

# Simplified method for creating a density-absorbed dose calibration curve for the low dose range from Gafchromic EBT3 film

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## ABSTRACT

Radiochromic film dosimeters have a disadvantage in comparison with an ionization chamber in that the dosimetry process is time-consuming for creating a density-absorbed dose calibration curve. The purpose of this study was the development of a simplified method of creating a density-absorbed dose calibration curve from radiochromic film within a short time. This simplified method was performed using Gafchromic EBT3 film with a low energy dependence and step-shaped Al filter. The simplified method was compared with the standard method. The density-absorbed dose calibration curves created using the simplified and standard methods exhibited approximately similar straight lines, and the gradients of the density-absorbed dose calibration curves were  $-32.336$  and  $-33.746$ , respectively. The simplified method can obtain calibration curves within a much shorter time compared to the standard method. It is considered that the simplified method for EBT3 film offers a more time-efficient means of determining the density-absorbed dose calibration curve within a low absorbed dose range such as the diagnostic range.

**Key words:** Calibration curve; diagnostic dose range; radiochromic film; step-shaped Al filter

## Introduction

Radiochromic films are used in many radiotherapy and radiography dose measurement techniques because they can measure two-dimensional absorbed dose distributions.<sup>[1-9]</sup> However, the process is cumbersome when an absorbed dose is measured using radiochromic

film as a film dosimeter, and it is necessary for the film density to be converted into an absorbed dose. For general measurement, time-scale methods requiring several dozen irradiations were performed. In addition, the creation of density-absorbed dose calibration curves for each package, i.e., the packaged unit of radiochromic film, is recommended by manufacturers to obtain high-precision data. Radiochromic film dosimeters have a considerable disadvantage in comparison with an ionization chamber (IC) dosimeter because the dosimetry process is time-consuming because of the frequent acquisition of density-absorbed dose calibration curves.

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The density-absorbed dose calibration curve for radiochromic film can be easily and quickly obtained using the density distribution and a step-shaped Al filter. Such a filter was designed by Gotanda *et al.*<sup>[3]</sup> The X-rays are filtered by the step-shaped Al filter, and then the radiochromic film is irradiated by X-rays at different absorbed doses which penetrate Al filters with varying thicknesses. The density-absorbed dose calibration curve can be created by measuring the film density and the absorbed doses corresponding to each Al filter thickness. However, the absorbed dose that penetrates the various Al filters of the X-ray generator must be measured beforehand. The density-absorbed dose calibration curve can be easily measured in any facility when the absorbed dose that penetrates the Al filter is known.

In this study, Gafchromic EBT3 (International Specialty Products, Wayne, NJ, USA) dosimetry film was used as the radiochromic film because it exhibits only slight energy dependency errors in comparison with other radiochromic films.<sup>[10-17]</sup> In a previous experiment, there was an energy-dependent error of approximately 0.2% from 30 keV to 60 keV.<sup>[18]</sup> Therefore, EBT3 film has been used for the measurement of X-rays in diagnostic radiology applications such as computed tomography, quality control, and quality assurance.<sup>[3-5]</sup> Although the scan mode for image acquisition is the transmission mode, it was suggested by several studies that a method using the reflection mode improved the precision of the measurement in the low absorbed dose range.<sup>[19,20]</sup> Therefore, this study was performed using the reflection mode. Another important characteristic of the EBT3 film is the density-absorbed dose calibration curve. Although the density-absorbed dose calibration curve has various forms according to the type of radiochromic film, the calibration curve for EBT3 film exhibits minimal curvature in the recommended dose range.<sup>[1]</sup> As a result, it is logical to consider that the density-absorbed dose calibration curve exhibits a straight line in a low-dose range such as the diagnostic range (<100 mGy).<sup>[3,6,19]</sup>

The purpose of this study is to develop a simplified method, based on the absorbed dose that penetrates the step-shaped Al filter, for creating a density-absorbed dose calibration curve using EBT3 film within a short period. Therefore, the absorbed dose and effective energy of each X-ray penetrating the step-shaped Al filter were investigated. In addition, the simplified method was evaluated in comparison with standard methods.

## Materials and Methods

### Quality of the X-rays which penetrate the Al filters (plates) of various thicknesses

To evaluate the quality of the X-rays which penetrated the Al filters with various thicknesses, an X-ray generator (UD150 L-40E, Shimadzu Corporation, Kyoto, Japan) and a semiconductor multidetector (Accu-Gold and AGMS-D,

Solid State kV/Dose Multisensor for Diagnostic Range Measurements, Radcal Corporation) were used. The exposure parameters of the X-ray generator were 100 kV, 100 mA, and 0.10 s. The semiconductor multidetector was able to measure the average tube voltage ( $\pm 2\%$ ), exposure time ( $\pm 1\% + 0.2$  ms), absorbed dose ( $\pm 5\%$ ), dose rate ( $\pm 5\%$ ), and half-value layer ( $\pm 10\%$ ).<sup>[21]</sup> In a previous experiment, the difference ratios for the effective energies (from 80 kV to 120 kV) obtained by the semiconductor multidetector and standard methods with an IC dosimeter were less than about 5%. Al plates with a purity of more than 99.8% with dimensions of 100 mm  $\times$  100 mm and a thickness of 0.5 mm were used to construct the filters. The Al filters ranged from 1 mm to 15 mm in thickness. The distances from the X-ray tube to the Al filter and from the Al filter to the semiconductor multidetector were set at 500 mm to reduce the influence of scattered radiation. The exposure field was set to be more narrow (40 mm  $\times$  40 mm) on the detector area of the semiconductor multidetector. The measurement was performed three times for each exposure condition, and the mean and standard deviation of the absorbed dose and the half-value layer were calculated. The effective energy was calculated on the basis of the half-value layer.

### Simplified method for creating the density-absorbed dose calibration curve using EBT3 film and a step-shaped Al filter

#### Gafchromic EBT3 dosimetry film

The EBT3 film is rectangular in shape with dimensions of 8 inch  $\times$  10 inch (20.5 cm  $\times$  25.5 cm) and is yellow before irradiation. EBT3 film is suitable for the absorbed dose measurement in the diagnostic range because it is recommended for dosimetry over a wide dose range (0.01–40 Gy).<sup>[1]</sup> In addition, it has a low energy-dependent characteristic, approximately 0.2% from 30 keV to 60 keV.<sup>[18]</sup>

#### Exposure method

The creation of the density-absorbed dose calibration curve was performed by setting the exposure parameters of the X-ray generator to 100 kV, 250 mA, and 4.0 s (0.5 s  $\times$  8). The anode – cathode direction of the X-ray tube was set parallel to the long axis of the EBT3 film to minimize the impact of the X-ray heel effect for each Al filter. The step-shaped Al filter has a rectangular form with dimensions of 20 mm  $\times$  100 mm, and its thickness increases from 1 mm to 25 mm (the specific thicknesses are 1, 2, 3, 5, 7.5, 10, 12.5, 15, 20, and 25 mm).<sup>[3]</sup> The thickness of the Al filter was varied in the long-axis direction of the EBT3 film. The exposed EBT3 film is shown in Figure 1. Regions of interest (75 pixels  $\times$  30 pixels), corresponding to the center of each Al filter thickness, were set on the EBT3 film. The central 100-mm band of the EBT3 film was set as the exposure area, and lead masking plates (thickness: 2 mm) were placed on either side of the exposure area to fix the EBT3 film. The step-shaped Al filter was placed at the center of the exposure area.

The experimental setup of the exposure method is shown in Figure 2. The distance from the X-ray focus to the step-shaped

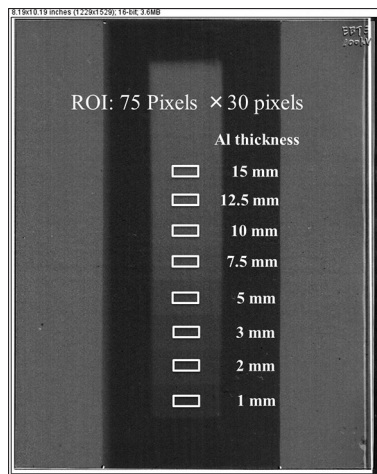


Figure 1: The regions of interest on the EBT3 sheet are indicated by the white rectangles, which have dimensions of 75 pixels  $\times$  30 pixels

Al filter was set at 500 mm to reduce the influence of diagonally incident X-rays. The distance from the step-shaped Al filter to the EBT3 film was also set at 500 mm to reduce the influence of scattered radiation from the step-shaped Al filter. In a previous experiment, any error due to the Al thickness and the inverse square law of the distance would have had little effect on the measurement in this study.<sup>[3]</sup>

#### Scanning and analysis of the EBT3 film

EBT3 film was scanned using a flatbed scanner (EPSON ES - 2200, Seiko Epson Co., Nagano, Japan) in the RGB (48-bit) mode at 150 dpi. To eliminate any error caused by image acquisition, including the effect of the light source of the flatbed scanner, the EBT3 film was scanned by setting the scanner to the reflection mode. To scan the EBT3 film using this setting, regular white paper (PaperOne™ Copier, APRIL Fine Paper, Indonesia) with a uniform density was attached to the back of the EBT3 film. In addition, the EBT3 film was scanned both before and after exposure to eliminate the nonuniformity error of the film layer. EBT3 film was scanned 24 hrs after exposure. The EBT3 was kept at room temperature (20°C–25°C) in a shaded bag.

The image data from the EBT3 film was divided into R, G, and B modes (16 bits each), and the R mode was used for high-density contrast. It was converted to a gray scale and analyzed using ImageJ version 1.48 v image analysis software (National Institute of Health, Maryland, USA). To measure the increase in the density of the EBT3 film, the image data before exposure were subtracted from the after exposure data in terms of pixel units in two dimensions and were then averaged [Figure 1]. The increase in the density was set as the net pixel value (NPV). The density-absorbed dose calibration curves for each thickness of the Al filter were calculated from linear approximation obtained using Excel software (Microsoft Office Professional 2016 Excel, Microsoft Corporation, Washington, USA).

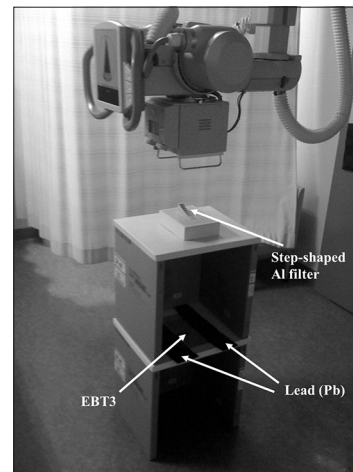


Figure 2: Arrangement of the exposure method using a simplified creation method

#### Comparison with the standard method

To compare the respective data from the simplified method using the step-shaped Al filter and the standard time-scale method, the averaged NPV, standard deviation, and absorbed dose were obtained. Based on this data, density-absorbed dose calibration curves were obtained for both methods at the same exposure parameter (100 kV). Various data (degree of leaning, coefficient of determination) from the calibration curves obtained using the simplified method were compared with the data obtained by the standard method.

#### Results

##### Quality of the X-rays which penetrate the Al filter (plate)

Table 1 summarizes the absorbed dose, half-value layer, and effective energy for each thickness of the Al filter at 100 kVp using the semiconductor multidetector. The effective energies calculated for each thickness of the Al filter changed in the range of approximately 38–58 keV. The influence of the energy dependence is <0.2% in this study because the EBT3 has an energy dependence of approximately 0.2% from 30 keV to 60 keV.

##### Density-absorbed dose calibration curve using EBT3 film and a step-shaped Al filter

Table 2 summarizes the absorbed dose and NPVs obtained using the simplified method with EBT3 film and a step-shaped Al filter. Table 3 summarizes the same parameters as Table 2 obtained using the standard time-scale method. Figure 3 shows the density-absorbed dose calibration curves. The density-absorbed dose calibration curves exhibited a linear relationship for both methods. The gradients of the density-absorbed dose calibration curves for each method were  $-32.336$  and  $-33.746$ , and there was no significant difference ( $t = 1.63$ ,  $df = 12$ ,  $P = 0.13$ ).

**Table 1: The absorbed dose, half-value layer, and effective energy provided by each thickness of the Al filter at 100 kVp**

| Al thickness (mm) | Absorbed dose (μGy) | Half-value layer (mm) | Effective energy (keV) |
|-------------------|---------------------|-----------------------|------------------------|
| 0.0               | 838.7±1.829         | 3.954±0.000           | 38.34                  |
| 1.0               | 667.7±4.063         | 4.572±0.002           | 41.07                  |
| 2.0               | 554.6±1.715         | 5.124±0.002           | 43.40                  |
| 3.0               | 465.8±1.512         | 5.615±0.002           | 45.41                  |
| 4.0               | 401.4±1.096         | 6.055±0.002           | 47.15                  |
| 5.0               | 348.4±2.151         | 6.452±0.004           | 48.68                  |
| 7.5               | 256.0±0.601         | 7.271±0.003           | 51.76                  |
| 10.0              | 196.4±0.818         | 7.885±0.003           | 53.98                  |
| 12.5              | 153.6±0.653         | 8.367±0.001           | 55.70                  |
| 15.0              | 122.2±0.330         | 8.785±0.002           | 57.15                  |

**Table 2: The absorbed dose and net pixel values using the simplified method with Gafchromic EBT3 film and a step-shaped Al filter**

| Simplified method   |                 |
|---------------------|-----------------|
| Absorbed dose (mGy) | NPV             |
| 12.21               | -572.14±359.11  |
| 15.36               | -722.02±368.87  |
| 19.64               | -824.24±346.52  |
| 25.60               | -1065.01±340.83 |
| 34.84               | -1546.54±333.03 |
| 46.58               | -1865.47±339.28 |
| 55.46               | -2061.09±330.86 |
| 66.77               | -2428.25±341.63 |
| 83.87               | -2855.11±349.24 |

NPV: Net pixel value

**Table 3: The absorbed dose and net pixel values using the standard method with Gafchromic EBT3 film**

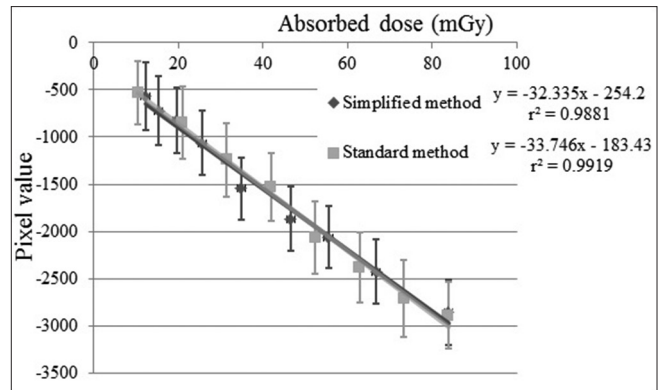
| Standard method     |                 |
|---------------------|-----------------|
| Absorbed dose (mGy) | NPV             |
| 10.48               | -534.61±337.47  |
| 20.96               | -850.27±382.72  |
| 31.45               | -1242.84±390.81 |
| 41.94               | -1531.85±355.64 |
| 52.42               | -2062.79±380.98 |
| 62.90               | -2385.84±370.04 |
| 73.39               | -2708.30±403.78 |
| 83.87               | -2887.14±357.61 |

NPV: Net pixel value

**Discussion**

**Energy dependence of the EBT3 film**

The manufacturer indicates that the EBT3 film has an energy-independent dose response.<sup>[1]</sup> This characteristic is more advantageous for the evaluation of the absorbed dose compared with other films. However, even a slight



**Figure 3: The density-absorbed dose calibration curve for the simplified and standard methods in the reflection mode with subtraction processing**

energy dependence must be considered because the intent of this study is to provide a highly precise calibration curve. In this study, Al filters with thicknesses in the range of 1–15 mm were used, and the effective energy changed from 38 keV to 58 keV. Therefore, it was necessary to evaluate the energy-dependent error in the range of effective energies. As a result of this evaluation, it can be seen that a simplified method using the step-shaped Al filter is available in this energy range because the energy-dependent error is <2% from 30 keV to 60 keV. Therefore, it is considered that the simplified method for creating a density-absorbed dose calibration curve is valid when the absorbed dose for every thickness of the Al filter is measured.

**Utility of the simplified method**

In this study, the proposed simplified method for creating a density-absorbed dose calibration curve from EBT3 film was investigated on the assumption that it would be used in the low-dose range. When the density-absorbed dose calibration curve was obtained using the standard method, it was necessary to irradiate the exposure fields of eight regions 36 times. When the simplified method was performed, the total number of radiation exposures was only eight. This suggests that the simplified method can be used to create a density-absorbed dose calibration curve in a very short period compared to the standard method.

**Conclusions**

A density-absorbed dose calibration curve method could be obtained using EBT3 film at a low energy dependence with a step-shaped Al filter in a very short period compared to the standard method. Therefore, the creation of density-absorbed dose calibration curves of a packaged unit of EBT3 film, as recommended by the manufacturer, could be easily executed using the simplified method. In light of these findings, it is considered that the simplified method using EBT3 film offers a simple means of determining the density-absorbed dose calibration curve in a low absorbed dose range such as the diagnostic range.

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### Conflicts of interest

There are no conflicts of interest.

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