

Scientific Paper

## Determining optimum wavelength of ultraviolet rays to pre-exposure of non-uniformity error correction in Gafchromic EBT2 films

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### Abstract

Gafchromic films have been used to measure X-ray doses in diagnostic radiology such as computed tomography. The double-exposure technique is used to correct non-uniformity error of Gafchromic EBT2 films. Because of the heel effect of diagnostic x-rays, ultraviolet A (UV-A) is intended to be used as a substitute for x-rays. When using a UV-A light-emitting diode (LED), it is necessary to determine the effective optimal UV wavelength for the active layer of Gafchromic EBT2 films. This study evaluated the relation between the increase in color density of Gafchromic EBT2 films and the UV wavelengths. First, to correct non-uniformity, a Gafchromic EBT2 film was pre-irradiated using uniform UV-A radiation for 60 min from a 72-cm distance. Second, the film was irradiated using a UV-LED with a wavelength of 353-410 nm for 60 min from a 5.3-cm distance. The maximum, minimum, and mean  $\pm$  standard deviation (SD) of pixel values of the subtraction images were evaluated using 0.5 inches of a circular region of interest (ROI). The highest mean  $\pm$  SD ( $8915.25 \pm 608.86$ ) of the pixel value was obtained at a wavelength of 375 nm. The results indicated that 375 nm is the most effective and sensitive wavelength of UV-A for Gafchromic EBT2 films and that UV-A can be used as a substitute for x-rays in the double-exposure technique.

**Key words:** ultraviolet ray wavelength; gafchromic films; computed tomography; diagnostic radiology; double-exposure technique.

### Introduction

Gafchromic films have been used for quality assurance, quality control, and radiation dose measurement in diagnostic examinations such as computed tomography [1–4]. Gafchromic EBT films are designed to measure absorbed doses of x-rays with minimal energy dependence [5]. The double-exposure technique is used in therapeutic radiology to correct the non-uniformity of the active layer of Gafchromic EBT films [6]. However, this technique uses UV-A rather than x-rays because uniform irradiation in diagnostic examination is difficult due to the heel effect of x-rays.

A previous study showed that a UV-A peak wavelength of 365 nm was most effective for Gafchromic EBT2 films, rather than UV-B or UV-C [7]. However, the specific wavelength (narrow bandwidth) of UV-A is still unclear. The UV-A bandwidth ranged from 315 to 400 nm [8] and a 10-W fluorescent UV lamp was used as a UV-A source. In addition,

UV-A pre-irradiation corrected the non-uniformity of Gafchromic EBT2 films [9].

The EBT2 film works on the basis of solid-state topochemical polymerization reaction initiated by irradiation (UV-A). The color of the film changes from light yellow to dark blue [5]. However, only the front side of the film is protected from UV irradiation [7]; the reaction of the active layer is observed when the back side of the film is irradiated with UV-A.

In this study, a UV-A light-emitting diode (LED: Nitride Semiconductors Co., Ltd., Tokushima, Japan) with a wavelength of 353–400 nm was used, which has a narrow bandwidth compared with fluorescent UV lamps, emitting photons in range of approximately 310 nm to 410 nm [10]. The most effective UV-A wavelength was determined during our investigation. This study aimed to determine the optimal UV-A wavelength using a UV-LED as a substitution for x-rays in the double-exposure technique for Gafchromic EBT2.

## Materials and Methods

### UV-LED

In this study, a UV-LED that emitted UV-A rays at a wavelength of 353 nm, with 5 nm increments from 360 to 400 nm, was used. **Table 1** shows the representative characteristics of UV-LED, and **Figure 1** shows UV-LED that was used in this study.

### Gafchromic film

We used a 10.2 cm × 25.4 cm Gafchromic EBT2 film (lot #02171403; Ashland, Inc., Covington, KY, USA).

### UV-A Irradiation device

A UV exposure acrylic plate (Comogras CG UV40 P, 3-mm thick, lot #140406C B; Kuraray Co., Ltd., Tokyo, Japan) containing 20 holes with a diameter of 30 mm each (**Figure 2**) was used for fixing the irradiation position of the Gafchromic EBT2 film. Because UV rays are known to cause cellular damage [10], a UV irradiation box was constructed using UV-cut acrylic board to prevent any radiation leakage from the box. UV-LED was attached to this acrylic box (**Figure 3**). A schematic of the setup is shown in **Figure 4**.

### Irradiation method

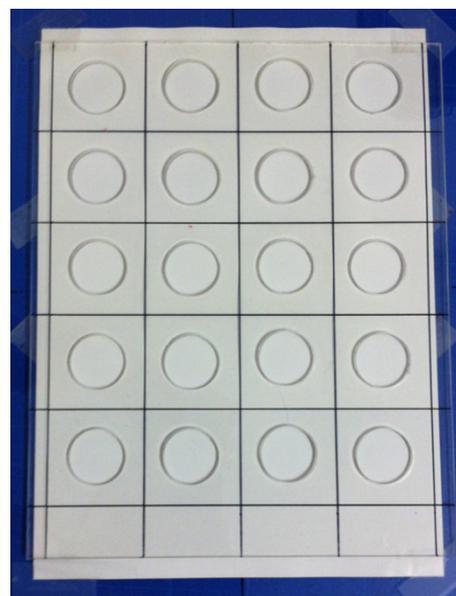
The Gafchromic EBT2 film was fixed onto the 3-mm-thick acrylic plate to improve the reproducibility of scanned images. First, the entire film was uniformly irradiated with UV-A for 60 min using a 10-W UV fluorescent lamp at a distance of 72 cm ( $69.4 \mu\text{W}/\text{cm}^2 \times 300 \text{ s} = 20.82 \text{ mJ}/\text{cm}^2$ ) [7]. Next, the film was irradiated through an irradiation hole using UV-LED at different wavelengths for 60 min each from a distance of 5.3 cm.

**Table 1.** Characteristics of UV-LED ( $I_F$  – direct current (DC),  $\lambda_p$  – peak wavelength, Int – interpolated values,  $V_F$  – voltage, PO – photo output.)

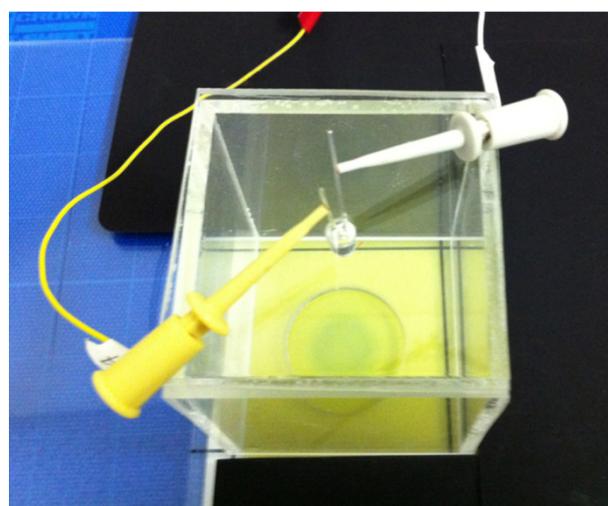
| LED Name    | $I_F$ (mA) | $\lambda_p$ (nm) | $V_F$ (V) | PO (mW) |
|-------------|------------|------------------|-----------|---------|
| NS355L-5RLO | 20         | 353              | 3.2       | 1.2     |
| NS360L-5RLO | 20         | 360              | 3.2       | 1.8     |
| NS365L-5RLO | 20         | 365              | 3.2       | 2.4     |
| NS370L-5RLO | 20         | 370              | 3.2       | 4.0     |
| NS375L-5RLO | 20         | 375              | 3.2       | 11.0    |
| NS385L-ERLO | 20         | 380              | 3.2       | 17.4    |
|             | 20         | 385 (Int.)       | 3.6       | 19.2    |
| NS395L-ERLO | 20         | 390              | 3.0       | 21.0    |
|             | 20         | 395 (Int.)       | 3.2       | 25.2    |
| NS400L-ERLO | 20         | 400              | 3.0       | 21.0    |



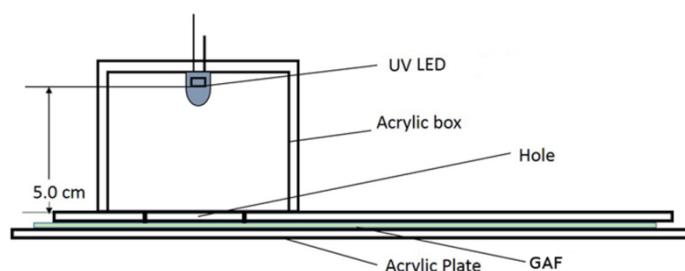
**Figure 1.** Output wavelengths of UV-LED ranged from 353 to 400 nm.



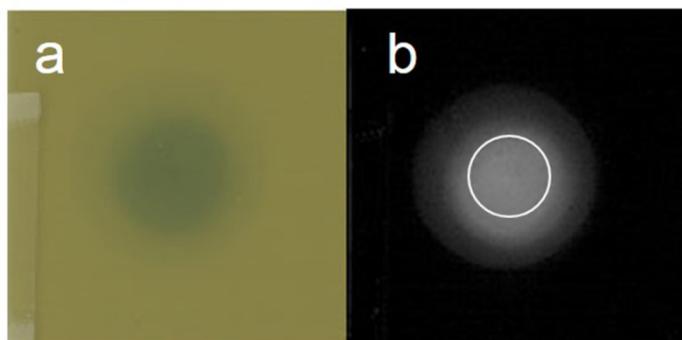
**Figure 2.** UV exposure plate



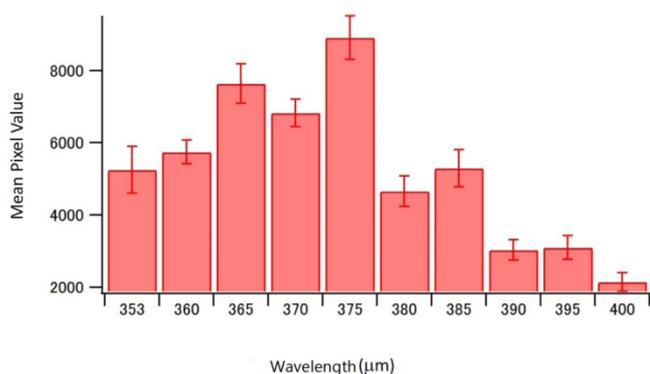
**Figure 3.** UV exposure device for a Gafchromic EBT2 film



**Figure 4.** Schematic of the exposure setup showing UV-LED and the Gafchromic EBT2 film



**Figure 5. Colored Gafchromic EBT2 film. (a) Scanned UV exposure image of the Gafchromic EBT2 film. (b) Subtracted image with ROI**



**Figure 6. Graph of UV-LED measurement data for the Gafchromic EBT2 film**

**Table 2. Pixel values of subtracted Gafchromic EBT2 images at each UV wavelength**

| $\lambda_p$ (nm) | Pixel values |      |                      |
|------------------|--------------|------|----------------------|
|                  | Max          | Min  | Mean $\pm$ SD        |
| 353              | 9035         | 0    | 5255.18 $\pm$ 655.41 |
| 360              | 6889         | 4777 | 5746.91 $\pm$ 326.72 |
| 365              | 9131         | 5853 | 7642.90 $\pm$ 546.88 |
| 370              | 8501         | 5069 | 6824.28 $\pm$ 378.18 |
| 375              | 12005        | 6972 | 8915.25 $\pm$ 608.86 |
| 380              | 5925         | 2933 | 4653.39 $\pm$ 430.81 |
| 385              | 7001         | 3393 | 5300.75 $\pm$ 511.43 |
| 390              | 4053         | 1877 | 3035.42 $\pm$ 279.83 |
| 395              | 4937         | 539  | 3100.12 $\pm$ 319.62 |
| 400              | 3697         | 952  | 2149.11 $\pm$ 261.96 |

**Table 3. Strength of each UV ray**

| $\lambda_p$ (nm) | UV power density ( $\mu\text{W}/\text{cm}^2$ ) |
|------------------|--|
| 353              | 187.07   |
| 360              | 220.36   |
| 365              | 507.10   |
| 370              | 653.70   |
| 375              | 1423.90  |
| 380              | 536.20   |
| 385              | 656.90   |
| 390              | 85.29  |
| 395              | 91.85  |
| 400              | 13.90  |

## Scanning method

Scanning was performed after every UV-A irradiation using a flatbed scanner (EPSON ES-10000G; Seiko Epson Corporation, Nagano, Japan). Images were acquired using Adobe Photoshop CS2 (Adobe Systems Inc., San Jose, CA, USA) at 48 bits, 100 dpi resolution, and in red, green, blue mode with a plain paper copier film (CR-PP686; 3M Company, St. Paul, MN, USA) with a protective film of liquid crystal (LCD-230W; Sanwa Supply Inc., Okayama, Japan) for the removal of Moiré artifacts (Newton rings) [2]. The temperature was maintained at 21°C–25°C during irradiation and image acquisition.

## Data analysis

The red channel image was used for analysis. A circular region of interest (ROI) of 1.27 cm diameter for measuring pixel values was set in the center of the UV-A irradiation field (Figure 5a, and b). The pixel value of each UV wavelength was measured using Image J version 1.44o image analysis software for Macintosh (National Institutes of Health, Bethesda, MD, USA). The maximum, minimum, and mean  $\pm$  standard deviation (SD) of the pixel values were evaluated.

## Results

Wavelength versus pixel value were presented on Figure 6. For 375 nm UV LED, the maximum, minimum, and mean  $\pm$  SD of pixel values were 12005, 6972, and 8915.25  $\pm$  608.86, respectively (Table 2). The UV-A power density was 1423.9  $\mu\text{W}/\text{cm}^2$  (Table 3).

## Discussion

### Wavelength of the UV-LED

As mentioned before, a previous study using a UV fluorescent lamp reported that a peak wavelength of 365 nm was most effective for Gafchromic EBT2 films [7]. However, this study showed that the maximum pixel values were obtained at a UV-LED wavelength of 375 nm. The cannonball-shaped UV-LED with a wavelength of 353 nm and a 5-nm interval from 360 to 400 nm was most suitable for this study. The bandwidth was narrower than that of the UV fluorescent lamp. Therefore, the results showed that a UV-LED is superior to a UV fluorescent lamp for irradiation of Gafchromic EBT2s with UV-A rays.

### Future studies

Although the most suitable irradiation wavelength is determined to be 375 nm, the optimal strength (irradiation duration) of UV-A is still unclear, for which further studies are necessary.

## Conclusion

The Gafchromic EBT2 film reacted most effectively to UV-A from a UV-LED at a wavelength of 375 nm. Therefore, to correct the non-uniformity error of Gafchromic EBT2 films should be used 375 nm from a UV-LED substitute for x-rays in the double-exposure technique.

## Acknowledgements

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## References

- [1] Gotanda T, Katsuda T, Gotanda R, et al: Half-Value Layer Measurement: Simple Process Method Using Radiochromic Film. *Australas Phys Eng Sci Med.* 2009;32(3):150-158.
- [2] Gotanda T, Katsuda T, Gotanda R, et al: Evaluation of effective energy using radiochromic film and a step-shaped aluminum filter. *Australas Phys Eng Sci Med.* 2011;34(2):213-222.
- [3] Gotanda R, Katsuda T, Gotanda T, et al: Computed tomography phantom for radiochromic film dosimetry. *Australas Phys Eng Sci Med.* 2007;30(3):194-199.
- [4] Katsuda T, Gotanda R. DOSE MEASURING METHOD AND PHANTOM, AND X-RAY IMAGE PICKING-UP DEVICE USED FOR THE DOSE MEASURING METHOD, WIPO Patent Application WO/2008; 087952.
- [5] Lewis F. David: Radiochromic Film. Advanced Materials Group Ashland Specialty Ingredients 2014; Spain: April 2014.
- [6] Zhu Y, Kirov AS, Mishra V, et al. Quantitative evaluation of radiochromic film response for two-dimensional dosimetry. *Med Phys.* 1997;24(2):223-231.
- [7] Katsuda T, Gotanda R, Gotanda T, et al. Comparing three UV wavelengths for pre-exposing Gafchromic EBT-2 and EBT-3 films. *J Appl Clin Med Phys.* 2015;16(5):449-457.
- [8] ISO 2007: ISO 2007 Space environment (natural and artificial)-process for determining solar irradiance. ISO. 2007; 21348 (Geneva: International Organization for Standardization).
- [9] Katsuda T, Gotanda R, Gotanda T, et al. Correction of nonuniformity error of Gafchromic EBT2 and EBT3. *J Appl Clin Med Phys.* 2016;17(3):41-51.
- [10] NEC, Data of FL10BL-B: NEC Lighting, Ltd. (in Japanese). [http://www.nelt.co.jp/products/\\_1833.html?p\\_encd=06111495](http://www.nelt.co.jp/products/_1833.html?p_encd=06111495). Accessed December, 19, 2017.
- [11] de Gruijl FR. Skin cancer and solar UV radiation *Eur J Cancer.* 1999; 35(14): 2003-2009.