Incorporating a lateral scan effect correction in a EBT3 calibration protocol

1. INTRODUCTION

Recently the radiochromic EBT series is extended with a third generation. According to the manufacturer the EBT3 film features a symmetrical construction and anti-Newton coatings for enhanced ease-of-use and accuracy\(^1\). As in the previous versions, EBT3 struggles with a lateral scan effect\(^2,3\) when digitized with a flatbed scanner.

The lateral scan effect, with dose errors in the order of 5% at 2Gy\(^2,3\) and 10% at 5Gy\(^3\), has an important impact on the gafchromic film dosimetry. The effect is inherent in the film-scanner transmission system. Therefore, we propose to tackle the lateral scan effect in the calibration procedure itself. To assess a sufficient sampling of both the dose and lateral dependency in the calibration procedure, eight dose levels are irradiated to two lateral locations on two uncut calibration films (one location per film). From this data the calibration parameters are estimated. The calibration curve is then validated by irradiating different uniform doses to eight strips cut from a single film. The film strips cover the full lateral length on the scanner. Both the calibration and the validation methodology is outlined bellow.

2. MATERIALS AND METHODS

a. Association between transmittance and delivered dose

Mathematically, the relative scan signal or transmittance \((T)\) decreases monotonically as the dose \((D)\) increases. The association between \(T\) and \(D\) can be described by a rational function\(^4\):

\[
T = \frac{\beta_1 + \beta_2 \cdot D}{\beta_3 + D}
\]  

Equation 1 can be interpreted as follows.

\(T_0 = \frac{\beta_1}{\beta_3}\) : The transmittance when no dose is delivered equals the ratio of \(\beta_1\) and \(\beta_3\).

\(T_{\text{max}} = \beta_2 : \beta_2\) is the transmittance resulting from a theoretical infinite dose, \(\lim_{D \to \infty} \left(\frac{\beta_1 + \beta_2 \cdot D}{\beta_3 + D}\right) = \beta_2 = T_{\text{max}}\). The presented validation of this theoretical model is concentrated on a clinical dose range. An estimation of the true maximal physical transmittance of the films is outside the scope of this work.

b. Lateral scan effect

The transmittance of a film decreases with the distance from the center of the light source. This is the so-called lateral scan effect\(^2,3,5\). To compensate this effect, Fiandra \textit{et al.}\(^3\) use a 3D matrix of correction factors to perform a correction in the dose domain. Because the effect is due to the scanner transmission system rather than the dose delivery, we propose a correction in the transmittance domain. Here, the effect is modeled by a second order polynomial function of the pixel position, \(X\), in the direction parallel to the light source (Equation 2).

\[
T(D, X) = T_{\text{max}} + \frac{T_0 - T_{\text{max}}}{1 + \frac{D}{\beta_5}} + \beta_4 \cdot X + \beta_5 \cdot X^2
\]  

\(c.\) Calibration

Eight static \(4 \times 4\) cm\(^2\) fields irradiate two calibration films. A 6MV photon beam from a Varian Linac 2100C/D is used. To estimate both the dose and the lateral dependency (\(X\), figure 1) each dose level has a centrally \((X = \pm 3\text{cm})\) and a laterally \((X = \mp 9\text{cm})\) positioned field (one position per film). Figure 1 shows a schematic overview of a calibration film. The sizes, the positions and orientation of the calibration fields are chosen to maximize the separation between fields.

The selected field size (FS) guarantees lateral electronic equilibrium. According to Todorovic \textit{et al.}\(^6\) the calibration function is not affected by the field size, for field sizes ranging from \(2 \times 2\) to \(10 \times 10\) cm\(^2\). The calibration setup allows the estimation of all five parameters, \(T_0, T_{\text{max}}, \beta_3, \beta_4, \beta_5\), with high significance \((p < 0.001)\).

\(d.\) Validation

To determine the dose accuracy, a film is cut in eight \(1 \times 10\) inch strips, and uniformly irradiated with various dose levels \((D= 0, 0.26, 0.57, 0.94, 1.42, 2.05, 2.91, 4.16)\). The average and standard deviation of the dose...
differences on the central pixel line are calculated as estimates of the dose error. On this line five 2 inch ROIs are defined. The root mean square error (RMSE) on these ROIs is used to evaluate a residual lateral dependence.

e. Measurement setup

Calibration: A stack of solid water plates (30×30×20 cm³) is positioned with 95 cm source to surface distance (SSD). The film is positioned at 5 cm depth, to ensure sufficient build up and backscatter (5–15 cm).

Validation: For the uniform irradiation of film strips the stack of solid water plates is positioned on the floor (SSD=213 cm), and a 40×40 cm² field is used.

Scanning procedure: Films are scanned on the central region of an Epson 10000 XL flatbed scanner, with the eight inch side parallel to the longer edge of the scanner. Scanned pixel values are calculated as the average of five subsequent scans, and noise is reduced by applying a Wiener filter as proposed in7.

3. RESULTS AND DISCUSSION

a. Dose error

The validation measurements are depicted in Figure 2. For the red color channel, relative mean dose errors are smaller than 2.0%, 2.2%, and 2.0% on a 0.57 to 4.16 Gy dose range, for the red, green, and blue color channel respectively. The standard deviations on these dose values are smaller than 1.8% which is comparable to the values reported for EBT 1 films by Devic et al.

They reported 1.5% dose error for dose values ranging from 0 to 4 Gy on film samples8. However, because of the size of the samples they used (4 × 2.5 inch), the lateral effect does not fully apply on these results. Additionally, our application (measuring large modulated treatment fields) requires the full length of the film. Fiandra et al. report 3.6% dose errors for doses above 0.3 Gy on uncut EBT 1 films, with post calibration lateral correction. van Battum et al. report 1.3% dose errors at 2 Gy for large uniform fields on EBT films, which is a slightly better performance than our EBT3 results.

6. Lateral dependency

In figure 2 the impact of the lateral correction is illustrated for the red color channel (corrected vs uncorrected). The RMSE is smaller than 0.5% for all ROI and dose levels ranging from 0.26 to 4.16 Gy. This is a reduction of 2% compared to the uncorrected red channel RMSE, with a maximal value of 2.5%.

4. CONCLUSION

A calibration protocol for the new gafchromic EBT 3 film is introduced for large modulated field dosimetry. The protocol estimates both the dose dependency of the film, and a quadratic transmittance correction for the lateral scan effect. A calibration on two calibration films is sufficient to estimate all required parameters (T₀, Tₘₐₓ, β₁, β₂, β₃) with high accuracy (p < 0.001). Resulting dose errors are in the order of 2%. The incorporated lateral scan correction reduced the RMSE on the outer inches of the film from 2.5% to 0.5%. All three color channels of the EBT3 film had comparable results for dose measurements.

FIG. 2. Validation of the proposed calibration protocol. The central pixel line of the uniformly irradiated film strips are converted in to dose for all color channels (dashed lines). To illustrate the lateral effect the uncorrected (X = 0 in Eq. 2) red channel data is depicted as well (dashed dotted lines). The solid lines represent the expected dose (IC-measurements). The vertical lines indicates the ROI used for the RMSE evaluation.

1Ashland Specialty Ingredients, Wayne, New Jersey (www.gafchromic.com).