Dosimetric characteristics of gafchromic EBT3 film on small field electron beam

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Abstract. This study was aimed to determine the dosimetry characteristics of the EBT3 film on a small field electron beam. The experiments were conducted using Linac Synergy-Platform with 6, 8, 10, 12, and 15 MeV. EBT3 films were cut into 3.2×2.5 cm² in size and were irradiated with varied dose of 0 to 500 cGy on 1×1, 2×2, 3×3, 5×5, 8×8 and 10×10 cm² radiation field sizes. The irradiated film was scanned using Epson Perfection V700 flatbed scanner to evaluate the pixel value. Then, the calibration curve was generated from netOD and given a dose. The uncertainty and sensitivity of the EBT3 film were evaluated using in-house and Image-J software to check the consistency of the result. The results showed that the largest uncertainty of characteristics curve was 4.6% at 1×1 cm². Whereas the sensitivity value tends to be identical for radiation dose greater than 100 cGy for all energy, it depends on energy for radiation dose less than 100 cGy.

1. Introduction
Radiotherapy with small field radiation has been widely implemented to treat the cancer patient. However, there was a lack of electron lateral scatter equilibrium [1]. In order to obtain a successful radiotherapy, the accuracy of dosimetry has to be achieved during verification. Radiochromic film can be used to measure the accuracy of dosimetry with small field condition since it has equivalent density with tissue, high spatial resolution and also sensitivity [2].

Gafchromic EBT film was released in 2004 by International Specialty Product (ISP) and is continuously being developed to increase its performance. 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 [3]–[6]. In 2012, Gafchromic EBT3 film was showed to be more suitable for the dose verification of radiotherapy than EBT2 film [7], [8]. A study on EBT3 film on electron beam and standard field size (10×10 cm²) indicated it was a good 2D dosimeter and had been meet the requirement for the dose distribution analyzer of the electron beam based on characteristics, readout method, and uncertainty estimation [9]. In this study, the dosimetry characteristics of the Gafchromic film EBT3 on a small field electron beam have been investigated. In addition, the implementation of the dosimetry of small field on the clinical case has also been conducted in this study.
2. Method and Materials

2.1. Irradiation
Gafchromic EBT3 film was cut into the dimension of 3.2×2.5 cm² (1.25”×1”) and was irradiated using electron beam energies of 6, 8, 10, 12, and 15 MeV with dose in the range of 0 to 500 cGy. The experiment was performed using two applicators; 10×10 cm² and 6×6 cm². For irradiation, the film was inserted to the slab phantom with a dimension of (30×30×5 cm³) at the \( d_{\text{max}} \). Thus, irradiation EBT3 film using small field electron beams with the field size of 8×8, 5×5, 3×3, 2×2, and 1×1 cm² is illustrated in Figure 1.

2.2. Digitalisation
After irradiation, Gafchromic EBT3 film was kept at the temperature between 20 to 24°C for 72 hours for developing purpose. Then, Epson V700 flatbed scanner with 72 dpi in 48 bit RGB mode was used to digitize Gafchromic EBT3 film. The digital film was saved in Tagged Image File Format (TIFF) image [7], [9]–[12].

2.3. Analysis
In this study, Image-J and in-house software were used to analyze the pixel value readout. The region of interest (ROI) of EBT3 film was 0.25×0.25 cm² in each center of the image. The response of each energy became our point of interest and hence the relation between dose and net optical density (netOD). The netOD value was calculated by subtraction the pre-scan OD value from the corresponding post-scan OD value [13]. The value of netOD which was used to analyze characteristic of the EBT3 film was given according to the equation (1):

\[
\text{netOD} = \log_{10}(\frac{PV_{\text{un}}}{PV_{\text{ex}}})
\]

where \( PV_{\text{un}} \) is an unexposed pixel value, and \( PV_{\text{ex}} \) is electron beam exposed pixel value [9].

Calibration curve formula in this research used the comparison of polynomial order three and trust-region described in the equation (2) [7], [10], [14]

\[
D = b \cdot \text{netOD} + c \cdot \text{netOD}^n
\]

where \( D \) is dose, \( b \) and \( c \) are free parameters with \( n \) is the problem-dependent parameter. Furthermore, the influenced dose and energy in each field size was analyzed. The uncertainty value was shown in equation (3) [15]

\[
\sigma_{\text{netOD}} = \frac{1}{\ln 10} \sqrt{\frac{\sigma_{\text{unx}}}{PV_{\text{unx}}} + \frac{\sigma_{\text{exp}}}{PV_{\text{exp}}}}
\]

where \( \sigma_{\text{unx}} \) is the deviation standard of the pixel value in EBT3 film before irradiation. Moreover, the sensitivity of EBT3 film in each energy was calculated using equation (4)

\[
S = \frac{\Delta \text{netOD}}{D^*} = \frac{\text{netOD} - \text{netOD}_{\text{cGy}}}{D^*}
\]

where \( S \) is the sensitivity of EBT3 film and \( D^* \) dose estimate of the EBT3 film.
3. Result and Discussion

Calibration of EBT3 film was conducted on $d_{\text{max}}$ using field size of $10\times10$ cm$^2$ within dose range of 0 to 500 cGy for each energy. Scanner response in each channel was studied in this study. The red channel was used to analyse since it had the highest netOD [9].

In EBT3 film calibration, the netOD value was analyzed according to Equation (1) on each calibration equation of energy as shown in Table 1. The comparison between polynomial and trust region equation for calibration indicated that the trust region equation was more accurate approximately 1%. Figure 2 (a) illustrates the graph of the relationship between the dose prescribed to the netOD in the field size of $10\times10$ cm$^2$. While the relationship curve between the dose and netOD for $1\times1$ cm$^2$ field size can be seen in Figure 2 (b). The curve tends to overlap at all energy electron beams for $10\times10$ cm$^2$, but it is influenced much by the energy of electron beams for the small field. For the dose and netOD relationship at various energy, the curves indicates the overlapping curve for high energy, whereas it is spread out the curve for low energy electron beams. These were caused by the scattering effect highly found in low energy than the high one.

Figure 3 (a) depicts the sensitivity of EBT3 film which has the large variation in the range of dose of 0 to 100 cGy, while the sensitivity for higher dose more than 100 cGy has low variation and tends to overlap and constant. It was in agreement with Papaconstantopoulos et al. (2014) explaining that the sensitivity of the EBT3 film was constant at the dose greater than 50 cGy [10]. Figure 3 (b) depicts the sensitivity on a $1\times1$ cm$^2$ field which is more influenced by the given electron beam energy. For example, the energy of 15 MeV electron beam had the greatest sensitivity in compared to other energies. The characteristic of EBT film sensitivity for various energy can be seen in Figure 3 (b).
Figure 3. Sensitivity of EBT3 film (a) 10×10 cm² (b) 1×1 cm² field size with dose variations

Table 1. Calibration equation in each energy electron beam of 10×10 cm² field size

| Energy   | Polynomial equation                       | Trust-region equation |
|----------|-------------------------------------------|-----------------------|
| 6 MeV    | $y = 5.129.08x^1 + 483.14x^2 + 1.085.83x + 0.48$ | 1120.12               |
| 8 MeV    | $y = 4.349.63x^1 + 540.75x^2 + 1.182.3x + 1.45$ | 1228.19               |
| 10 MeV   | $y = 3.688.25x^1 + 893.02x^2 + 1.087.53x - 0.79$ | 1095.44               |
| 12 MeV   | $y = 2.899.38x^1 + 1.144.79x^2 + 1.088.49x + 0.35$ | 1124.23               |
| 15 MeV   | $y = 4.878.02x^1 + 531.37x^2 + 1.111.49x - 1.03$ | 1107.93               |

Table 2. Uncertainty value comparison using other research

| Parameter                              | Uncertainty (%) | References               |
|----------------------------------------|-----------------|-------------------------|
| Image-J 10×10 cm² field size (EBT3)   | 3.23            | 1.95                    | Fan-Chi Su, et al. (2007) |
| Electron beam 8×8 cm² field size (ETB3)| 2.26            | 1.79                    | Moylan, et al. (2013)     |
| Electron beam 5×5 cm² field size (EBT3)| 3.55            | 1.75                    | This study                |
| Electron beam 3×3 cm² field size (EBT3)| 2.93            | 1.59                    |                          |
| Electron beam 2×2 cm² field size (EBT3)| 3.16            | 3.14                    |                          |
| Electron beam 1×1 cm² field size (EBT3)| 4.61            | 4.36                    |                          |
| Electron beam (ETB) 10×10 cm² field size| 4               | Fan-Chi Su, et al. (2007) |
| Photon and electron beam 9 MeV (ETB2) 10×10 cm² field size| 2.6 | Moylan, et al. (2013)     |
| 6 MV (ETB3) 10×10 cm² field size      | 4               | Borca, et al. (2013)    |
| Electron (ETB3) 10×10 cm² field size  | 2               | Soriaux, et al. (2012)  |
| Photon 6 MV and electron10×10 cm² field size | 3.7 | Sipilä, et al. (2016)    |

This study also analyzed the uncertainty output of the EBT3 film of electron beam energy according to Equation (3). The percentage uncertainty was generated by dividing the standard deviation of irradiated film to the mean of netOD and multiplied by 100% using the Image-J software. From calculation, the average of the uncertainty was circa of 3.23% of 10×10 cm² field size as indicated in Table 2. Furthermore, the table also presents that EBT3 film offers more accurate results than that previously studied by Fan-Chi Su et al.[16]. In addition, the evaluation of EBT3 film sensitivity for 8×8, 5×5, 3×3, 2×2, and 1×1 cm² field size was around of 2.26%, 3.55%, 2.93%, 3.16% and 4.61% s, respectively. Furthermore, the EBT3 sensitivity was also evaluated using the in-house software for comparison as described in Table 2. The result showed that the EBT3 sensitivity of Image-J software is higher than the in-house software calculation. The differences of EBT3 sensitivity between Image-J and in-house software output is due to the ROI technique on the digitized film. The ROI in Image-J was generated manually while the ROI in in-house software was generated automatically.
The implementation of small field electron beams was performed using simple planning at PrecisePLAN Release 2.16–28.76. We simulated the calculation with a prescribed dose of 200 eGy and using 100 cm SSD at gantry angle 0° for the field size of 10×10 cm² to 1×1 cm². The measurements were compared to the reference field size of 10×10 cm² as illustrated in Figure 4. According to AAPM TG 25, the tolerance range of dose discrepancy of the small field electron beam is circa of 3% - 7% [18].

Figure 4 showed that the EBT3 calibration curve equation of 10×10 cm² can be implemented until 5×5 cm². This is indicated by the discrepancy of the measurements of small field size 5×5 cm² is higher more than 7%. In addition, the calibration equation can also be implemented for in the dose calculation analysis of 3×3 cm² field size for 12 MeV and 15 MeV and 2×2 cm² for 15 MeV energy.

The comparison the Trust-region algorithm and the calibration formula of polynomial order three was also conducted. This method was adapted from the work of Papaconstadopoulos et al. [10]. Other researchers such as Sorriaux et al. (2012), Devic et al. (2005), and Reinhardt et al. (2012) were also carried out this methodology for determining the calibration curve of EBT film [8], [14], [19]. The trust-region algorithm result was slightly different from polynomial order three measurements base on the discussion above.

4. Conclusion

Characteristics of the EBT3 film depend on dose, field size, and energy of the electron. Sensitivity value is almost similar for dose more than 100 eGy, whereas it depends on energy for radiation dose less than 100 eGy. Moreover, the highest uncertainty was found approximately of 4.6% at 1×1 cm². The uncertainty of measurements tends to increase with decreasing field size. In addition, the use of 10×10 cm² calibration curve was sufficient for calculating the dose up to 5×5 cm² field size for all energies. However, it can also be used for 3×3 cm² and 2×2 cm² for 12 MeV and 15 MeV, respectively.

5. References

[1] Sharma S C, Johnson M W and Gossman M S 2005 Practical considerations for electron beam small field size dosimetry Med. Dosimetry 30 104

[2] Amin M N, Heaton R, Norrlinger B and Islam M K 2011 Small field electron beam dosimetry using MOSFET detector Journal Appl. Clin. Med. Phys 12 50

[3] Richley L, John A C, Coomber H and Fletcher S 2010 Evaluation and optimization of the new EBT2 radiochromic film dosimetry system for patient dose Phys. Med. Biol 55 2601
[4] Butson M J, Yu P K N, Cheung T and Alnawaf H 2010 Energy response of the new EBT2 radiochromic film to x-ray radiation Radiat. Measurements 45 836

[5] ISP 2010 Gafchromic® EBT2 self-developing film radiotherapy dosimetry

[6] Devic S, Aldelaijan S, Mohammed H, Tomic N, Liang L, Deblois F and Seuntjens J 2010 Absorption spectra time evolution of EBT-2 model gafchromic™ film Int. J. Med. Phys. Res. Pract. 37 2207

[7] Borca V C, Pasquino M, Russo G, Grosso P, Cante D, Sciacero P, Girelli G, Porta M R L and Tofani S 2013 Dosimetric characterization and use of gafchromic EBT3 film for IMRT dose verification J. Appl. Clin. Med. Phys. 14 158

[8] Sorriaux J, Kaçperek A, Rossomme S, Lee J A, Bertrand D, Vynckier S and Sterpin E, 2013 Evaluation of Gafchromic EBT3 films characteristics in therapy photon, electron and proton beams Phys. Med. 29 599

[9] Sipilä P, Ojala J, Kaijaluoto S and Jokelainen I 2016 Gafchromic EBT3 film dosimetry in electron beams — energy dependence and improved film read-out J. Appl. Clin. Med. Phys 17 360

[10] Papaconstadopoulos P, Hegyi G, Seuntjens J and Devic S 2014 A protocol for EBT3 radiochromic film dosimetry using reflection scanning A protocol for EBT3 radiochromic film dosimetry using reflection scanning Med. Phys. 41 122101-1

[11] Chelminski K, Bulski W, Georg D, Bodzak D, Maniakowski Z, Oborska D, Rostkowska J and Kania M 2010 Energy dependence of radiochromic dosimetry films for use Rep. Pract. Oncol. Radiother 5 40

[12] Villarreal-barajas J E and Khan R F H 2014 Energy response of EBT3 radiochromic films: implications for dosimetry in kilovoltage range J. Appl. Clin. Med. Phys 15 331

[13] Ning Wen, Siming Lu, Jinkoo Kim, Yujiao Qin, Yimei Huang, Bo Zhao, Chang Liu and Indrin J. Chetty 2016 Precise film dosimetry for stereotactic radiosurgery and stereotactic body radiotherapy quality assurance using Gafchromic™ EBT3 films Radiation Oncology 11 132

[14] Devic S, Seuntjens J, Sham E, Podgorsak E B and Soares C G 2005 Precise radiochromic film dosimetry using a flat-bed document scanner Med. Phys. 32 2245

[15] Massillon G, Chiu-Tsao S, Domingo-Munoz I and Chan M F 2012 Energy dependence of the new gafchromic EBT3 film: dose response curves for 50 kV, 6 and 15 MV X-ray beams Int. J. Med. Physics, Clin. Eng. Radiat. 1 60

[16] Su F, Liu Y, Stathakis S, Shi C and Esquivel C 2007 Dosimetry characteristics of gafchromic EBT film responding to therapeutic electron beams Appl. Radiat. 65 1187

[17] Gerbi B J, Antolak J A, Deibel F C, Followill D S, Herman M G, Higgins P D, Huq M S, Mihailidis D N, Yorke E D, Hogstrom K R and Khan F M 2009 Recommendations for clinical electron beam dosimetry: supplement to the recommendations of Task Group 25 Med. Phys. 36 3239

[18] Gibbons J P, Antolak J A, Followill D S, Huq M S, Klein E E, Lam K L, Palta J R, Roback D M, Reid M and Khan F M 2014 Monitor unit calculations for external photon and electron beams: Report of the AAPM Therapy Physics Committee Task Group No. 71 Med. Phys. 41 031501-1

[19] Reinhardt S, Hillbrand M, Wilkens J J and Assmann W 2012 Comparison of Gafchromic EBT2 and EBT3 films for clinical photon Med. Phys. 39 5257

Acknowledgments
This work was supported by National General Hospital Cipto Mangunkusumo and Hibah Publikasi Internasional Terindeks Tugas Akhir (PITTA) Universitas Indonesia 2016 with contract number: 2050/UN2.R12/HKP.05.00/2016.