Calibration of Gafchromic EBT Film Using the Microtek ScanMaker 9800XL Plus Flatbed Scanner with a Modified One Red-Channel after Three-Channel Method

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Abstract

Purpose: Using the Microtek ScanMaker 9800XL Plus (9800XL$^+$) flatbed scanner, a method is presented to accurately calibrate EBT film, which cannot be calibrated simply using a general three-channel method because of the nonhomogeneous scanning. **Materials and Methods:** Through the percentage-depth-dose method, 6-MV photon beams with two different monitor units were delivered to eight EBT2 films, each of which was tightly sandwiched in a 30-cm cubic polystyrene phantom and positioned parallel to the central axis of the beam. Before and after irradiation, all films were scanned using the Microtek 9800XL$^+$ scanner and the pixel values (PVs) were measured along the central axis of the beam on the film and fitted to the corresponding depth doses. Before calibration, the irradiated film image was first modified using a template matrix, which was generated using the prescanned background images. Then, a modified one red-channel after three-channel method was used to calibrate the film. **Results:** Without a template matrix, the three-channel method cannot be used because the PVs do not correspond to a rational fitting form. Using the proposed method, the difference between the fitted dose and the delivered dose is <2%. The green channel, and not the red, is found to have the largest dynamic range. **Conclusion:** The proposed technique allows the use of the three-channel method to calibrate film using a Microtek 9800XL$^+$ scanner.

Keywords: EBT film, Microtek scanner, template matrix, three-channel calibration

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INTRODUCTION

Gafchromic EBT film is widely used to determine the differences of dose distribution in the treatment volume for a patient between planning and delivery, largely because it is self-developing, has a near dose-to-water equivalence,[1] gives high spatial resolution, is re-readable, features a relatively uniform dose-response across a wide range of photon energies[2-4] and is an inexpensive technique that uses commercially available flatbed document scanners.[5]

Several generations of Gafchromic film have been developed, but only EBT2 and EBT3 film are recommended by Ashland company for the verification of beam-modulated techniques[6] because spatial nonhomogeneity is corrected by the yellow marker dye,[5,7-12] it has a lower sensitivity to the visible spectrum and it can be used for repeated scans.[13,14] Using a matte polyester substrate to avoid the formation of Newton's rings,[15-18] EBT3 film has a similar composition for the active layer and dosimetric properties as EBT2[16] and either side of the film can be used.[19] The Ashland report states that the respective effective atomic numbers for EBT2 and EBT3 films are around 6.8 and 7.3, respectively, which is approximately equivalent to that for water. Therefore, they are eminently suited to patient dosimetry.[14,20]

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The red, green, and blue color levels of EBT films can be analyzed for calibration. The red level calibration is sensitive to the dose of daily treatments within a range of 0–5 Gy[6,12,18] and the green and blue level calibrations are better for larger doses.[5,21,22] Multichannel techniques generally give a better pass rate than a single-red-channel calibration for the verification of treatment planning using the local gamma index.[23] Using the three-channel calibration method, Micke *et al.* proposed parameters that are dependent and independent of dose in the optical density (OD) domain to model and reduce deviations in dose-independent (DI) nonuniformities.[24] van Hoof *et al.* noted[25] that nonuniformity corrections must be examined for larger fields. To further reduce nonuniformities, Chang *et al.* proposed a new parameter: channel-dependent (CD) scanner-nonuniformity in the OD domain. To reduce the calibration uncertainties, a power-function fitting process using only the red channel OD was used for the three-channel technique.[26]

All of these methods mentioned use Epson scanners. An alternative cheaper choice is the Microtek 9800XL Plus ($9800XL^+$) scanner, which is an A3 size scanner with a dynamic range of 48-bit. However, if the film dose is calibrated using a Microtek $9800XL^+$, the multi-channel method cannot be used, except the presented template matrix is used first.

MATERIALS AND METHODS

Gafchromic™ EBT2 films (Ashland Inc., USA) of 8”×10” and a Microtek $9800XL^+$ (MICROTEK™ company, Taiwan) scanner were used to generate 127 dpi tiff images before and after irradiation, for the purpose of calibration. The films were scanned using Scan Wizard Pro software (MICROTEK™ edition V7.26, Taiwan) and the functional mode, “averaging multiple-sampling of 2 lines,” was used.[27]

To ensure that the film was oriented identically on the scanning bed for each scan, a homemade 43 cm × 36 cm × 0.2 cm acrylic transparent frame with a film-fitted hole was placed on the scanning platform in the portrait orientation. The scanner was warmed up by scanning a waste film eight times. The percentage-depth-dose (PDD) method[28] was used to calibrate the film using the 6 MV photon beam from an Elekta Synergy® accelerator, which was previously calibrated at a depth of 5 cm according to the AAPM TG reports.[29-32]

Before the dose was delivered, the film was sandwiched in a 30 cm × 30 cm × 30 cm PTW™ (PTW-NEW YORK Corporation) RW3 polystyrene phantom and the midline that longitudinally separates the film into two equal parts was oriented to be coincident with the central beam axis. The film was also oriented parallel to the central beam axis and the upper edge of the film was parallel to the gantry rotation axis, which is conventionally the Y-axis in the literature.[14,26-28,33] To measure the reference dose, a 0.6 cc Farmer chamber was located at a depth of 31 cm, 10 cm thick backup plates were placed under the entire 30 cm × 30 cm × 30 cm phantom, and the source-surface-distance was set to 100 cm. The reference dose measurement using the chamber at depth 31 cm may not be necessary if the monthly dosimetry calibration was performed just before the film-dose calibration. With field size 20 cm × 20 cm, four films were irradiated using a 290 monitor unit (MU) with delivered doses (D_d) around 320, 304, 280, 225, 177, and 108 cGy at respective depths, d_{max}, 3, 5, 10, 15, and 25 cm, and another four using an 88 MU with D_d around 97, 92, 85, 68, 54, and 33 cGy at respective depths, d_{max}, 3, 5, 10, 15, and 25 cm. The absorbed doses then ranged from around 30 cGy to 300 cGy on the midlines of the films. The doses are calculated using the verified PDDs and the measurements from the Farmer chamber.[14]

After around 48 h, each film was rescanned with the same 127 dpi and “2-lines-average scanning (each color 16 bit).” All of the tiff format images were analyzed using MathWorks® Matlab software (version R2017b). The inverse transmittance (IT) for the U channel (one of the R, G, and B channels), I_U, for each image pixel is expressed as:

$$I_U = (2^{16} - 1)/P_U, \quad (1)$$

where P_U is the pixel value (PV) for the U channel. However, equation (1) must be modified with a template matrix, T_U, because the IT values do not correspond to a rational fitting form (equation 4) and the calibration cannot be correctly performed, as shown in Figure 1. Therefore, it is not possible to use the three-channel method[26] if T_U is not used. Multiplying I_U by the template matrix, the modified IT, N_U, is written as:

$$N_U = I_U \times T_U \quad (2)$$

The template matrix of channel U is given by:

$$T_U = S_U/M_U \quad (3)$$

where M_U is a 2-dimensional PV matrix of channel U, using the average for the eight prescanned background films, and S_U is a single value that is the average of all values for M_U.

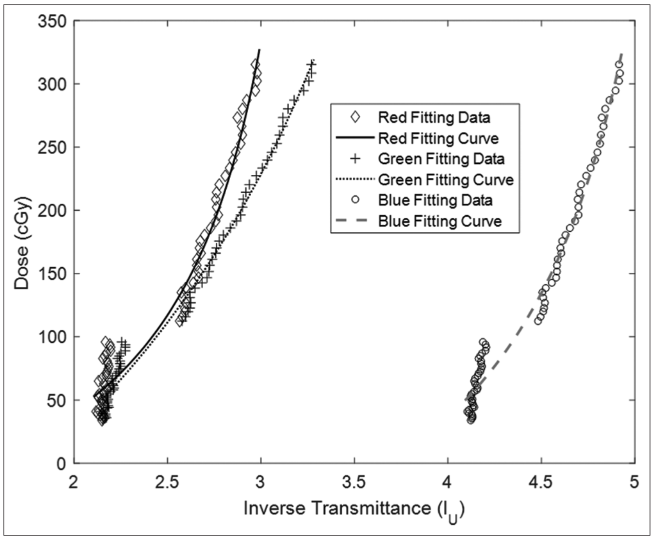

Figure 1: The inverse transmittance versus the delivered dose: the film was scanned using Microtek 9800^+ without the template matrix T_U

The delivered reference dose D_d as a function of N_U along the central beam axis is fitted using the rational fitting form:

$$D_U = (A_U - B_U \times N_U)/(N_U - C_U) \tag{4}$$

where A_U, B_U, and C_U are the fitting parameters for the calibration of the U channel and D_U is the fitted dose for channel U. The inverse function is written as:

$$N_U = (A_U + C_U \times D_U)/(B_U + D_U) \tag{5}$$

Using the "one red-channel after three-channel (R-3C) method,"[26] the OD of the U channel, O_U, is the product of $O_{dd,\ U}$, O_{di} and $O_{L,\ U}$, which is the OD for CD and dose-dependent (DD), the OD for channel-independent and DI[24] and the OD for the CD scanner nonuniformity effect (the lateral effect), respectively. Therefore, the DD component of N_U, which is $N_{dd,\ U}$, is expressed as:

$$N_{\mathrm{dd,u}}\ (D_{\mathrm{d}}) = N_{\mathrm{u}}\ (D_{\mathrm{d}})^{\frac{1}{O_{L,U}} \times \frac{1}{O_{di}}}, \tag{6}$$

where $N_{dd',\ U}$ is equal to $10^{O_{dd,u}}$. D_R should be equal to D_G and D_B, but this is not the case because the O_{di} exists, but not the $O_{L,\ U}$. This is because the depth doses are extracted from the middle line of the film, where no correction for lateral effect is required.[28] Therefore, O_{di} is determined by minimizing K:

$$K = (D_R - D_G)^2 + (D_G - D_B)^2 + (D_B - D_R)^2, \tag{7}$$

by using equation (4) and (6) with the command "fminbnd" in MATLAB software. When O_{di} is eliminated, A_U, B_U, and C_U are calculated again using equation (4) and are, respectively, renamed A_{nU}, B_{nU}, and $C_{nU.}$

The profile doses for the 290-MU films with depths of 5, 10, and 20 cm (the request depths for inputting profiles into the planning system), which are related to the doses, D of 280, 225, and 140 cGy, or to PDDs of 87.8, 70.4, and 43.6, are used to calculate the OD for the lateral effect, $O_{L,\ U}$, using the following equation:[26]

$$\frac{\left(A_{nU} - B_{nU} \times N_U\ (D)^{\frac{1}{O_{L,U}\ (y)} \times \frac{1}{O_{di}}}\right) / \left(N_U\ (D)^{\frac{1}{O_{L,U}\ (y)} \times \frac{1}{O_{di}}} - C_{nU}\right)}{\left(A_{nU} - B_{nU} \times N_U\ (D, y = 0)^{\frac{1}{O_{di}}}\right) / \left(N_U\ (D, y = 0)^{\frac{1}{O_{di}}} - C_{nU}\right)} = R_D(y) \tag{8}$$

where R_D (y) is the profile dose that is obtained from the scan of the water phantom, normalized to that of the central beam axis at the depth of dose D (280, 225, or 140 cGy). The left part of the equation also applies to the normalized profile doses but is calculated using equation (4) with A_{nU}, B_{nU}, and C_{nU}. The y-axis is parallel to the gantry-rotation axis with its origin at the isocenter. $O_{L,\ U}$ is calculated using the fitted results for a third-order polynomial form.[26] When $O_{L,\ U}$ is obtained, the value of $N_{dd,\ U}$ for the entire film is calculated using the equation.[6]

Calibration in the red channel is more sensitive to a range of daily doses,[6,12,18] and hence, the red channel of $N_{dd,\ U}$, $N_{dd,\ R}$, was obtained and this calibration is named "the red IT with the template." To decrease the uncertainty further, a conventional fitting process with a power function was used with the equation:

$$F_R = A' \times O_{dd,\ R} + B' \times O_{dd,\ R}{}^{C'} + D' \tag{9}$$

where $O_{dd,\ R} = \log_{10}(N_{dd,\ R})$; F_R is the fitted dose for fitting parameters, A', B', C', and D'. The fitting process was repeated twice, with C' first bounded between 1 and 3, and then with C' and D' fixed to the value of the first fit.

For the dose calculation using $N_{dd,\ R}$, the total standard uncertainty, which is the combined uncertainty due to the experiment and the fitting processes, is calculated using equation (4) and equations in reference 26 with the fitted dose in percentage terms and the uncorrelated input quantities $N_{dd,\ R}$, A_{nR}, B_{nR}, and C_{nR}. The calculation is performed based on the guidelines of the Joint Committee for Guides in Metrology (JCGM).[34]

Similarly, the relative total standard uncertainty for the dose calculation using $O_{dd,\ R}$, is calculated using equation (9) and equations in reference 26 according to the JCGM guidelines, using the uncorrelated input quantities $O_{dd,\ R}$, A' and B'. The accuracy of the fitted dose and the uncertainty calculation using the traditional red channel net optical density (NOD) and the PDD method[28] is also calculated and compared with that for the R-3C method using the template.

RESULTS AND DISCUSSION

In contrast to Figure 1, when a template matrix is used and the DI OD (O_{di}) is eliminated using equations (3), (6), and (7), N_U can be neatly fitted to the D_d using equation (4) for all three channels, as shown in Figure 2. The results demonstrate that the template matrix (equation 3) is required for the rational fitting form of equation (4). If it is not used, the difference between the fitted dose and the D_d could be >50%.

If an Epson scanner is used, the red channel has a greater dynamic range than the green channel.[26] In contrast, if the Microtek scanner is used, the green channel has a greater dynamic range than the red channel [Figure 2].

The fitted doses that are calculated using equations (4) and (6) in Figure 3 better match the D_d than those that are calculated using the NOD of the red channel and the PDD method. All differences using the R-3C with a template are <2%, which are similar to the calibration results using an Epson scanner.[26,28]

Figure 4 shows the OD calibration for lateral effect. It is seen that all of the calibration factors are approximately between 0.99 and 1.01, because the template matrix regulates inhomogeneity in the scanner. This calibration factor gives a more refined dose calculation.

When the DI OD and lateral effect are eliminated, the dose profiles for 280, 225, and 140 cGy are normalized to the dose at the central axis and then compared to the profile measured in the water phantom. The difference is <2% for all channels [Figure 5].

The results of the uncertainty calculation are shown in Figure 6. It is seen that the total standard uncertainty relative to the fitted dose for the R-3C method using the template and the NOD calibration for the red channel is <10%. This value is high, when compared with the value of 5% for the Epson 10000XL scanner.[26] However, the total uncertainty for red IT using the template is even higher and can be higher than 20% for D_d around 50 cGy.

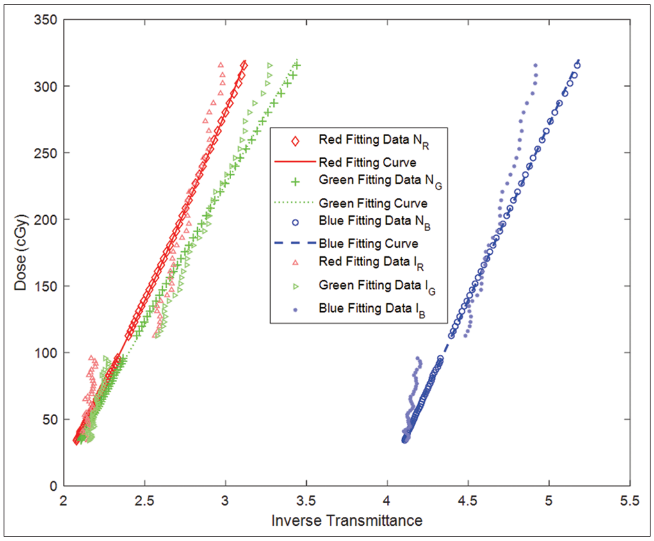

Figure 2: A comparison of the fitting results for the inverse transmittances N_U using the red-channel after three-channel method with a template matrix with those for the fitting data for I_U in Figure 1

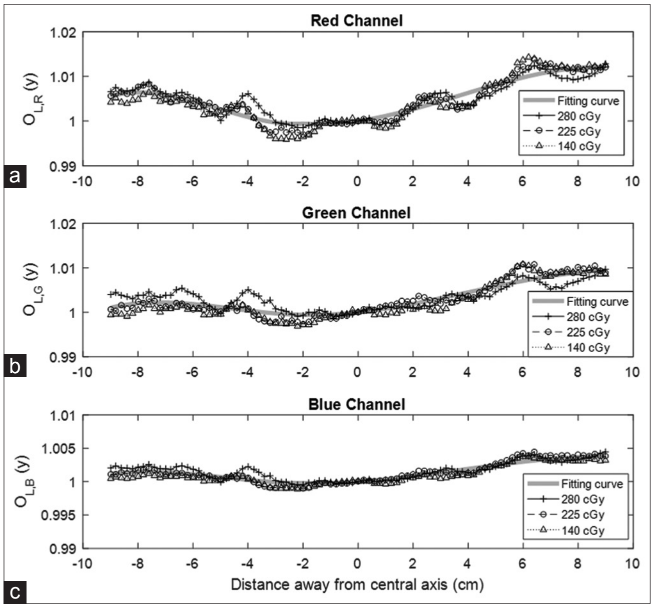

Figure 4: The optical density of lateral effect, $O_{L,U}$, using equation (8) for doses of 280, 225, and 140 cGy: (a) The red channel, (b) The green channel, and (c) The blue channel

CONCLUSION

This study demonstrates that a template matrix is required for the rational fitting process using equation (4). If it is not used, there is a significant error and the fitting cannot be performed. Using the proposed technique, the differences between the fitted dose and the D_d are <2%. The difference for the traditional one red-channel method is >3%. The calibration accuracy is similar to that for an Epson 10000XL scanner. The lateral effect can also be ignored because this calibration uses a template matrix.

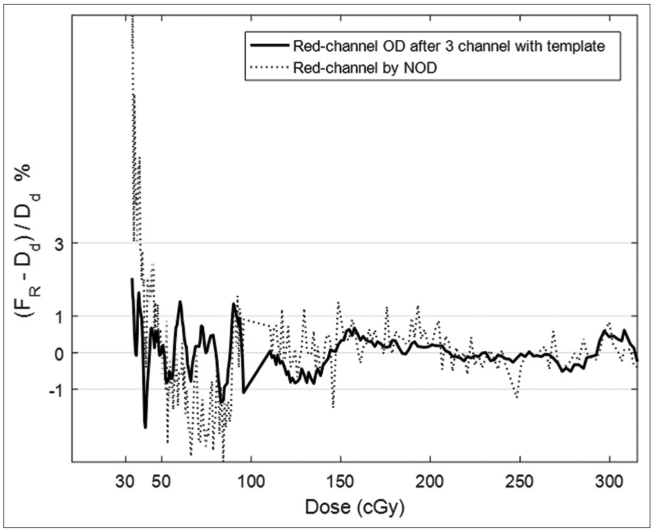

Figure 3: Differences between the fitted dose and the delivered dose, calculated using the red-channel after three-channel method with a template matrix and using the existing percentage-depth-dose method with red-channel net optical density

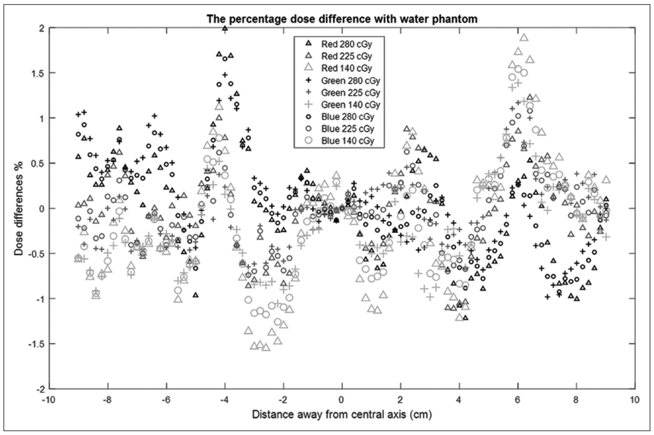

Figure 5: Difference between the normalized dose profiles calculated after eliminating dose-independent and optical density for the lateral effect and the profile measured from the water phantom for the three channels: note that no data points are obscured by the legend

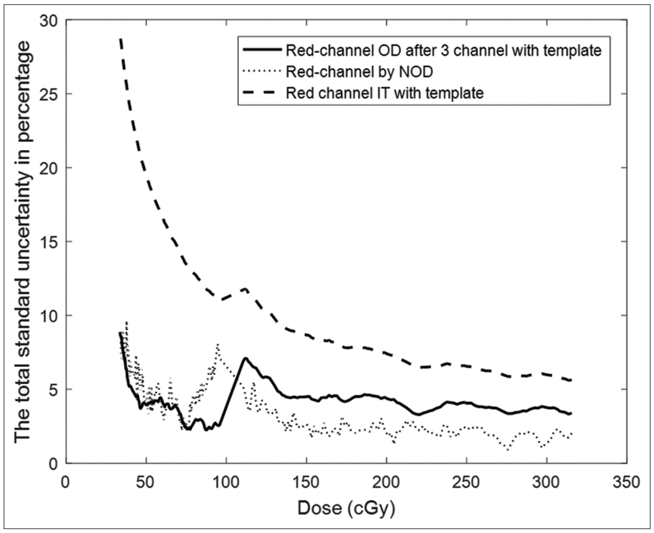

Figure 6: The total standard deviation, calculated using the red-channel after three-channel method and a template, the red-channel net optical density method and red inverse transmittance with a template

This method means that the three-channel method can be used to calibrate film using a Microtek 9800XL$^+$ scanner and the template matrix can be useful for other brand scanners. The greater dynamic range of the green channel is a subject for future study. The green channel may replace the red channel for the verification of clinical daily treatment using a Microtek scanner.

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Conflicts of interest

There are no conflicts of interest.

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