Short Communication

Evaluation of Dose Rate and Photon Energy Dependence of Gafchromic EBT3 Film Irradiating with 6 MV and Co-60 Photon Beams

Abstract

Gafchromic films are utilized for two-dimensional dose distribution measurements, especially in radiotherapy. In this study, we investigated a close connection between energy and dose rate of Gafchromic EBT3 films irradiating with 6 MV and Co-60 photon beams over a broad dose range. EBT3 films were exposed to 6 MV and Co-60 photon beams using 4 and 2 Gy/min dose rates over a 10–400 cGy dose range. The films were scanned in red, green, and blue channels to obtain the optical density (OD)–dose curves. The OD–dose curves resulted from three-color scans for different photon energies and dose rates were compared by statistical independent *t*-test. For the radiations of Co-60 and 6 MV photon beams, the highest correlation was obtained between the 2 and 4 Gy/min dose rates with red and green channels, respectively. Moreover, the red channel had a greater OD response per dose value, following the green and blue channels. There was no significant difference between different photon energies' (Co-60 and 6 MV) and dose rates' (2 and 4 Gy/min) dependence on OD-dose response of EBT3 films over a broad domain of radiation dose, except for different photon energies in the blue channel. Our results revealed that the OD-dose response of EBT3 films is independent on photon energies (Co-60 and 6 MV) and dose rate (2 and 4 Gy/min) in the evaluated dose range (10–400 cGy). Therefore, the EBT3 films are suitable, consistent, and reliable instruments for dose measurements in radiotherapy.

Keywords: *Dose rate response, dosimetry, EBT3 films, energy dependence, radiotherapy*

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Introduction

In radiation therapy, quantitative evaluation or estimation of dose distribution and measurement of patients' delivered absolute dose is necessary. In fact, the correctness and precision of treatment planning process and dose delivery are important for controlling the tumor and sparing the normal tissues from inessential radiation doses.[1,2] One of the dosimetric procedures for the measurements of dose distribution is film dosimetery, and it would be more useful when a permanent record of the measurement is required.[3]

Gafchromic™ films have lots of advantages and they are broadly utilized in radiotherapy; for example, verifying treatment planning systems, evaluating two-dimensional ambient absorbed dose, and investigating dose distribution in small radiotherapy fields.[4] The EBT and EBT2 films are typical types of Gafchromic™ films which are used in radiation therapy quality assurance (QA) and have several important advantages including better spatial resolution, energy and dose rate independency, effective atomic number and a density close to the soft tissue or water, lower sensitivity to room light (resulting in easy handling), and low postirradiation growth.[5-7] In addition, these films are self-developing; therefore, they do not need the conventional chemical processing[6] and also, they can be shaped to fit in any phantom.[7]

In 2011, the latest version of Gafchromic films, the EBT3 films (International Specialty Products, Wayne, NJ, USA), were introduced which have the active layer composites similar to EBT2 but with symmetric structure and higher dosimetric accuracy.[8] Nowadays, the EBT3 film is most commonly used for clinical dosimetry, due to its symmetric structure which eliminates the response dependence of the exposure direction[9]

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and also the active layer which is located between the two equal polyester layers which prevents the formation of Newton's Rings.[10]

There are several studies investigating the responses of EBT, EBT2, and EBT3 films which were irradiated to different beams. In a study, Massillon *et al*.[4] reported that the photon energy dependence of EBT2 and EBT3 films is related to the innate characteristic of each film, type of photon beams, and the color channel. In another study[8], they demonstrated that the dose-response curves of EBT3 films related slightly to the high photon energies such as 6 and15 MV, but this relation was significant for photon with low energies (e.g. 50 kV). Also the dose-response depended the color channel.

The EBT3 films are alternatives for the widely used old versions "EBT/EBT2;" it is extremely important to understand these new kinds of film characteristics, especially the energy and dose rate dependence over various dose ranges. There is no study comparing the dose response of EBT3 film for Co-60 and 6 MV photon energies in different dose rates. Thus, in the current study, energy and dose rate dependence of EBT3 films exposed to 6 MV and Co-60 photon beams has been investigated over a wide dose range.

Materials and Methods

Gafchromic™ EBT3 film

Gafchromic™ EBT3 film of size 8" ×10" was used in this study. All measurements were conducted based on the recommendations of the IAEA-TRS398 protocol.[11]

These films are composed of an active layer, with a thickness of 28 µm, located between two 125 µm matte-polyester materials[12] [Figure 1]. The structure of the EBT3 film eliminates its placement position dependency in the scanning procedure. The polyester used in the EBT3 film has a particular surface which contains silica particles of microscale size, which produces an interval between the film surface and the glass window in a flatbed scanner and prevents the Newton's Rings effect.

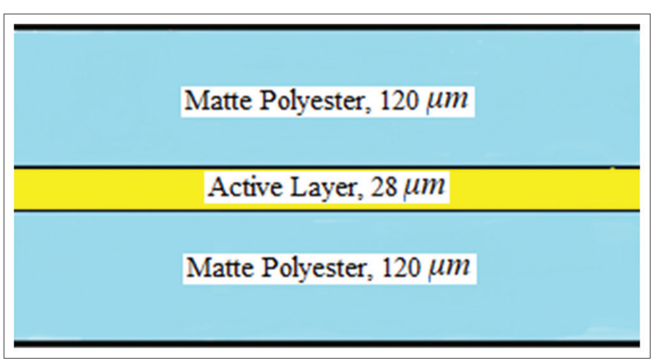

Figure 1: Configuration of EBT3 film

Film irradiation and calibration process

The film was exposed to 6 MV X-ray photon beams emitted from a Varian clinac 600C linear accelerator (Varian Medical Systems, Palo Alto, CA) and Co-60 gamma rays from a Theratron 780-C therapy machine (Theratronics, Ontario, Canada).

For calibration of the films, slab phantom plates (PTW, Freiburg, Germany) made up of acrylic with 1-cm thickness and size of 30 cm × 30 cm were used. Source-to-surface distance was chosen as 100 and 65 cm for 6 MV and Co-60 photon beams, respectively. Field size of 10 cm × 10 cm was selected for all the irradiations. Finally, the film pieces were placed at the maximum dose depth in the phantom irradiating with 6 MV and Co-60 photon beams.

A calibration data set was acquired by placing the 10-cm slabs of water-equivalent materials underneath to produce full scattering conditions.[3] Corrections related to scattering and thickness were applied as follows for equalizing the acrylic slabs' phantom measurements to water phantom measurements:[13]

$$Z_w = 1.136 \times Z_p \times 0.998 \quad (1)$$

Where Z_w and Z_p are water-equivalent and acrylic slab phantom thicknesses, respectively. For creating the full scattering condition, 9-cm acrylic slabs which are equivalent to 10 cm of water were positioned under the films. To produce a buildup region, 5-cm and 2-cm acrylic slabs were also used on the top of the EBT3 films when irradiated to 6 MV and Co-60 photon beams, respectively.

To verify the delivered absolute dose values at the films' locations, a Farmer type 30013 ionization chamber with a sensitive volume of 0.6 cc (PTW, Freiburg, Germany) was used at the dosimetric condition similar as the film irradiation setup.

Dose rate and photon energy dependency of the EBT3 film

To investigate the dose rate dependency of the EBT3 films, they were exposed to 6 MV beams at dose rates of 200 and 400 cGy/min. To investigate their response dependency to photon energy, the EBT3 films were exposed to 6 MV and Co-60 photon beams at the dose rate of 200 cGy/min. Dose levels selected for plotting the calibration curves were 10, 20, 40, 80, 120, 160, 200, 240, 300, and 400 cGy. Three film pieces were exposed sequentially to each of the 10 dose levels. One piece of the same sheet was utilized to evaluate the background dose.

Scanning and analysis of the film

All films were kept under the same condition (temperature, humidity, etc.). They irradiated in the same day to decrease the variability. After 48 h of irradiation, all film pieces were scanned three times consecutively at the same location at the center of a Microtek 9800XL scanner (Microtek Inc., Santa Fe Spring, CA, USA). The films were scanned with a 150-dpi (0.17 mm) spatial resolution at the transmission scan mode, landscape orientation, and in three- color channels (48-bit red, green, and blue channels). The obtained images were stored in the tagged image file format and analyzed by ImageJ software (National Institute of Health, Bethesda, MD, USA). Finally, net optical densities (ODs) were obtained as follows, based on the proposed method by Devic:[14]

$$\Delta(net\ OD) = netOD - netOD^{control} = log\frac{PV_{unirradiated}}{PV_{irradiated}} - log\frac{PV^{control}_{unirradiated}}{PV^{control}_{irradiated}} \quad (2)$$

Where $PV_{unirradiated}$ and $PV_{irradiated}$ are "average pixel value of nonirradiated film" and "average pixel value of irradiated film," respectively. The control film was kept in the irradiation room for the same time period as the calibration film. It is notable that all filters and contrast enhancers as well as other factors were switched off, and analysis was performed at the center of the film applying a region of interest equal to 1.21 cm × 1.21 cm.

Statistical differences between the net OD of two dose rate values in the two energies and responses of three-color channels were determined using the independent *t*-test by SPSS software version 11.5 (SPSS Inc., Chicago, IL, USA). $P < 0.05$ was considered as the statistical significance level.

Results

The responses of EBT3 films for Co-60 (2 Gy/min) and 6 MV (4 and 2 Gy/min) photon irradiations are illustrated in Table 1. Furthermore, the dose-OD responses of the EBT3 film over a 10–400 cGy dose range for different photon energies and dose rates in three colors are shown in Figures 2 and 3, respectively. The points shed light on the experimental data, whereas the lines display the fitted functions. The regression formula of each curve was calculated using Microsoft office Excel 2013 software.

According to the R^2 values represented in Figures 2 and 3 for three-color channels, the highest R^2 values for Co-60 and 6 MV photon beams are related to red channel. As illustrated in Table 1, the red channel has a greater response, following the green and blue channels. The results demonstrated that the fluctuation of mean OD (three channels) between the various photon energies (6 MV and Co-60 with 2 Gy/min dose rate) was 21%, 31%, and 52% for the red, green, and blue channels, respectively. Moreover, there was a significant difference between OD values of different photon energies in the blue channel ($P = 0.023$), but there was no significance for other channels (red and green) [Figure 4].

Figure 3 represents the highest R^2 values for 2 and 4 Gy/min dose rates related to red and green channels, respectively. The results revealed that the fluctuation of mean OD (three channels) between the different dose rates (6 MV with 4 and 2 Gy/min) was 9.4%, 4.6%, and 14% for the red, green, and blue channels, respectively. It is noticeable that a slight difference was apparent between the dose rate values resulted from the three-color channels. The findings of Figure 4 demonstrated that there is no significant difference among the OD values of various dose rates in three-color channels ($P > 0.05$).

Discussion

There are several studies on the assessment of film capability for the QA of different radiotherapy techniques.[15-17] High-resolution radiochromic films had been used for the QA of radiotherapy techniques in the high-gradient dose regions and small fields.[18,19] Therefore, the EBT3 films have been employed in advanced and high-precision radiotherapy techniques due to their high spatial resolution. Furthermore, these films have some benefits compared to the EBT and EBT2 films, such as symmetry, simplicity of application, and lower Newton's artifact halos (because of the surrounding matte polyester components).[20,21]

Table 1: The net optical density for two photon energies of EBT3 film in different dose rate values and channels

Dose (cGy)	Net OD; Co-60 (2 Gy/min)			Net OD; 6 MV (2 Gy/min)			Net OD; 6 MV (4 Gy/min)		
	Red	Green	Blue	Red	Green	Blue	Red	Green	Blue
10	0.005±0.01	0.004±0.02	0.003±0.01	0.005±0.01	0.004±0.02	0.001±0.01	0.006±0.02	0.004±0.02	0.001±0.01
20	0.015±0.01	0.011±0.02	0.005±0.01	0.016±0.02	0.014±0.02	0.002±0.02	0.016±0.02	0.012±0.01	0.002±0.01
40	0.026±0.02	0.020±0.01	0.004±0.02	0.030±0.02	0.026±0.01	0.001±0.01	0.033±0.01	0.024±0.01	0.001±0.01
80	0.046±0.01	0.033±0.01	0.006±0.01	0.053±0.01	0.044±0.01	0.002±0.03	0.059±0.01	0.041±0.01	0.002±0.01
120	0.067±0.01	0.042±0.01	0.007±0.01	0.083±0.02	0.069±0.02	0.004±0.03	0.090±0.01	0.062±0.01	0.003±0.01
160	0.079±0.03	0.050±0.02	0.008±0.01	0.102±0.01	0.085±0.01	0.003±0.01	0.116±0.01	0.083±0.01	0.004±0.01
200	0.094±0.01	0.061±0.01	0.009±0.02	0.132±0.03	0.112±0.02	0.004±0.01	0.141±0.03	0.098±0.02	0.005±0.01
240	0.117±0.01	0.078±0.02	0.011±0.01	0.153±0.02	0.132±0.01	0.005±0.02	0.166±0.02	0.114±0.01	0.006±0.02
300	0.140±0.03	0.095±0.02	0.014±0.01	0.188±0.02	0.156±0.01	0.007±0.03	0.197±0.01	0.141±0.01	0.009±0.03
400	0.173±0.02	0.112±0.02	0.018±0.03	0.210±0.01	0.175±0.01	0.011±0.01	0.250±0.01	0.200±0.02	0.014±0.01
Mean	0.0762	0.0506	0.0085	0.0972	0.0817	0.004	0.1074	0.0779	0.0047

OD – Optical density

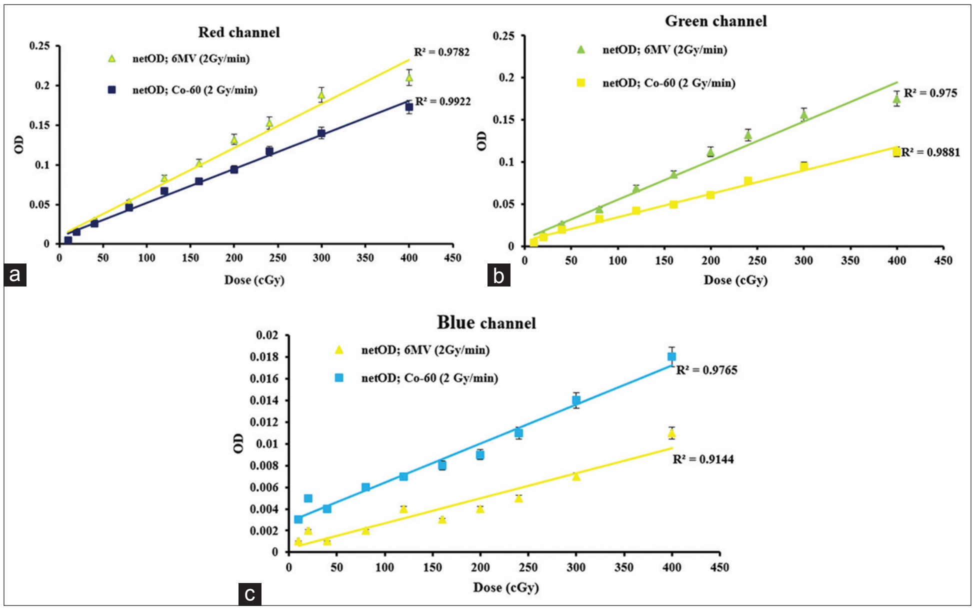

Figure 2: Dose–optical density curves of EBT3 film irradiated with various photon energies at 2 Gy/min dose rate for red (a), green (b), and blue channels (c). Fitting dose response curves are depicted by solid line, and the points represent the experimental data

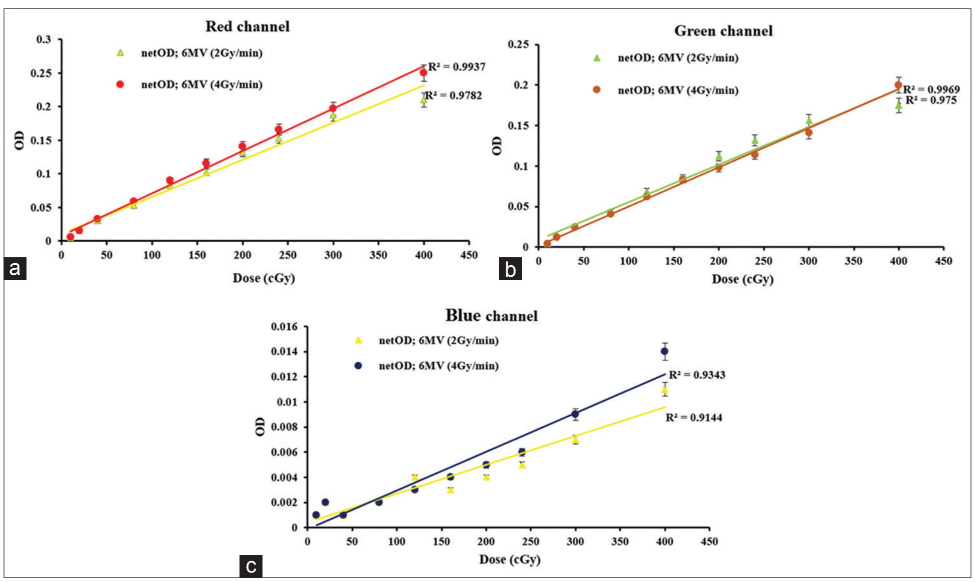

Figure 3: Dose–optical density curves of EBT3 film irradiated with 6 MV photon energy at different dose rates for red (a), green (b), and blue channels (c). Fitting dose response curves are depicted by solid line, and the points represent the experimental data

In this study, we scrutinized the dose-OD response of EBT3 films that were exposed to 6 MV with two different dose rate values (4 and 2 Gy/min). For demonstrating the response of the EBT3 films to different energies, we chose the Co-60 radiation at the 2 Gy/min dose rate. Ten dose levels from 10 to 400 cGy were chosen for irradiating, and the response was compared in three-color channels. The mean OD values indicated higher sensitivity of the red channel, compared with the green and blue channels as revealed in Table 1. Previous studies reported similar results, up to 10 Gy doses,[22,23] because the maximum absorbency of the EBT3 film is in wavelengths ranged from 600 to 700 nm, with absorption peak at 678 nm in the red region of the visible spectrum.[24,25] According to a previous study,[26] the green channel could be preferable to be used for higher doses and the blue channel has a lower response gradient at any dose and also it depends on the active layer of the EBT3 films.

The results demonstrated that the mean OD differences among the various photon energies were 21%, 31%, and 52%, for the red, green, and blue channels, respectively, but differences among the various photon dose rates were 9.4%, 4.6%, and 14% for the red, green, and blue channels, respectively. We found that the response of the films is more sensitive to the energy of radiation beam compared to

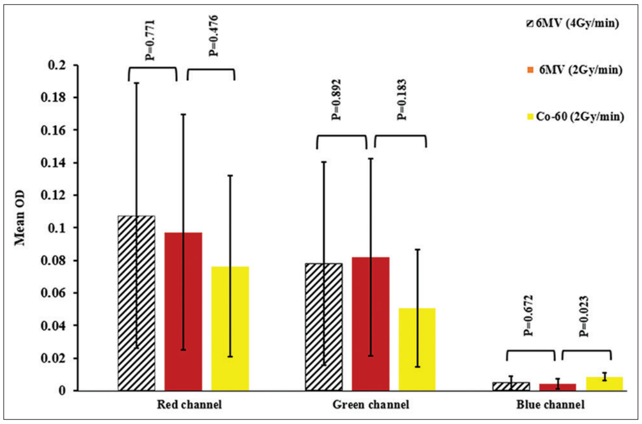

Figure 4: Comparison between the mean optical density values of various photon energies and dose rates

the dose rate value but that was not significant for red and green color channels.

There are several studies reporting energy and also dose rate response of the EBT3 films that are exposed at megavoltage range.[20,26] In a study, Casanova Borca *et al*.[10] evaluated some of the main characteristics of EBT3 such as energy and dose rate dependence in intensity modulated radiation therapy (IMRT) (6 MV and 15 MV X-ray beams of the Varian linac) among various dose rates (100, 300, and 600 MU/min). They found that the energy quantity and dose rate had no significant differences. In another study by Sorriaux *et al*.,[20] the uncertainties and characteristics of the EBT3 films irradiating with megavoltage radiotherapy photon, electron, and proton beams were evaluated. It was found that the EBT3 films have low combined uncertainty and energy dependence, and so, it can be used for dosimetry in various applications. The results of the current study indicated similar findings with that of previous studies about the energy independency of the EBT3 dose response in megavoltage ranges.

Some other studies reporting energy and dose rate response of the EBT3 films irradiated with kilovoltage range.[9,26] In a study, Villarreal-Barajas *et al*.[9] studied the energy dependence of the EBT3 in the range of 70–300 kVp. They showed that EBT3 had energy response dependence in the orthovoltage X-ray energy ranges so that an underresponse of more than 20% was observed for photon beams with the 70 kVp energy. Although the dose response dependence was low for 300 kVp, it was still significant from the clinical point of view. Brown *et al*.[26] indicated the dose–response curves of EBT, EBT2, and EBT3 films. A dose–response curve was acquired at 35 keV for EBT film and at 25, 30, and 35 keV for EBT2 and EBT3 films using tomography beamline. They found that EBT and EBT2 films had energy dependence strongly for the energy range of >25 keV, unlike EBT3 films which showed weak energy dependence.

Massillon *et al*.[8] showed that the dose-response of the EBT3 films for both megavoltage (6 MV and 15 MV) and kilovoltage (50 kV) X-ray beams was weakly dependent on the energy of the photon beams, absorbed dose, and color channels.

Regarding the results of these studies and the current study, the EBT3 films have weak energy and dose rate dependence.

For future research, further evaluating EBT3 films, it was suggested that other dose rates (such as 3 and 5 Gy/min) should be exposed with photon and proton beams and then the dose OD response should be compared.

Conclusions

In the current study, photon energy and dose rate dependence of the EBT3 films were evaluated. The OD dose response of the EBT3 for red, green, and blue color channels demonstrated that there is no significant dependency to different photon energies (Co-60 and 6 MV) and various dose rates (2 and 4 Gy/min) over a broad dose range, except for photon energies in blue color channel.

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Conflicts of interest

There are no conflicts of interest.

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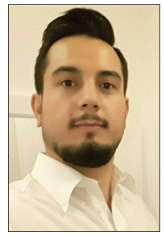

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