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TECHNICAL NOTES

A comparison between radiochromic EBT2 film model and its predecessor EBT film model

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Abstract The manufacturer has introduced the new EBT2 film model so as to improve its predecessor, the EBT radiochromic film model. According to the manufacturer, some of its main advantages include a higher tolerance to light exposure and it can correct non-uniformity of the active layer thickness using a marker dye. However, the equivalence in uniformity between both models was questioned by some authors, and the asymmetrical configuration of layers of the EBT2 film model produces a new dependence on the film side being scanned (front and back orientation). In this study, the EBT2 radiochromic film model was compared with the EBT model and the new marker dye feature was assessed. We also compared this correction method with a pre-irradiated pixel value correction method. An Epson Expression 10000XL scanner in transmission mode was used to scan the films and the red channel response was analyzed. We confirmed the lower-measured signal dependence on the visible light exposure of the EBT2 film model. Differences in pixel values remained below 0.5% for a minimum of 15 days. In regard to the uniformity, similar results for EBT2 and EBT film models were obtained; in both cases inhomogeneity was found to be less than 1%, in relative pixel value from the mean. However, we found that the signal-to-noise ratio was reduced for low doses by 37% for old EBT2 batch and by 21% for new EBT2 batch compared to signal-to-noise ratio for EBT. The EBT2 film model's pixel value difference for the front and back orientation reached up to 1.0% in the red channel. Our results did not show a clear advantage between to use a pre-irradiated pixel value correction and to use the manufacturer's correction.

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Introduction

Radiographic film was the most commonly used verification system in radiotherapy for years. Nowadays, new radiochromic films are increasingly used due to their greater sensitivity and their wider useful dose range in comparison to traditional films. Moreover, as radiochromic film is self-developing, no chemical processing is needed, and it can be handled and prepared in room light. Therefore, it has been established as a verification system for 3DCRT treatments [1–3], IMRT [4–7], dynamic arc therapy and brachytherapy [8,9]. In addition, radiochromic films are useful for quality control of linear accelerators [10,11].

The Gafchromic® EBT was the first model to be widely used for dosimetry (International Specialty Products, ISP) [12]. The main features of these films were: sensitivity range between 1 cGy and 800 cGy; energy independence between keV and MeV; nearly tissue equivalent ($z_{eff} = 6.98$); they can be immersed in water for short periods of time, and they can be cut into several pieces.

These films have been analyzed and characterized in many papers [13–17]. According to these studies, the EBT model was reliable for dosimetry, although a film dosimetry protocol was required to minimize the dosimetric uncertainties. The most important factors are the landscape-portrait orientation of the film on the scanner, inhomogeneity of the scanner response, film inhomogeneity, and the time delay between irradiation and scanning.

This film model has been replaced by the Gafchromic® EBT2 model [18], which is different to the previous model – its yellow color being the most evident difference. This arises from the presence of a yellow dye incorporated into the active layer, whose purpose is to improve the homogeneity by using the response of the yellow dye in the blue channel. Moreover, the active layer is sensitive to blue light, which the yellow dye absorbs, thereby reducing the light dependence of the radiochromic films. The manufacturer has cited other improvements, i.e. less energy-dependent, because a natural polymer has been replaced by a synthetic polymer. This has improved the safety of the film's composition, and reduced damage to the film when cut due to the use of an over-laminate with pressure sensitive adhesive.

Gafchromic EBT2 films' energy dependence has been extensively studied [19–22]. However, to date there are few studies about other radiochromic EBT2 films' characteristics [23–26], the film uniformity being the most controversial issue [27,28]. The lack of uniformity has several contributions [29], on the one hand, Newton's ring-like scanning artifacts, which can be avoided by elevating the film above the scanner's surface, on the other hand, the inhomogeneity of the film itself, which depends on the coating technology. The manufacturer proposes a correction procedure to improve this second kind of inhomogeneity using the marker dye's blue absorption band. Only one study [29] takes the use of this procedure into account, resulting in disagreement with the manufacturer, since the uniformity is worse when the manufacturer's recommended procedure is used. The film uniformity of some early batches investigated [28] shows unacceptable values for clinical quality assurance. A review has been recently published [30] that urges homogeneity and correction procedure research to continue, while the film manufacturing becomes stable. Given the previous results, we investigated the uniformity in this study, including the manufacturer's recommended procedure, on batches of EBT2 films. Besides, we studied other characteristics of these films using the Epson Expression 10000XL scanner and we have compared them with the results obtained for EBT films. A recent study [31], assessed some EBT2 model characteristics comparing them with the EBT film, however, there are important items like film and scanner uniformity that were not studied. Centers have film dosimetry protocols established for the EBT model, meaning that the differences and similarities with the EBT2 model must be studied so that necessary changes in these protocols can be made. The factors we have considered are: light sensitivity, orientation of the film, reproducibility with the number of previous scans, position of the film in the scanner, time between irradiation and scanning, and film uniformity.

Materials and methods

In this work we characterized the EBT2 Gafchromic® films, digitized with an Epson Expression 10000XL scanner, which allows A3 scan sizes. In our protocol, all the films were stored at room temperature in an opaque envelope in order to protect them from visible light. They were cut into 4×5 cm^2 pieces on the day of irradiation, marked in the upper right corner, and scanned individually before irradiation and after 24 h. For studies using the EBT film model we have used one batch, 47277-04I. For studies using the EBT2 model we have used films from the F031810001A batch, but for the homogeneity study we used two batches, F10070902A and A09171002. The films used for this study were irradiated under calibration conditions: we used a 6 MV photon beam for irradiation (Varian 600C LINAC, Varian Medical Systems, Palo Alto, CA) a solid water phantom, at a depth of 1.5 cm, and with at least 10 cm water phantom behind it to provide full backscatter conditions. The beam field size was 10×10 cm^2 at the isocenter and the source-surface distance was 100 cm.

The Epson Expression 10000XL scanner is recommended by the EBT2 film manufacturer. Since this scanner is A3 in size, opaque black cardboard frames should be placed in the scanner to ensure that the film is positioned in the center, without having to remove it during scanning [15,16]. We used the Epson Scan software, in the professional mode. Settings were created to always keep the same regions of interest (ROI). A preview image was acquired and afterwards the film was scanned in 'positive' mode, which produces low pixel values in dark areas, without color correction, with resolution of 72 dpi, using transmission mode and 48 bit depth [14]. The image was exported in TIFF format and analyzed by ImageJ (ImageJ software 2010) [32], choosing the red channel for the dosimetry because the active layer's maximum absorption is 636 nm [33], showing more sensitivity in the range of doses commonly used in the clinical setting [1]. We used a 1.4×1.4 cm^2 scan area to study the films [14] and we used an ImageJ's macro to ensure the reproducibility of its position. Film darkening was quantified through the pixel