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Radiation Film Calibration In Three-Dimensional RGB Color Space

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ABSTRACT

Purpose: To propose a novel calibration equation and computational algorithms for film dosimetry using all three RGB color data.

Methods: The film calibration method uses the optical transmission or reflection properties to convert the characteristic changes in the films into absorbed dose. Modern equipment for quantifying color change can acquire images in the three colors: red (R), green (G), and blue (B). The proposed method used all three colors to derive a single calibration equation. A spline equation was generated in the three-dimensional RGB color space from the average pixel intensities of films irradiated to various known radiation dosages. To estimate the unknown dose delivered to a new film, the RGB color intensity values were measured. It was represented as a point A in the RGB space. Then, a corresponding point P on the 3D calibration curve was identified as the point on the curve closest to Point A. The dose at Point P was easily estimated using the spline calibration equation. We tested the method to evaluate the feasibility. Ingenious radiochromic films were scanned with a flat-bed color scanner to obtain the RGB color data of irradiated films.

Results: The 3D curve of the test films exhibited a snake-like shape, indicating the true complexity of the spectral changes in film characteristics as a function of absorbed dose. A single dose was obtained with the new method for a given RGB value of a film irradiated by a fixed dose, whereas the standard calibration method yielded three noticeably different estimated doses corresponding to three colors.

Conclusion: A novel calibration equation formulated in the three-color 3D space was proposed to achieve more accurate film calibration. The method's performance is being tested for 2D film dosimetry.

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INTRODUCTION

PURPOSE: To propose a novel calibration equation and computational algorithms for film dosimetry using all three RGB color data.

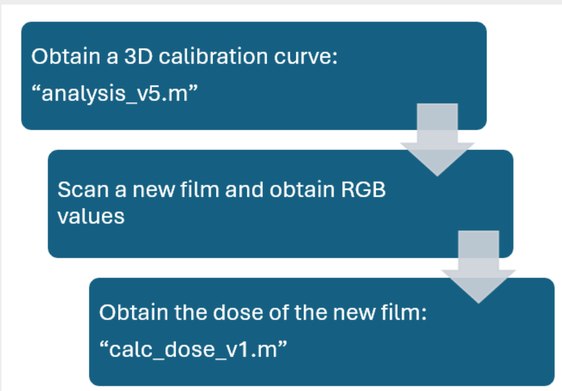
INNOVATION: The film calibration method uses the optical transmission or reflection properties of the films to convert the color change of the films into the absorbed dose. Modern equipment for quantifying color change can acquire images in the three colors: red (R), green (G), and blue (B). It is well known that the spectral changes in the absorbance and transmittance of irradiated films are complex and ideally require optical spectra for more accurate dosimetry. Unfortunately, there is no readily available, affordable spectroscopy equipment, especially for obtaining spectral data at the high spatial resolution required for radiation dosimetry. Hence, using three colors for dosimetry is a practical step to improve the accuracy of film dosimetry. Currently, no method is available to fully exploit three-color dosimetry. Therefore, in this study, we developed a novel method that uses a 3D RGB spline curve, replacing the traditional 2D calibration curve of dose versus optical quantity, which is separately obtained for three colors.

METHODS AND MATERIALS

METHODS: The film calibration method uses the optical transmission or reflection properties to convert the characteristic changes in the films into absorbed dose. Modern equipment for quantifying color change can acquire images in the three colors: red (R), green (G), and blue (B). The proposed method used all three colors to derive a single calibration equation or *trajectory*. A spline equation was generated in the three-dimensional RGB color space from the average pixel intensities of films irradiated to various known radiation dosages. To estimate the unknown dose delivered to a new film, the RGB color intensity values were measured. It was represented as a point A in the RGB space. Then, a corresponding point P on the 3D calibration curve was identified as the one closest to Point A. The dose at Point P was easily estimated using the spline calibration equation.

The dose measurement procedure with the new calibration method is summarized in Figure 1 along with the names of in-house MATLAB-based analysis codes.

Fig.1: Dosimetry flow diagram. The program names are included



APPLICATION EXAMPLES

TEST METHODS: The proposed method was applied to two types of radiochromic films: radiochromic films of JP Labs (JPL) [1] and the EBT2 Gafchromic films of Ashland (EBT2). To obtain the dose-response data, Several small pieces of film were irradiated to known doses, ranging from 50 cGy to 4000 cGy for JPL and 50 cGy to 1000 cGy for EBT2, in solid-water phantoms using a high-energy photon beam. The irradiated films were scanned using an Epson V500 flatbed scanner. The RGB data from the scanned films were saved in an Excel file for subsequent data processing.

RESULTS: The light intensities vs the dose in cGy and the calibration curves in the RGB space are shown in Figs.2 and 3 for JPL and EPBT2, respectively. Fig.2(a) and Fig.3(b) demonstrated the differences in the dose-response characteristics between JPL and EBT2 films although both are radiochromic. The 3D calibration equation of the JPL film is strongly curved in 3D; whereas the EBT2 curve looks linear.

Table 1 shows the doses estimated by the new and old methods for five points scattered in the RGB space. There were significant differences between the two methods.

Fig.2: The calibration curve in 3D space.
JP Lab radiochromic films

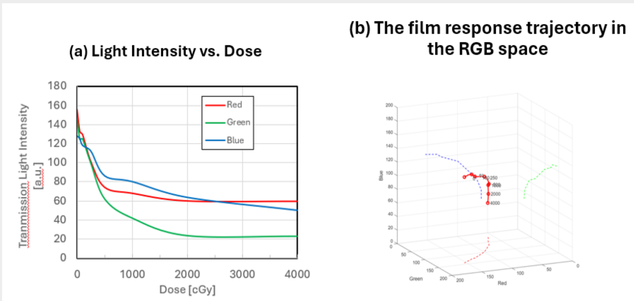


Fig.3: The calibration curve in 3D space.
Ashland EBT2 films

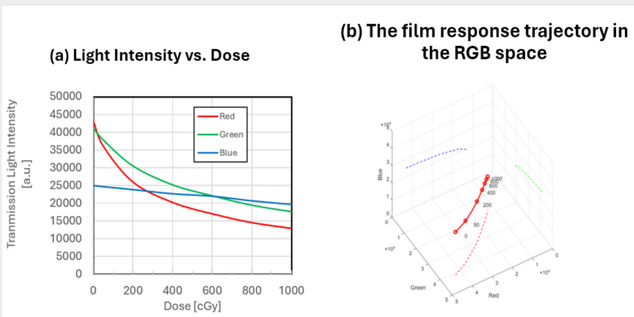


Table 1: Test results (JPL films). Comparison of estimated doses from the new method with those from the single-color method. Nominal dose is the calibration dose closest to the selected points in the RGB space.

Point No.	Nominal Dose	3D	Red	Green	Blue
1	50	56.3	58.8	61.2	55.7
2	100	109.6	106.8	104.2	112.4
3	250	256.7	263.1	260.3	255.5
4	500	492.6	496.9	495.5	493.7
5	2000	1969.2	1968.9	1979.5	1945.8

DISCUSSION

In the past, several investigators proposed methods to utilize three colors in film dosimetry. In 2006, Hupe et al. [3] proposed to take a mean of doses independently determined by calibration equations of three colors with some weighting factors. A research group comprised of developers of the commercial radiochromic films [4] developed a computational method that could eliminate the effects of film thickness variation on dose estimation by combining three color data in one algorithm, demonstrating the value of the new algorithm "Triple channel film dosimetry method". In 2019, Aldellaijan et al developed a method in which a revised linear dose-response equation was derived from three color response data [5]. Although the work is not a utilization of three-color dose-response data to the calibration, Anetai et al. developed an AI-aided technique to find the film thickness non-uniformity from three color data [6].

The 3D curves of the test films exhibited a snake-like shape, indicating the true complexity of the spectral changes in film characteristics as a function of absorbed dose. A single dose was obtained with the new method for a given RGB value of a film irradiated by a fixed dose, whereas the standard calibration method yielded three noticeably different estimated doses corresponding to three colors.

To find a corresponding point on the dose-response curve from the measured RGB values, the distance minimization algorithm was employed. This method is justified because the shortest distance indicates that the probability of the point is the largest among the possible doses considering the Gaussian measurement noise.

CONCLUSIONS

A novel calibration equation formulated in the three-color 3D space was proposed to achieve more accurate film calibration. The method's performance is being tested for 2D film dosimetry.

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