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ORIGINAL PAPER

# Fast protocol for radiochromic film dosimetry using a cloud computing web application

Juan-Francisco Calvo-Ortega *, Miquel Pozo, Sandra Moragues, Joan Casals

*Hospital Quirónsalud Barcelona & Hospital Universitari Dexeus, Barcelona, Spain*

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ABSTRACT

*Purpose:* To investigate the feasibility of a fast protocol for radiochromic film dosimetry to verify intensity-modulated radiotherapy (IMRT) plans.

*Method and materials:* EBT3 film dosimetry was conducted in this study using the triple-channel method implemented in the cloud computing application (Radiochromic.com). We described a fast protocol for radiochromic film dosimetry to obtain measurement results within 1 h.

Ten IMRT plans were delivered to evaluate the feasibility of the fast protocol. The dose distribution of the verification film was derived at 15, 30, 45 min using the fast protocol and also at 24 h after completing the irradiation. The four dose maps obtained per plan were compared using global and local gamma index (5%/3 mm) with the calculated one by the treatment planning system. Gamma passing rates obtained for 15, 30 and 45 min post-exposure were compared with those obtained after 24 h.

*Results:* Small differences respect to the 24 h protocol were found in the gamma passing rates obtained for films digitized at 15 min (global: 99.6% ± 0.9% vs. 99.7% ± 0.5%; local: 96.3% ± 3.4% vs. 96.3% ± 3.8%), at 30 min (global: 99.5% ± 0.9% vs. 99.7% ± 0.5%; local: 96.5% ± 3.2% vs. 96.3 ± 3.8%) and at 45 min (global: 99.2% ± 1.5% vs. 99.7% ± 0.5%; local: 96.1% ± 3.8% vs. 96.3 ± 3.8%).

*Conclusions:* The fast protocol permits dosimetric results within 1 h when IMRT plans are verified, with similar results as those reported by the standard 24 h protocol.



## 1. Introduction

Over the years, film dosimetry has been a powerful tool for radiotherapy treatment verification and quality assurance (QA). With the advent of the GAFChromic™ (International Specialty Products, Wayne, NJ) films models, initially designed to replace silver halide radiographic film for intensity modulated radiotherapy (IMRT) QA procedures [1], there has been a rapid incorporation of radiochromic film for use in radiotherapy dosimetry. Unlike silver halide-based radiographic film, radiochromic film does not require a processor for generating the optical density response to ionizing radiation.

Radiochromic film offers a high spatial resolution for dosimetry of IMRT and stereotactic radiosurgery (SRS) treatments, where extremely steep dose gradients and very small fields are present [2–4]. In addition, because of its low energy dependence, dose-rate independence and near-water equivalence, radiochromic film can be used to acquire accurate dose distribution measurements [5–7].

Radiochromic films change their color directly in response to irradiation and do not require chemical processing. Image formation occurs as a polymerization process changes the color of the film dye. The color formation in the irradiated radiochromic film is not complete at the end of the irradiation and it continues indefinitely. The consequence of the continued polymerization is that the optical density grows over time; therefore films should be left for at least 6 h [8] after exposure, while 24 h is commonly used. As Lewis et al. [9] described, the response of a radiochromic film continues to change after exposure in proportion to log (time-after-exposure). Hence, if a dose–response calibration is established by scanning calibration films at a given time-after-exposure, an error in dose will result if the verification film used for patient specific QA (PSQA) is scanned at a different time-after exposure.

Lewis et al. [9] established an efficient one-scan protocol that combines calibration and verification films in a single scan enabling measurement results to be obtained in less than 30 min

* Corresponding author at: Departamento de Oncología Radioterápica, Hospital Quirónsalud, Plaza Alfonso Comín, 5-7, 08023 Barcelona, Spain.
*E-mail address:* jfcdrr@yahoo.es (J.-F. Calvo-Ortega).

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after irradiation. This protocol was implemented in the commercial software Film QA Pro (Ashland Inc., Wayne, NJ).

In our department, film dosimetry is performed using the Radiochromic.com cloud computing web application (https://radiochromic.com) [10,11]. From version 2.0, a response correction feature was included allowing to scan the verification film simultaneously with one or several films with known doses, to mitigate the interscan variability as well as other perturbations (as difference of post-irradiation times between calibration film and verification film). We investigated whether the use of this response correction allows obtaining film measurement results within a short time (less than 1 h), by using only a calibration film, an unexposed film, and the verification film, instead using the 24 h post-irradiation protocol used currently in our department.

## 2. Materials and methods

### 2.1. Radiochromic film

We used the GAFChromic™ EBT3 film model (Lot #: 04191602) with sheet dimensions of 20.3 × 25.4 $cm^2$. A single film was cut into six strips of 20.3 × 4.2 $cm^2$ to acquire the pixel value-dose calibration curve (calibration strips). Film pieces of 20.3 × XX $cm^2$ were cut for IMRT treatment plan QA (verification films). Dimension XX was variable depending on the plan to verify. Also, 4 × 4 $cm^2$ film patches were cut for dose correction purposes (control films).

The scan response of EBT3 radiochromic film is sensitive to the orientation of the film on the scanner bed [6]. Therefore, the orientation of each piece of film with respect to the original sheet was marked using permanent ink.

### 2.2. Irradiation and scanning procedure

All irradiations were performed with 6 MV photon beams from a Varian Clinac 2100 CD linac (Varian, Palo Alto, CA, USA). The film was placed in a dedicated acrylic phantom (Universal IMRT phantom, PTW, Freiburg, Germany), with 5 cm of buildup material above the film.

The exposed films were scanned in portrait orientation and in transmission mode with an Epson Pro V750 flatbed scanner (Seiko Epson Corporation, Nagano, Japan) using the Epson Scan v.3.0 software. The light source used by the scanner is a cold cathode fluorescence lamp. RGB positive images were collected at a color depth of 16 bits per color channel, with a resolution of 72 dpi (0.35 mm/pixel) and the image processing tools were turned off.

The scanning was done according to the recommendations given in https://radiochromic.com. The scanner was warmed-up for at least 30 min before the scanning. After the warm-up, five empty scans were taken to stabilize the scanner lamp. The films were then placed on the center of the scanner. To avoid the Callier effect [12], a 1 mm-thick glass sheet was placed over the films to avoid film curling. This plate also allows keeping constant the film-light source distance that is known to have an impact on film response [13]. Five consecutive scans were made for each film. The first scan was discarded and the resulting image was the average of the remaining four.

### 2.3. Film calibration and dosimetric algorithm

The 20.3 × 4.2 $cm^2$ strips were used for pixel value-dose calibration (sensitometric curve). Each calibration strip was placed inside the Universal IMRT phantom and was irradiated with a field size of 25 × 25 $cm^2$ and a source–axis distance (SAD) of 100 cm.

To create a characteristic pixel value-dose curve, each calibration strip was irradiated at a known dose ranging from 0 to 5 Gy (0, 0.3, 0.6, 1.2, 2.4, and 4.8 Gy). The monitor units required to deliver these doses were computed with the Eclipse v.10.0 (Varian Medical Systems, Palo Alto, CA) treatment planning system (TPS) using its anisotropic analytical algorithm (AAA). The accuracy of Eclipse to compute these doses was within 1%, as it was evaluated during its commissioning. The irradiated strips were scanned 24 h after irradiation.

The images were uploaded into Radiocromic.com (v. 2.4) and a calibration was derived to transform film pixel values to dose values. Radiochromic.com uses a channel-independent perturbation (CHIP) model for radiochromic film dosimetry. Particularly, dosimetry was done using the truncated normal (TN) CHIP model described by Méndez et al. [10]. It uses pixel value as film-scanner response, employing combinations of three color channels (i.e., triple-channel model), and applying the lateral correction implemented in the software, which follows the correction model proposed by Lewis el al [14]. For each color channel, Radiochromic.com uses natural cubic splines to adjust the sensitometric curve; the control points of the spline associate reference homogeneous doses with their median pixel values. Once calibration is done, film dosimetry was performed by Radiochromic.com using the triple-channel TN method.

### 2.4. Fast protocol for radiochromic film dosimetry

Radiochromic film-based patient specific QA has been performed in our department by delivering the clinical plan onto an acrylic phantom containing a film piece (verification film) that was scanned 24 h after exposure, i.e., the same post-irradiation time used for dose response film calibration.

The "response correction" option of Radiochromic.com, based in the work of Lewis et al. [9], allows rescaling the sensitometric curve using films exposed to known doses (control films). So, it is possible to mitigate the difference of post-irradiation times between the calibration film and the verification film. So, we want to explore whether the response correction option can be used to obtain dosimetric results within one after film irradiation instead of waiting the conventional time of 24 h (24 h protocol).

The fast protocol investigated in this work consisted of simultaneously scanning two pieces of films exposed to known doses (control films) alongside the verification film, and applying the "response correction" feature of Radiochromic.com in order to obtain the dose distribution in the verification film (Fig 1). One of the control films has to be irradiated to a known dose and the other one is an unexposed film. Film scanning at 15, 30 and 45 min (15 min protocol, 30 min protocol and 45 min protocol, respectively) after irradiation of the film control was investigated in this study. The elapsed time since the starting of the verification film irradiation and the completion of the control film irradiation is referred in this study as the "elapsed time".

Analysis of the dose accuracy of the fast protocol was performed as follow. A radiation field consisting on a pattern of eight dose steps (from 0.4 to 4.5 Gy, Fig 2) was delivered in three different sessions (three tests). A different elapsed time was used in each test (3.5, 6.5 and 15 min). For each test, one 12 × 12 $cm^2$ film (verification film) and two 4 × 4 $cm^2$ control patches (4.5 Gy and zero dose) were extracted from a whole radiochromic film sheet. So, three different film sheets of a same batch were used to take account for potential intra-batch variations.

For each test, the doses provided by the fast protocol (at 15, 30 and 45 min) and the standard 24 h protocol were registered for each step. The response correction was applied to all images. The average dose in an inner region of interest (ROI) centered over each step was considered as the "step dose" (Fig 2). The relative differ-