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Original paper

Comparison of dose response functions for EBT3 model GafChromic™ film dosimetry system

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ABSTRACT

Objective: Different dose response functions of EBT3 model GafChromic™ film dosimetry system have been compared in terms of sensitivity as well as uncertainty vs. error analysis. We also made an assessment of the necessity of scanning film pieces before and after irradiation.
Methods: Pieces of EBT3 film model were irradiated to different dose values in Solid Water (SW) phantom. Based on images scanned in both reflection and transmission mode before and after irradiation, twelve different response functions were calculated. For every response function, a reference radiochromic film dosimetry system was established by generating calibration curve and by performing the error vs. uncertainty analysis.
Results: Response functions using pixel values from the green channel demonstrated the highest sensitivity in both transmission and reflection mode. All functions were successfully fitted with rational functional form, and provided an overall one-sigma uncertainty of better than 2% for doses above 2 Gy. Use of pre-scanned images to calculate response functions resulted in negligible improvement in dose measurement accuracy.
Conclusion: Although reflection scanning mode provides higher sensitivity and could lead to a more widespread use of radiochromic film dosimetry, it has fairly limited dose range and slightly increased uncertainty when compared to transmission scan based response functions. Double-scanning technique, either in transmission or reflection mode, shows negligible improvement in dose accuracy as well as a negligible increase in dose uncertainty. Normalized pixel value of the images scanned in transmission mode shows linear response in a dose range of up to 11 Gy.

1. Introduction

If a piece of GafChromic™ film is exposed to ionizing radiation, charged particles will be depositing energy throughout the sensitive layer and will initiate polymerization of a sensitive component (diacetylene monomers). The irradiated film piece will change its color due to created polymers, which has the highest absorption in the red part of the optical spectrum. While the change in absorbance measured with a spectrophotometer would be the simplest method to evaluate the response of the film to ionizing radiation, use of such a complex instrument even for point dose measurement (let alone two-dimensional ones) would be quite cumbersome and expensive. More than a decade ago, a renaissance of radiochromic film dosimetry emerged with the introduction of the EBT GafChromic™ film model [1–5]. When compared to its predecessors, the new film model was larger in size (8″ × 10″), it was less expensive and new film dosimetry protocols were emerging that were using relatively inexpensive flat-bed document scanners [2]. While the film dosimetry in general was performed with various optical devices [6], the use of document scanners became the common practice not only due to its low cost, but also thanks to their straightforward implementation into both clinical and research film dosimetry procedures. Following the previously established film dosimetry protocols with radiographic films, it was somewhat natural to choose optical density as a quantity of choice to describe response of the irradiated film pieces. Optical density change was easily calculated from the transmission images obtained with flat-bed document scanners.

While there were several models of document scanners with transparency scanning options, in 2002 Alva et al. [7] suggested using reflection scanning mode to measure response of irradiated transparent

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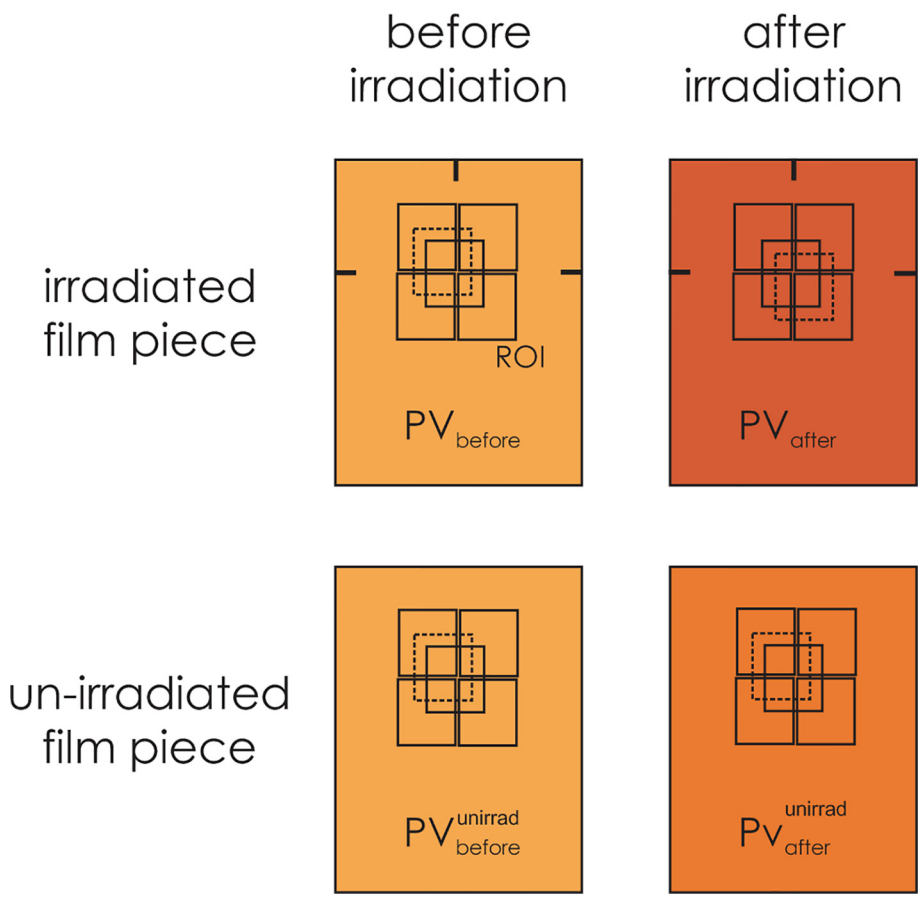

Fig. 1. Sampling response of irradiated and un-irradiated film piece using both transmission and reflection mode scanned TIFF images from a flat-bed document scanner. (ROI sizes are for illustrative purposes and are not to scale).

(MD-55-2 model at the time) radiochromic films. In 2008, Kalef-Ezra and Karava [8], reported on comparative dosimetry results when using either reflection or transmission scanning, and reported the reflection mode was superior when used with the MD-55-2 model GafChromic™ film. Méndez et al. [9] reported on the increased robustness using a novel plan-based method while using the reflection scanned film images.

More recently, Papaconstadopoulos et al. [10] investigated response of EBT3 model GafChromic™ film in terms of uncertainty and spatial resolution for different color channels in both reflection and transmission mode. While they also found the reflection mode to be superior in terms of sensitivity (particularly at low doses up to 2 Gy based on the red channel), they observed higher uncertainties and lower accuracy that they attributed to signal saturation effects. On the other hand, compared to transmission scanning, they did not observe any loss of spatial resolution despite the additional light scattering (noise) arising from the fact that light was passing twice through the film. Use of reflection scanning mode with transparent films would further extend implementation of radiochromic film dosimetry having in mind much wider abundance and even lower cost of document scanners without transparency option.

Yet another method has been suggested by the film inventor and manufacturer, which is to use only the raw pixel values provided by the document scanner [11,12]. Commercially available software provided by the film manufacturer was working using pixel values provided by document scanners that correspond to the light that was transmitted through the film piece. In addition, while some reference radiochromic film dosimetry protocols suggest scanning the film pieces before and after irradiation (double-scanning technique) to calculate response as a change in the film's absorbance [2], there are protocols suggesting that only one scan (single-scan technique) of irradiated film piece together with another un-irradiated film piece provides acceptable radiochromic film dosimetry system [12]. In the single-scan method, un-irradiated film piece serves both as a fog (allowing for a change in the response signal to be calculated) and, at the same time, as a control film piece, the latter being suggested [13] to correct for any changes in film absorbance due to environmental conditions (temperature, humidity, UV-light, …).

In this work we investigate the most optimal quantity in terms of sensitivity to be used as a radiochromic film response to radiation for EBT3 GafChromic™ film model based reference film dosimetry system. Pieces of EBT3 model films were irradiated to various doses in the range of up to 11 Gy and reference radiochromic film dosimetry systems were created using twelve different response functions based on film images obtained in both transmission and reflection scanning mode. While the majority of the response functions were already suggested in the literature, for each of response function investigated in this work we defined two variations: one with double-scanning and another one with single-scanning technique. Suitability of different response functions for radiochromic film dosimetry protocol was then assessed by using the error vs. uncertainty analysis.

2. Materials and methods

For this study, we used the EBT3 GafChromic™ film model (Ashland Inc., Wayne, New Jersey), batch number (09071601), which represents an improved version of its predecessor having a symmetric structure and silica particles within polyester layers that led to removal of Newton rings [14,15]. The readout device used was a flatbed Epson Expression 10000XL document scanner (Epson, Nagano, Japan) that