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Ultraviolet ray irradiation duration for the pre-exposure of Gafchromic EBT2

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Abstract

The strength and density change of the ultraviolet (UV) ray of Gafchromic EBT2 were investigated. Previous studies suggested that UV-A rays can be substituted for the x-ray double-exposure technique to correct Gafchromic EBT2's non-uniformity error. In this study, we aimed to determine the appropriate strength of UV-A rays for irradiating an active layer that would correct the non-uniformity error of Gafchromic EBT2.

UV-A rays with a wavelength of 375 nm were used to irradiate Gafchromic EBT2 in various durations, and the resulting density change was investigated. To correct Gafchromic EBT2's non-uniformity error, a pre-irradiation with a UV-A lamp was conducted at a distance of 72 cm for 30 min. To determine the most appropriate irradiation duration, a UV light-emitting diode generating UV-A of 375 nm was used to irradiate the Gafchromic EBT2 film with varying durations of 1, 2, 3, 4, 5, 10, 15, 20, 25, and 30 min at a distance of 5.3 cm. A 12.7 diameter region of interest was set by the irradiation area, and a histogram of pixel values was created. The condition options were decided based on two important requirements: 1) no zero values of the mode and seconds exist, and 2) the 1/10 value of the mode intersects both histogram sleeves.

In the case of Gafchromic EBT2, the irradiation strength was 85.43 mJ/cm^2 for one minute in which the pixel value of mean ± SD was 255.34 ± 213.29. The irradiation duration of 4 min was the border duration of the above two conditions. When a UV ray of 375 nm wavelength is used to irradiate Gafchromic EBT2 as a substitute for x-ray exposure, the 4-min pre-irradiation duration (341.74 mJ/cm^2) is demonstrably sufficient.

Key words: ultraviolet rays; non-uniformity; Gafchromic film; radiation measurement; computed tomography.

Introduction

Gafchromic films are used for quality assurance, quality control, and dose measurements of computed tomography in diagnostic examinations [1-6]. Gafchromic EBT2 and EBT3 films can measure particularly low doses [7] and are used in diagnostic radiology because of this minimal energy dependence [7]. When Gafchromic EBT is used in radiation therapy, a double-exposure technique is used to correct the non-uniformity errors associated with the active layer [8]. Uniform irradiation of x-rays is difficult in diagnostic radiology due to the heel effect [9] associated with the double-exposure technique. Substituting ultraviolet (UV) radiation is a way to correct for the uneven thickness of the Gafchromic film's active layer.

Non-uniformity correction is associated with pre-irradiation of Gafchromic EBT2 by UV-A [10]. UV-A most effectively reacts at a peak wavelength of 365 nm from a fluorescent lamp for Gafchromic EBT2 [11]. In addition, the 375 nm wavelength of UV-A radiation emission from a UV-light emitting diode (LED) was most effective for Gafchromic EBT2 [12]. Thus, in this study, the 375 nm LED was used. However, the most suitable strength (and associated irradiation duration) of UV-A radiation remains unknown.

This study aimed to determine and decide on an appropriate irradiation strength (irradiation duration) when substituting UV-A for the x-ray double-exposure technique.

Materials and Methods

UV LED

A UV LED (375 nm) lamp (NITRIDE SEMICONDUCTORS Co., Ltd. Tokushima) was used. The key representative characteristics of the UV LED used are listed as follows:

· LED Name: NS375L-5RLO
· Direct current, I_F (mA): 20
· Peak wavelength, λp (nm): 375
· Voltage, V_F (V): 3.2
· Photo output, P_0. (mW): 11

Gafchromic films

Gafchromic EBT2 (lot #02171403, Ashland, Inc., Covington, KY) was used in this study. It was cut into 4 inch width and 10 inch height. These cut pieces were fixed into a 3-mm-thick acrylic plate for the reproducibility improvement of the scanning position of the Gafchromic EBT2 film.

Irradiation tool

The UV-A LED irradiation position fixation device that made 30-mm holes for the irradiation of the Gafchromic film (**Figure 1**) were created by UV-cut acrylic plate (Comogras CG UV40 P; 3 mm thickness; Lot # 140406C B Kurarey Co., Ltd. Tokyo). The UV-A LED was irradiated in combination with these devices.

Given that UV rays are known to cause cellular damage [13], a UV irradiation box was constructed using the UV-cut acrylic board to prevent any radiation leakage from the box. Subsequently, the UV LED was attached to this acrylic box (**Figure 2**). A schematic of the setup is shown in **Figure 3**.

Irradiation methods

Gafchromic EBT2 was fixed to a 3-mm-thick acrylic plate for scanning. Pre-irradiation of the Gafchromic EBT2 film was performed for 30 min ($0.0694\ mW/cm^2 \times 1800\ s = 124.92\ mJ/cm^2$) with a 10-W UV-A fluorescent lamp at a distance of 72 cm. To correct the non-uniformity error, the Gafchromic EBT2 film was irradiated with UV-A as the pre-UV irradiation. Subsequently, it was fixed to the plate to maintain its irradiation position, and a 375-nm UV-A wavelength was used to irradiate it from a distance of 5.3 cm through an irradiation hole for 1, 2, 3, 4, 5, 10, 15, 20, 25, and 30 min.

Scanning

An irradiated Gafchromic EBT2 was scanned using an EPSON ES-10000G flatbed scanner (Seiko Epson Co. Nagano, Japan). The images were acquired using Adobe Photoshop CS2 (Adobe Systems Incorporated, San Jose, CA). The images were read with 16-bit, 100-dpi resolution, in RGB mode, with a plain paper copier overhead projector film (CR-PP686, 3M Company St. Paul, MN) and a liquid crystal protective film (LCD-230 W, Sanwa Supply Inc., Okayama) for the removal of Moiré artifacts (Newton's rings) [2]. The Gafchromic films were always scanned in the same orientation (i.e., portrait).

The Gafchromic EBT2 film was fixed to an acrylic board to keep the film from moving during plural scans by balancing one corner to the corner of the scanner surface. Thereafter, the film was scanned.

The scanning preparations of the Gafchromic EBT2 film were performed at a room temperature range of 21-25°C.

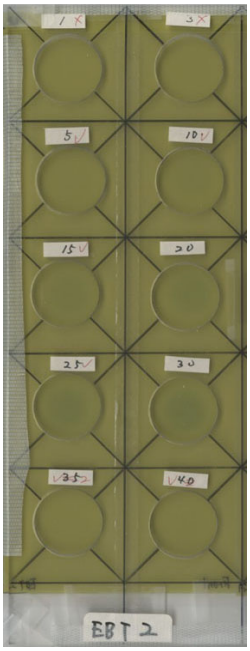

Figure 1. Exposure region of the acrylic plate on the Gafchromic EBT2 film.

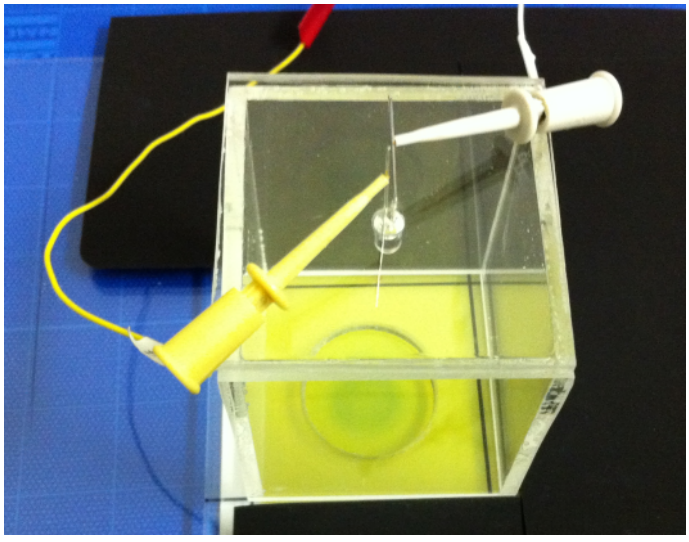

Figure 2. UV exposure device for the Gafchromic EBT2 film.

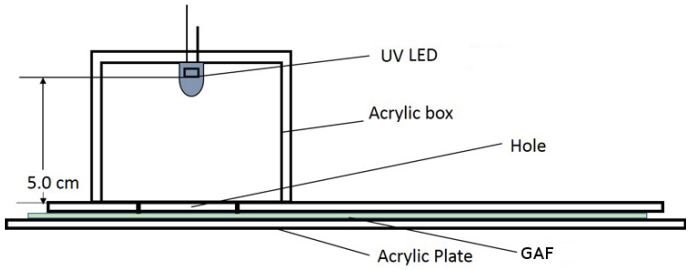

Figure 3. Schematic of the exposure setup illustrating the UV LED and the Gafchromic EBT2 film.

Subtraction processes

To improve scan position reproducibility of the films, a 3 mm thick acrylic plate was used. To ensure uniform scan positions, one angle of the acrylic plate was adjusted to the scanner surface angle in all scan times. First, the Gafchromic films were attached to the 31 × 38 cm^2 acrylic plate and UV-A was irradiated for 30 min for to correct the non-uniformity error with the subtraction method (Image A, **Figure 4**). Second, the first scan was performed. Third, the UV-A LED irradiation position fixation device was attached and the film was irradiated with UV-A (Image B, **Figure 4**). Finally, the UV-A LED irradiation position fixation device was removed, and the second scan was performed (Image C, **Figure 4**). Images A and B were split into R, G, B channels and only the R channel image was used. The subtraction image (image D, **Figure 4**) for the analysis was obtained from images C and A.

Analysis

The circular region of interest (ROI) for the pixel value measurements has a diameter of 0.5 inch (12.70 mm) at the center of the UV irradiation region (**Figure 5**). After obtaining the subtraction image, the ROI was set in the irradiated area, and the measurements were performed in each irradiation duration, as well as the maximum, minimum, mode, and mean ± standard deviation (SD).

UV irradiation duration

The appropriate irradiation duration was determined by considering the following two requirements:

1. The mode pixel value was not indicated in the 0 value of the subtraction image. When no difference is observed, many pixel value data become 0 value between the pre- and true irradiation during subtraction. The mode value became 0.
2. The full width-tenth (1/10) height mode value of the mode pixel value was intersected in both histogram sleeves. The 0 values are not the modes because 0 value data are included. Given that this 0 may be an accidental value (e.g., the dust), it must be removed. Therefore, with the 1/10 mode value width, both sleeves indicating the bell-shaped distribution were subject to a case to show the value that was lower than the 1/10 mode value.

Results

The UV irradiation duration from 1 to 30 min was performed using UV-A of 375-nm wavelength. The pixel values were approximately linearly increased with the irradiation duration. In addition, with an irradiation duration of 1 min, the increased pixel value can be slightly seen with an equilateral value. The graph of this measurement result is shown in **Figure 6**. The pixel value of Gafchromic EBT2 and the strength of the irradiated UV are listed in **Table 1**.

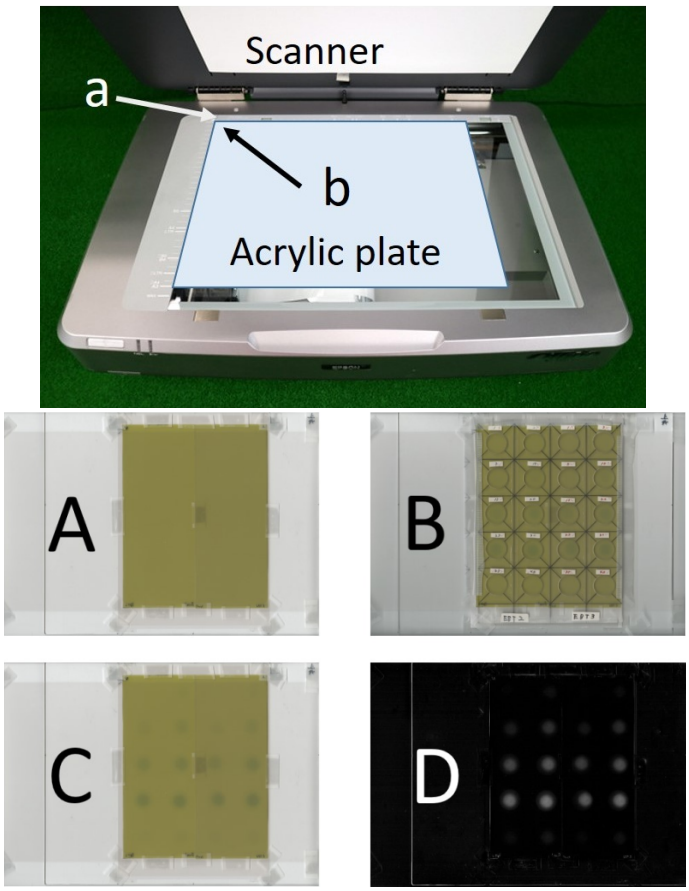

Figure 4. Subtraction process of two times scanning.

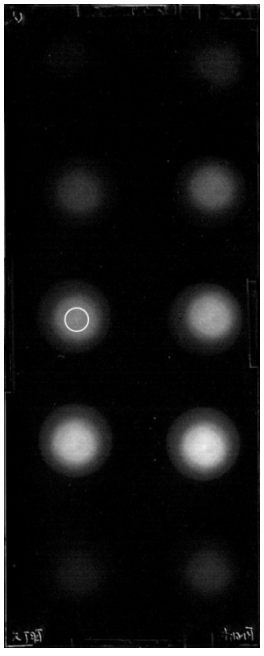

Figure 5. Subtracted image of the 375-nm UV-A of the Gafchromic EBT2 red channel with the ROI of the pixel value measurement to establish a histogram.

Table 1. Pixel values of Gafchromic EBT2 in the subtraction image and the exposure strength of the 375-nm UV

Irradiation duration (min)	Pixel value			Exposure strength (mJ/cm^2)
	Max	Min	Mean ± SD	
1	2016	0	255.34 ± 213.29	85.43
2	1676	0	573.47 ± 251.43	170.86
3	2210	0	704.50 ± 277.48	256.30
4	1784	16	978.38 ± 247.64	341.74
5	3500	378	1256.30 ± 252.30	427.17
10	3654	904	2138.94 ± 324.33	854.34
15	6522	168	3096.61 ± 377.65	1281.51
20	4861	2579	3908.16 ± 339.34	1708.68
25	6045	3103	4693.00 ± 411.56	2135.85
30	6821	3995	5408.46 ± 435.60	2563.02

The distance from the source to the film is 5.3 cm. The exposure is 1.4239 mW/cm^2.

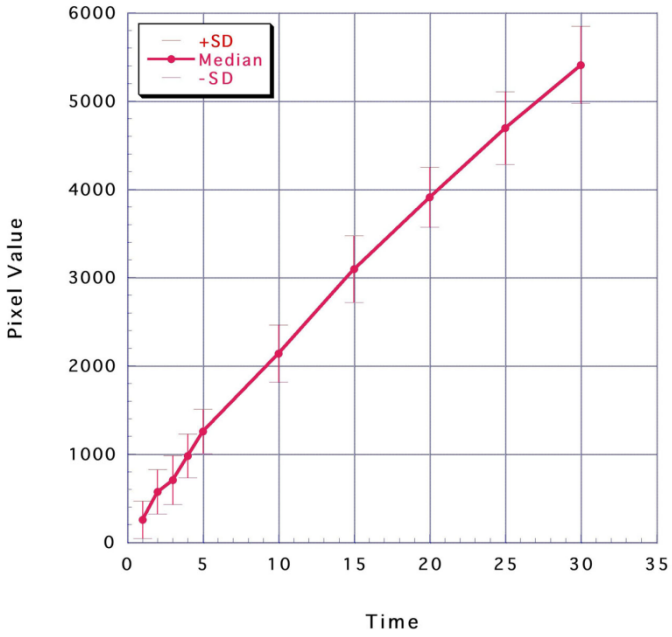

Figure 6. Graph of the measurement data of the 375-nm UV LED.

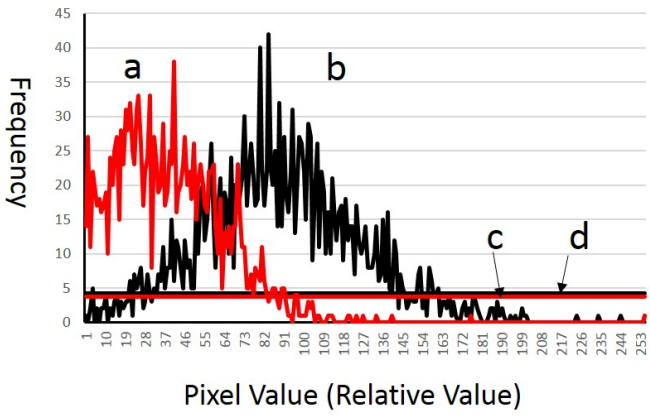

Figure 7. Histogram and full width at the 10th maximum of the Gafchromic EBT2 film. Line a: 1 min of the 375-nm UV-A exposure. Line b: 4 min of the 375-nm UV-A exposure. Line c: 1/10 mode value of the frequency of line a. Line d: 1/10 value of the frequency of line b.

Figure 6 shows the increasing pixel value of the Gafchromic EBT2 film. In the irradiation duration of 2 min, the pixel values started to increase. However, the irradiation condition of 170.86 mJ/cm^2 was enough to apply the following examination of the irradiation duration. The maximum pixel value was 1,676, the minimum value was 0, the mode was 42, 1/10 value was 4.2, and the mean ± SD was 573.47 ± 251.43 (**Figure 7**).

Table 2 shows the frequency of the minimum, 1/10 mode value, and mode value.

Table 2. Frequency of the minimum, 1/10 mode value, and mode

Irradiation duration (min)									
1	2	3	4	5	10	15	20	25	30
Minimum value and frequency									
0:365	0:28	0:9	108:1	378:1	0:1	168:1	2691:1	3103:1	4071:1
Full width at tenth maximum									
3.8	4.2	3.9	3.2	6.2	5.9	7.2	3.4	3.5	2.7
Mode									
38	42	39	32	62	59	72	34	35	27

After 1, 2, 3, and 10 min of irradiation of the subtraction images, the minimum pixel value became 0, but the frequency was 1 min in 365, 2 min in 28, 3 min in 9, and 10 min in 1. The 1/10 mode value of this time was 3.8, 4.2, 3.9, and 5.9 each.

Discussion

UV Wavelength

In this study, the wavelength of the UV-A radiation was 375 nm. When using a fluorescent lamp, a peak wavelength of 365 nm and broadband UV was irradiated [14]. However, the UV-A LED was used in this study. Hence, only a narrowband UV and the 375-nm wavelength of UV-A were irradiated.

Scanning

Irregularities may occur during image scanning because of the liquid crystals' protective film, and a plain paper copier overhead projector film is spread for Moiré (Newton's rings) reduction when used between the glass surface of a scanner and the Gafchromic film. However, these irregularities can be reduced by subtraction, and only the changes that occur will be expressed by the UV-A exposure.

Optical density increase

At certain times after the exposure began, the film density increased [7]. Given that this study is an evaluation of non-uniformity, the density increased when the exposure was not considered.

Conclusion

In the case of Gafchromic EBT2, an irradiation duration of 4 min (341.74 mJ/cm^2) was found to be ideal, with a pixel value of mean 978.38 ± 247.64. The study result study showed that approximately more than 4-min duration is a sufficient UV irradiation for Gafchromic EBT2.

Acknowledgements

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