe P (1998) Measurement of off-axis and peripheral skin dose using radiochromic film. Phys Med Biol 43:2647–2650
9. Cheung T, Butson MJ, Yu PKN (2006) Indepence of calibration curves for EBT Gafchromic films of the size of high-energy x-ray fields. Appl Radiat Isot 64:1027–1030
10. Butson ET, Cheung T, Yu PKN, Butson MJ (2010) Measuring solar UV radiation with EBT radiochromic film. Phys Med Biol 55:N487–N493
11. Butson ET, Yu PKN, Butson MJ (2013) Solar ultraviolet radiation response of EBT2 gafchromic, radiochromic film. Phys Med Biol 58:N287–N294
12. Sorriaux J, Kacperek A, Rossomme S, Lee JA, Bertrand D, Vynckier S, Sterpin E (2013) Evaluation of gafchromic EBT3 films characteristics in therapy photon, electron and proton beams. Phys Med 29(6):599–606
13. Villarreal-Barajas E, Khan RF (2014) Energy response of EBT3 radiochromic films: implications for dosimetry in kilovoltage range. J Appl Clin Med Phys 15:1–7