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Utilization of Gafchromic ebt3 Films for Postal Dose Audits of 6 mv X-Ray Beam Calibration of Linear Accelerator

*Said Mahdi Mutahari [1,2,3], Abasin Tajmalzai [3]

1. International Atomic Energy Agency, Vienna, Austria
2. National Research and Innovation Agency (Badan Riset dan Inovasi Nasional - BRIN), Indonesia
3. Department of Radiology, Kabul University of Medical Science, Kabul, Afghanistan

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*Corresponding Author:

E-mail: sm_mutahari@kums.edu.af

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ABSTRACT

Background: Periodic dose quality audits of medical linear accelerators are essential to ensure proper calibration and accurate dose delivery. We aimed to assess the accuracy of 6 MV x-ray beam calibration through a postal dose audit using Gafchromic EBT3 films.

Methods: The experiment was conducted at RSUD Pasar Minggu Hospital in Jakarta, Indonesia, in October 2023. A reference calibration curve for Gafchromic EBT3 films was created by irradiating 3×3 cm² films at a 10 cm depth in a water phantom with a 10×10 cm² field and 100 cm source-to-surface distance, using doses 0-300 cGy with a 6 MV x-ray beam from a Varian Trilogy medical linear accelerator at RSUD Pasar Minggu hospital in Jakarta, Indonesia. The films were scanned with a Microtek TMA1600-III scanner, and optical density values were plotted against delivered doses. Three unexposed films were sent to the hospital for irradiation to 2 Gy in October 2023, and the returned films were analyzed by comparing their optical density values to the calibration curve. The measured dose was 1.92 Gy, a -4.2% deviation from the prescribed 2 Gy dose, within the ±5% tolerance. A parallel verification using Optically Stimulated Luminescence Dosimeters confirmed the Gafchromic results. This study demonstrates the feasibility of using Gafchromic EBT3 films for accurate, efficient calibration of linear accelerator x-ray beams in postal audits.

Results: The measured dose was 1.92 Gy, representing a -4.2% deviation from the prescribed 2 Gy dose, within the accepted ±5% tolerance. A parallel verification using Optically Stimulated Luminescence Dosimeters showed agreement with the Gafchromic results.

Conclusion: The study confirms the feasibility of using Gafchromic EBT3 films for accurate and efficient calibration of linear accelerator x-ray beams in postal audits.

Keywords: Gafchromic EBT3 film, Linear accelerator, Dose quality audit, Dose calibration curve

Introduction

Radiation therapy as a cornerstone in cancer treatment, is administered to over half of all cancer patients, predominantly through medical linear accelerators (1). Ensuring a consistent and stabilized beam quality from linear accelerators is critical for improving the overall performance, safety and quality of radiotherapy treatments (2). In order to establish a medical radiation-traceable system between primary standard dosimetry laboratories (PSDLs) and secondary standard dosimetry laboratories (SSDLs) as well as between SSDLs and medical facilities, an external dose audit according to standardized procedure is crucial. On-site external dose audits offer increased consistency and precision, but they are significantly more costly, labor and time intensive since they require not only phantom and transportation costs but also audit staff (3). Remote (postal) dose quality audits by mailed dosimeters provide an alternative to fulfill requirements stipulated under various audit programs. For example, since 1967 the IAEA/WHO thermoluminescence dosimeter (TLD) postal audit program has verified calibration of over 6200 photon beams across 1500 hospitals over 37 years (4). In Europe, since 1998 The ESTRO-Quality Assurance Network (EQUAL) under Europe Against Cancer Program, has been conducting quality assurance project for radiotherapy through postal dose quality audit. Nevertheless, TLDs present notable challenges, such as the need for labor-intensive procedures, dependence on specialized equipment, and vulnerability to environmental conditions like temperature and humidity. These drawbacks highlight the importance of developing more practical and efficient solutions (5).

The main purpose of the postal dose quality audit for linear accelerator beams is to provide independent verification of the dose delivered by the treatment machines. In postal audit process, a radiotherapy center receives a dosimeter from an accredited audit body. The dosimeter is irradiated according to instructions to simulate patient treatments. The irradiated dosimeters are subsequently returned to the audit body for analysis. The measured doses are compared to benchmark values to verify the accuracy of the radiotherapy center’s beam calibration. Such audits play an important role in quality improvement by identifying dosimetry issues that may exist (4). The International Commission on Radiation Units and Measurements (ICRU) recommends a dose error for radiotherapy of ±5% as acceptable (6).

While previous studies (7-9) highlighted the potential of Gafchromic EBT films as effective radiation dosimeters, their adoption in clinical settings has remained limited, largely due to challenges such as perceived calibration complexities and the need for specialized analysis techniques. These studies emphasize the films’ advantages, including high spatial resolution, minimal energy dependence across the kV–MV range, near tissue equivalence, and the absence of post-irradiation processing, which make them highly suitable for dose verification. However, their role in routine applications like remote dose quality audits has been underexplored. By addressing these gaps, this study aims to further validate the feasibility and practical benefits of Gafchromic EBT3 films, comparing their performance with established TLD-based methods to support their broader clinical adoption (8). Gafchromic EBT film was released in 2004 and continuous development efforts are dedicated to enhancing the performance of the film. In 2009, Gafchromic EBT film was replaced by Gafchromic EBT2 film. The structure of Gafchromic EBT2 film has a combination of yellow marker dye in the active layer and synthesis polymer as material strap (10,11). In 2012, Ashland Inc. released Gafchromic EBT3 film, which demonstrated its superior suitability for the dose verification of radiotherapy compared to EBT2 film (12,13).

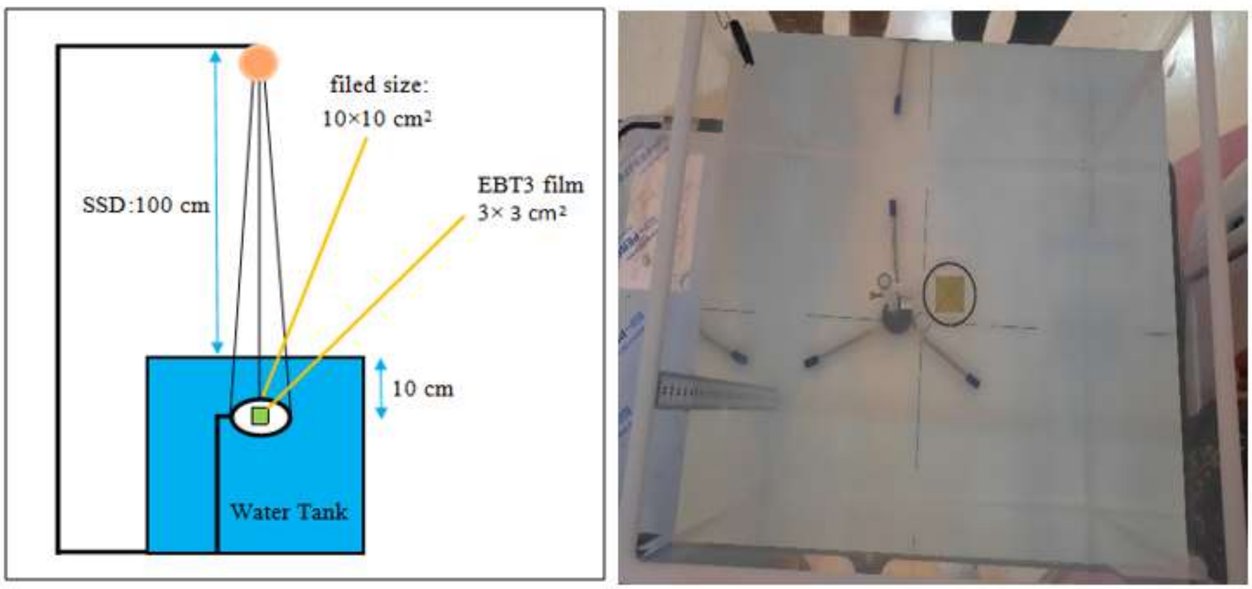
We aimed to further validate the feasibility of employing Gafchromic EBT3 films for remote dose quality audit for megavoltage x-ray beam calibration of linear accelerators. In addition, the implementation of the dose quality audit for 6 MV x-ray beam calibration on a medical linear accelerator also been conducted in this study.

Materials and Methods

Generating the calibration curve for Gafchromic EBT3 film

Irradiation

To perform dose measurements utilizing Gafchromic EBT3 films, a reference calibration curve was first generated. For this purpose, Gafchromic EBT3 films with dimensions of 3×3 cm^2 were placed in a water phantom 1d scanner sun nuclear with dimensions 35.0×35.0×36.2 cm^3 at the depth of 10 cm of water and a 10×10 cm^2 filed size, perpendicularly to the central axis. Films were exposed to 6 MV photon beam under a source-to-surface (SSD) distance of 100 cm on a Varian Trilogy/6258 medical linear accelerator under radiation doses of 0, 20, 50, 100, 200, and 300 cGy. The experiment was conducted at RSUD Pasar Minggu Hospital in Jakarta, Indonesia, in October 2023. Schematic diagram of the irradiation setup is illustrated in Figure 1(A).



(A) (B)

Figure 1: Experimental setup for calibration curve of Gafchromic EBT3 film. (A) Schematic represents the configuration employed for irradiating the films, showing the placement of Gafchromic EBT3 films in a water phantom at depth of 10 cm, irradiated by 6 MV x-ray beam directed perpendicularly at the central axis. Key parameters: field size (10×10 cm^2), source-to-surface distance (100 cm), dose range (0–300 cGy).(B) Photograph of the irradiation process of a Gafchromic EBT3 film illustrating the practical application of the setup.

Film Scanning protocol

After irradiation, Gafchromic EBT3 films were kept at the temperature between 20-24 ^{o}C for 72 h for developing purpose. Then, films were scanned with a Microtek TMA1600-III color scanner which generates a response in three channels: red, green and blue at the depth of 48 bit per color channel and a spatial resolution of 300 dpi. The scanning was conducted in a transmission mode and software settings were chosen to disable all color correction options. To minimize the influence of the lateral differences of scanner response, all the film samples were placed in the center of the scanner. The digital images were saved in Tagged Image File Format (TIFF).

Image Analysis

All the image analysis carried out using the ImageJ software (ver. 1.54d). A region of interest (ROI) of 0.25 cm^2 was determined in the center of each image for read-out process. The response of the Gafchromic EBT3 films at each radiation dose was of particular interest, and thus the relationship between the delivered dose and resulting net optical density (netOD) values of the films were investigated. The netOD value which mean the subtraction the pre-scan OD value from the corresponding post-scan OD value, was given according to the equation [1]:

$$netOD = log10(\frac{PV_{un}}{PV_{ex}}) \quad [1]$$

where PV_{un} is an unexposed pixel value, and PV_{ex} is X-ray-beam exposed pixel value (14). Plotting measured netOD values versus the delivered radiation dose yielded the reference calibration curve for Gafchromic EBT3 film. The curve was subsequently employed for the dose determination of the films irradiated in the audited hospital.

Irradiation and analysis of the Gafchromic Films

The postal dose quality audit methodology entailed mailing a set of six 3×3 cm^2 Gafchromic EBT3 films to the audited hospital, comprising three samples to be irradiated for dose measurement and three unexposed films to obtain background optical density values. Prior to irradiation of the films, the audited center was asked to calibrate the linac according to the IAEA TRS-398 code of practice (15). Linac was calibrated to deliver 1 Gy per 100 monitor unit (MU) at the depth of the 10 cm and 100 cm SSD in a 10×10 cm^2 field size with Farmer type ionization chamber with active volume of 0.6 cc.

Instructions were provided for the audited hospital to position films at a depth of 10 cm of water, in a 10×10 cm^2 field size, 100 cm SSD, and perpendicular to the central axis of a water phantom that corresponded to the phantom used for film calibration process, and subsequently to irradiate films with 2 Gy dose using 6 MV x-ray beam from audited clinic's Varian Trilogy/6258 linac. Following irradiation, the Gafchromic EBT3 films were returned from the audited hospital and underwent optical density analysis after a 72-hour time interval to allow stabilization of the polymerization process. The measured net optical density values permitted quantification of the radiation dose delivered to the films during the postal audit. By comparing the measured dose to the prescribed dose of 2 Gy, the accuracy of the megavoltage x-ray beam calibration for the clinical linear accelerator at the audited hospital could be assessed.

Reference Film Calibration Curve

The reference calibration curve for the Gafchromic EBT3 films was established by irradiating films to known doses from 0 to 300 cGy and determining their net optical density (netOD) values. Scanner response in each channel was examined. The red channel was used to analyze since it represented the highest netOD values (16). Figure 2 shows the calibration curve obtained by plotting the measured netOD values against the delivered radiation doses. The dose received by the films irradiated at the audited hospital was determined through comparison to a polynomial (2nd order) calibration curve formula described by the following equation described in the equation [2] (16):

$$D = -\alpha.netOD^2 + \beta.netOD - \gamma \quad [2]$$

Where D is the dose in Gy, α, β, and γ are free parameters of the formula.

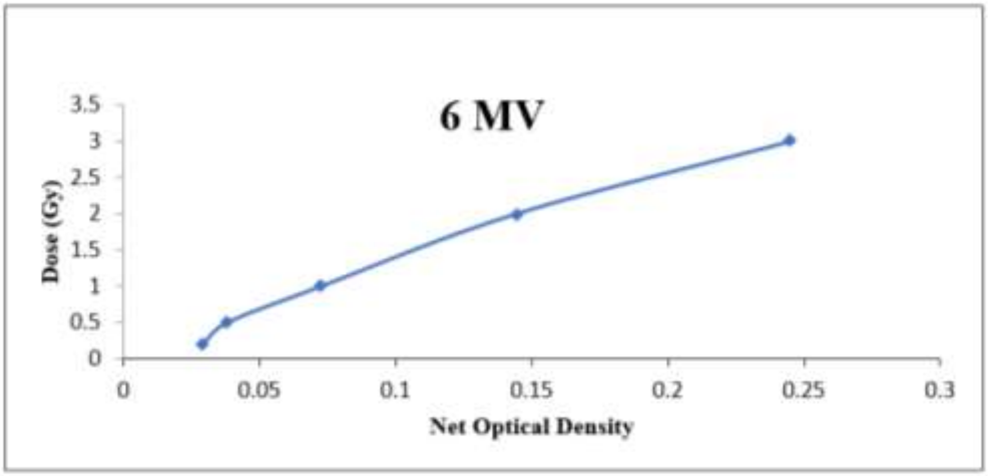


Figure 2: Calibration curve for Gafchromic EBT3 film.The graph illustrates the relationship between delivered radiation doses (0–300 cGy) and the net optical density (netOD) values.

Results

Dose Measurement of the Audited Linac

Digitalization of the Gafchromic films irradiated with 2 Gy using a 6 MV linear accelerator beam at the audited hospital was performed after 72 h of irradiation. Table 1 represents the pixel values obtained from the digitalization process of the films that further used for the calculation of the net OD values. The netOD values of the irradiated films were calculated and averaged using Equation 1. In comparison with the calibration curve formula (Equation 2), the measured average netOD value indicates an absorbed dose of 1.92 Gy to the films. This represents a -4.2% deviations compared to the intended 2 Gy dose. As per the acceptable beam calibration accuracy criteria, this -4.2% deviation is within the tolerated limit of ±5%. Therefore, the postal dose quality audit for 6 MV x-ray beam of the audited linear accelerator implies to have passed the postal dose quality audit, indicating adequate and accurate clinical dosimetry.

Table 1: Pixel values resulting from the digitalization process of the irradiated films in the audited hospital, utilized in the subsequent computation of net Optical Density (OD) values.

Variable	*Unexposed mean pixel value*	*Exposed mean pixel value*
Film 1	49905.282	38244.225
Film 2	1784.325	36060.727
Film 3	52394.994	38226.386
	Mean: 52394.994	Mean :37510.446

Discussion

The primary objective of this study was to further validate the feasibility of utilizing Gafchromic EBT3 films for conducting dose quality audit of the megavoltage x-ray beam calibration for medical linear accelerators. The calibration curve for Gafchromic film was generated by irradiating films to known doses from 0 to 300 cGy. Our calibration curve reveals good agreement with published data on the dosimetric properties of EBT films (17). The films were effectively able to verify the accuracy of dose delivery from the audited hospital's linac to within ±5% of the prescribed dose. This level of agreement meets accepted tolerance limits for beam calibration and clinical reference dosimetry (18). Similar passing results have been reported by other postal audits of clinical linac calibration using films (19). As a parallel verification, a dose audit was conducted at the audited hospital for the same dose and energy, utilizing an Optically Stimulated Luminescence (OSL) dosimeter. The results obtained from the OSL dosimeter were found to be in agreement with the measurements obtained using Gafchromic film. This concordance in results across different dosimetry methods enhances the reliability of this feasibility study. This study not only highlights the feasibility of employing Gafchromic EBT3 films for postal dose audits but also highlights their practical usability in clinical postal dosimetry practices. Unlike earlier researches (7,8), which largely emphasized laboratory-based evaluations, this investigation incorporates Gafchromic films into a structured postal audit system. By validating their accuracy against OSL dosimeters, the study paves the way for their wider use in quality assurance process. This is an important step forward in making remote dosimetry simpler and more efficient in the clinical practices.

In the present work, a water phantom was used for irradiating the films to generate the calibration curve and conduct the postal audit dosimetry. However, solid water phantoms are more commonly employed for this purpose to provide stability and reproducible geometry. A study investigated the dosimetric differences between solid water and water tanks for megavoltage beam calibrations. It found minimal impact on depth dose curves and beam profiles (20). Thus, while water phantoms offer convenience and save on costs, the use of solid water for this postal dosimetry is unlikely to significantly influence the accuracy of the film-based dose measurements. Further Monte Carlo modeling could provide confirmation by evaluating phantom-related uncertainties for the specific irradiation set-up used here. In this study, a water phantom was used for irradiating the films to generate the calibration curve and conduct the postal audit dosimetry. While water phantoms offer conveniences, such as reduced costs and simpler handling, solid water phantoms are more commonly used due to their stable geometry and reproducibility in radiotherapy dosimetry practices. Previous studies have shown minimal differences in depth dose curves and beam profiles between water and solid phantoms for megavoltage beam calibrations, suggesting that the choice of phantom may not significantly affect the accuracy of film-based dose measurements (20).

However, this study was not focusing on validation the similarity of results of water versus sloid phantom, and the comparison warrants further investigation. Such analyses would not only provide stronger empirical support for selecting the appropriate phantom but also help quantify any potential uncertainties related to specific irradiation setups. This would enhance confidence in using either phantom for clinical quality assurance and dosimetric accuracy.

Conclusion

This study demonstrated that Gafchromic EBT3 films provide an accurate and reliable method for postal dose quality audits of 6 MV x-ray beam calibration in medical linear accelerators, with results agreeing within the ±5% tolerance criteria. The findings confirm their potential for use in clinical dosimetry and quality assurance programs.To enhance the clinical applicability of Gafchromic EBT3 films, future research could investigate their use in auditing different beam energies or more advanced treatment techniques, such as intensity-modulated radiotherapy (IMRT). Furthermore, evaluating the long-term stability of these films under diverse environmental conditions would offer important information for their integration into standard radiotherapy quality assurance protocols.

Conflict of interest

The authors declare that there is no conflict of interests.

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