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Analysis of Gafchromic EBT3 film calibration irradiated with gamma rays from different systems: Gamma Knife and Cobalt-60 unit

Monsen Najafi, MS.c.,[*] Ghazale Geraily, Ph.D.,[*] Alireza Shirazi, Ph.D.,[*] Mahbod Esfahani, MS.c.,[†] and Javad Teimouri, M.D.[‡]

[*]Medical Physics & Biomedical Engineering Department, Tehran University of Medical Sciences, Tehran, Iran; [†]Imam Khomeini Hospital, Tehran University of Medical Sciences, Tehran, Iran; and [‡]Iran Gamma Knife Center, Tehran, Iran

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ABSTRACT

In recent years, Gafchromic films are used as an advanced instrument for dosimetry systems. The EBT3 films are a new generation of Gafchromic films. Our main interest is to compare the response of the EBT3 films exposed to gamma rays provided by the Theratron 780C as a conventional radiotherapy system and the Leksell Gamma Knife as a stereotactic radiotherapy system (SRS). Both systems use Cobalt-60 sources, thus using the same energy. However, other factors such as source-to-axis distance, number of sources, dose rate, direction of irradiation, shape of phantom, the field shape of radiation, and different scatter contribution may influence the calibration curve. Calibration curves for the 2 systems were measured and plotted for doses ranging from 0 to 40 Gy at the red and green channels. The best fitting curve was obtained with the Levenberg-Marquardt algorithm. Also, the component of dose uncertainty was obtained for any calibration curve. With the best fitting curve for the EBT3 films, we can use the calibration curve to measure the absolute dose in radiation therapy. Although there is a small deviation between the 2 curves, the *p*-value at any channel shows no significant difference between the 2 calibration curves. Therefore, the calibration curve for each system can be the same because of minor differences. The results show that with the best fitting curve from measured data, while considering the measurement uncertainties related to them, the EBT3 calibration curve can be used to measure the unknown dose both in SRS and in conventional radiotherapy.

Introduction

Film dosimeters provide 2-dimensional dose information and can validate isodose curves including depth-dose distributions.[1] The radiochromic external beam therapy (EBT) film was released in 2004 by International Specialty Products (Wayne, NJ). In 2009, a second type of Gafchromic EBT film replaced it. EBT2 films have a yellow marker dye in the active layer and a synthetic polymer as the binder component. In 2011, International Specialty Products released a new film generation, EBT3 film.[2] According to the producer's note, the EBT3 film provides significant performance improvement over the EBT2 film. Although the active layer in the 2 films is the same, the EBT3 has a special polyester substrate that prevents the formation of Newton ring interference patterns in images acquired using flatbed scanners. Also, the structure of the EBT3 film is symmetric and eliminates the need of keeping track of which side of the film was placed on the scanner, as is the case with EBT2. Some benefits of the EBT3 film are the following: not requiring postirradiation processing, capable of using without need of the darkroom, having a high spatial resolution (at least 25 μm), low energy dependence, and near tissue equivalent ($Z_{eff} = 6.73$).[3] EBT3 is targeted to dose measurement in brachytherapy, external beam radiotherapy, and stereotactic radiosurgery (SRS) (*i.e.,* an important development in the treatment of brain tumors that uses very high doses of radiation per fraction that is sent into target with a very narrow beam of radiation).

In fact, over the past few decades, conventional radiotherapy, which used simpler rectangular treatment fields, has changed significantly to conformal radiotherapy including 3-dimensional conformal radiotherapy, intensity-modulated radiotherapy, and SRS. An example of SRS is the Leksell Gamma Knife[4] (LGK) (Elekta, Sweden), which is a popular and complete system for radiosurgery. LGK uses 201 Cobalt-60 sources that are placed on a hemisphere of 400 mm in diameter. The narrow beam of each source that is used accumulates at the center of the hemisphere to reach the target in the brain. The treatment is usually delivered by focusing many of these sources on the target.[5]

Some properties of the EBT3 film that have been studied include comparison of dose-response curves for several photon energies,[6] comparison of calibration curves for 2 different particle types

Reprint requests to Alireza Shirazi, Ph.D., Medical Physics & Biomedical Engineering Department, Tehran University of Medical Sciences, Tehran, Iran.
E-mail: shirazia@sina.tums.ac.ir

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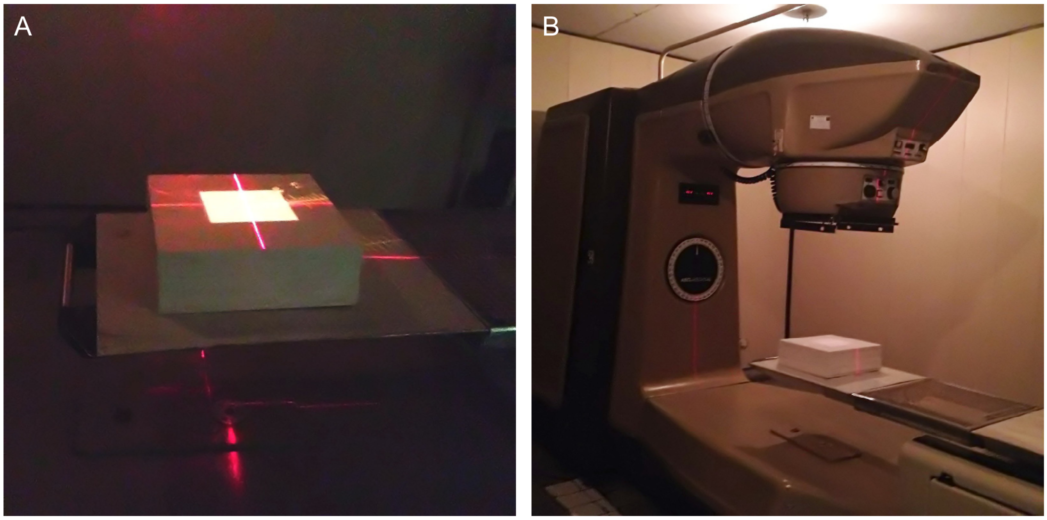

Fig. 1. (A) Perspex layers in the field of radiation. (B) The Theratron 780C system.

(electron and photon), and comparison of sensitivities for 2 different scanner types.[7] A study comparing the response of these films in external beam radiotherapy and SRS has not been done. In this study, the EBT3 films were calibrated for the Theratron 780C (Med WOW, Canada) as a conventional radiotherapy system, and the LGK was calibrated for SRS. Both systems use Cobalt-60 sources, thus using the same energy to deliver prescribed doses to the target volume. However, other factors may influence the calibration curve such as source-to-axis distance (SAD), number of sources, dose rate, direction of irradiation, shape of phantom, field shape of radiation, and different scatter contribution, and these were investigated. Our main interest is to compare the response of the EBT3 films exposed to gamma rays provided by these 2 different machines (*i.e.,* the Theratron 780C and the LGK 4C).

Methods and Materials

In this study, 8″ × 10″ sheets of Gafchromic EBT3 films were used; the 14″ × 17″ size is also available. According to the scan handling guide of the EBT3 film, the measurement area of each film piece was marked at its top to be congruent with the original sheet.[3] At all stages of the calibration process, samples were carried using latex gloves to avoid stains. The samples are folded with care in a darkened envelope when not in use to avoid ambient light and other source effects during storage.[7]

Irradiation procedure in conventional radiotherapy

The irradiation in conventional radiotherapy was performed using a Theratron 780C system. A PTW ionization chamber model M31010 (PTW, Germany) was used to measure the dose rate. For this purpose, the American Association of Physicists in Medicine (AAPM)'s Task Group 51 (TG-51) protocol was considered.[8] According to this protocol, the absorbed-dose-to-water calibration factor for this ion chamber ($N_{D,w}^{60Co}$) is traceable to the Nuclear Science and Technology Research Institute, Atomic Energy Organization of Iran (Karaj, Iran) as a secondary standard dosimetry laboratory. The irradiation was performed in a water phantom. By applying the pressure and temperature correction factors and a traceable calibration factor, an absolute dose rate at D_{max} was obtained. The irradiation of the EBT3 film was done in Perspex (Perspex, UK) layers. According to the scan handling guide for EBT3, the field size of the radiation was set to 10×10 cm^2. To account for scatter, a piece of film was placed on top of the 10 (1-cm thick) Perspex layers, and an additional Perspex layer of 1-cm thickness was placed on top of the film to establish electronic equilibrium. The source-to-surface distance of the Perspex was 80 cm, and the film was centered in the radiation field (Fig. 1). According to AAPM's TG-21,[9] the correction factor to liquid water from Perspex (acrylic) was considered and the irradiation was repeated 3 times for each dose level, ranging from 0 to 40 Gy. All films after the irradiation were placed in a darkened envelope.

Irradiation procedure in stereotactic radiotherapy system

The irradiation for the SRS was performed using an LGK model 4C. An acrylonitrile butadiene styrene spherical plastic phantom for Gamma Knife quality assurance was used. The shape and size of the phantom simulates the head of an adult human. The phantom is divided into 2 half spheres between which a cassette can be inserted. Collimator 18 with all sources was used to measure the dose rate at the unit center point according to the instructions for use of the LGK.[10] Because AAPM's TG-51 protocol cannot reliably be applied to the Gamma Knife calibration,[11] a correction factor is required to adapt this protocol to the small and nonstandard fields.[12] The value of the correction factor for our PTW M31010 ion chamber and acrylonitrile butadiene styrene phantom in LGK model 4C is 0.999.[11,13] This ion chamber was placed at the center of the spherical phantom at the special cassette. Before the irradiation, background or leakage measurements were obtained. By applying the pressure and temperature correction factors, a traceable calibration factor, and the correction factor for small and nonstandard fields, the absolute dose rate at the unit center point was obtained. As before, samples of film were cut into pieces of 5×5 cm^2 and placed at the center of the spherical phantom at the special cassette, and the irradiation was performed (Fig. 2). Figure 3 shows the samples of film after the irradiation. The setups of the irradiation for the Theratron 780C and the LGK are presented in Table 1.

Scanning procedure and image processing

Each film was scanned at a resolution of 150 dpi and saved in uncompressed Tagged Image File Format.[14] Forty-eight hours after the irradiation, the scanning procedure was performed using a Microtek ScanMaker 9800XL (Microtek, Taiwan).[1] Saved images were analyzed using ImageJ software (Microtek, Taiwan), and 3 values were acquired for the mean pixel value with its standard deviation in each region of interest. The RGB, red, and green components of the color are taken into account.[7,15]

The net reflective optical density (OD) is calculated using the pixel value from the scanned image according to the following expression:

$$x = \log(I_u/I_i) \quad (1)$$

Here, x is the net reflective OD, and I_u and I_i are the average pixel values of the reflected intensities through nonirradiated and irradiated films, respectively.[7]

Dose-response curves

Here, the analyses of irradiated films were considered in 2 steps because the scan handling guide for EBT3 film asserts that the acceptable dose range of film is up to 10 Gy with the red color channel and greater than 40 Gy with the green color channel. First, dose-response calibration curves were plotted at the red color channel for doses ranging from 0 to 10 Gy, and then the green color channel for doses ranging from 0 to 40 Gy for both the Theratron 780C and the LGK 4C systems.

Table 1
Setups of irradiation for the Theratron 780C and the LGK

System	Theratron 780C	Leksell Gamma Knife 4C
Phantom	Perspex layers	ABS (acrylonitrile butadiene styrene)
SAD (cm)	80	40
Field	10×10 cm^2	18 mm
Field shape	Rectangular	Spherical