The Role of Gafchromic EBT3 Film in the Quality Assurance of Dynamic Irradiation Techniques

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Received: June 12, 2018; Published: June 28, 2018

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DOI: 10.26717/BJSTR.2018.06.001316

Research Article
Open Access

Abstract

Introduction: The aim of this study was to gain experience with self-developing EBT3 films and to assess their utility in the clinical practice for the dosimetric verification of dynamic techniques and for in vivo dosimetry.

Patients and Methods: A 6-point calibration series was performed in solid water phantom of the 6-MV photon beam. Subsequently, a reference film was irradiated using the same parameters. A series of CT scans were performed on the head and neck phantom in vertical and horizontal positions. IMRT and VMAT treatment plans were generated. The films were placed at the isocenter level and were irradiated in both positions. To take advantage of the novel possibility to test the film in our planning systems and accelerators during treatment, we placed a film in the oral cavity of 3 head and neck patients who had artifact due to dental filling.

Results: The verification of the IMRT and VMAT treatment plans revealed that the differences between the calculated and measured doses at the isocenter in a horizontal phantom were -3.9% and -1.1%, respectively, whereas those in vertical position were 0.5% and 1.7%, respectively.

In Vivo Dosimetry: The differences between the calculated and measured doses on the surface of the amalgam fillings in the patients were 3.2%, 1.2%, and 1.2%.

Conclusion: All 4 evaluation software products were found suitable for the calibration and evaluation of the films. The EBT3 self-developing film can be reliably used in the dosimetric verification of radiation treatment plans for both the IMRT and VMAT techniques.

Keywords: EBT3; Film Dosimetry; Head and Neck; Quality Assurance

Abbreviations: IMRT: Intensity Modulated Radiotherapy; VMAT: Volumetric Modulated Arc Therapy; 3DCRT: Three-Dimensional Conformal Radiation Therapy; SSD: Source to Surface Distance; OD: The Optical Density

Introduction

Intensity-modulated radiotherapy (IMRT) and volumetric modulated arc therapy (VMAT) techniques that provide improved conformity have become standard treatment options for irradiation of complex target volumes if the goal is to deliver high doses to tumors that are located in the immediate vicinity of sensitive and healthy tissues [1]. Several studies demonstrate that higher survival rates can be achieved by increasing the total dose delivered to the tumor in the case of certain types of neoplasms (e.g., prostate cancer or malignancies in the head and neck region). Treatment of patients with higher total doses requires the use of modern, cutting-edge technologies in order to provide the homogeneous treatment of the tumor in association with a decreased dose burden on healthy tissues. IMRT and VMAT are modern radiotherapy techniques that are capable of meeting the above criteria [2]. Using appropriately chosen radiation directions during the planning of IMRT and VMAT improves the chance for tumor control, increases the dose delivered to the target volume, and reduces the exposure of organs at risk [3]. Compared to the three-dimensional conformal radiation therapy (3DCRT) technique, the use of IMRT or VMAT is associated with decreased toxicity, shortened treatment time, and improved quality of life of the patients [4].

In the case of IMRT, the fields comprise multiple segments; therefore, the dose distribution calculated by the planning system must be verified prior to the first treatment of the patient when applying any sort of intensity-modulated plans. On this basis, dosimetric verification procedures are to be implemented into
Radiotherapy protocols. One of the cornerstones of quality assurance in radiotherapy is the verification of the prescribed dose, especially when using small fields that may be associated with uncertainties in measurement results due to the measurement ranges of the dosimeters. This uncertainty can also be present in the beam model data. Furthermore, with recent advances in IMRT and VMAT techniques as well as the optimization algorithms, sharp dose gradients can be achieved [5]. The use of these sophisticated techniques likewise requires the implementation of largescale dosimetric verification procedures in daily routine.

In external radiotherapy, in vivo dosimetry is a widely accepted quality assurance procedure to compare the planned and actually delivered doses during the treatment [6]. In Hungary between 1896 and 2013, the only dental filling material covered by the social security for the treatment of dental caries was amalgam, composed of silver, tin, copper, zinc, and mercury. Consequently, patients above 40 years of age who have dental fillings might have amalgam in their mouth, which can cause artifact. Metal implants made of chemical elements with high atomic number, such as dental fillings, dental bridges, and other devices associated with artifacts, may influence the dose distribution of the radiation plan due to dose perturbation. In the case of patients with head and neck tumors having such dental filling, interaction between the photons and the high-electron-density metal should be expected during radiation treatment. The scattering increases in proportion with the atomic number of the metal implants.

During radiation treatment of patients with head and neck tumors, therefore, dose perturbations develop on the surface of metal prostheses resulting in scattering in the neighboring gingiva, where it may lead to under- or overdosing. This phenomenon is responsible for the development of radiation-induced mucositis; indeed, the development of ulcerative lesions in the oral mucosa is to be expected, resulting in painful difficulty swallowing, which causes significant discomfort for the patients [7-13]. Due to the multidirectional and multisegment fields, the scattered dose originating from the artifact inducing dental filling is less in the cases of IMRT and VMAT techniques compared to that in the case of a direct field. According to the literature, there is no significant difference between the measurement uncertainties of dosimetry performed with the use of a film or an ionization chamber; therefore, they can be used interchangeably.

In cases where ionization chamber dosimetry cannot be conducted, such as for the measurement of interactions on the surface of a tooth, the use of a film is feasible. CT-based planning systems alter the contour of the tumor and other structures in slices containing high-density artifacts; in addition, they underestimate the actual dose in the vicinity of the metal. On the basis of all these, as a quality assurance of our planning systems and accelerators at our Department, we placed films onto the dental filling during a treatment of the 3 patients with artifacts: we applied in vivo dosimetry to assess whether the planning system makes corrections for the scatter during calculation. We did not use a phantom since we considered the inclusion of the patients themselves to the study the most suitable solution, because it does not require calculations with corrections/equivalence, which would be necessary when using a phantom. Several publications provide descriptions of precise and reliable 2D and 3D of quality assurance procedures [14-20].

One of the publications describes the use of the EBT3 film in a solid water phantom to verify the calculated dose distribution. Radio chromic films are used in daily, weekly, and monthly quality controls as well. Gafchromic films represent a useful alternative, as they are appropriate for the visualization of a 2D dose map of the IMRT and VMAT fields [21]. Film dosimetry is a simple and quick measurement procedure [22-28]. The EBT3 film represents a new generation of self-developing films, which can be used in the clinical practice similarly to its predecessor, EBT2. Several publications are available about studies on EBT films regarding their homogeneity, scanning orientation independence, widerange energy independence, absorption spectrum, post irradiation coloration, and sensitivity to ambient light. The study of Borca et al. confirmed that there are no significant differences in most of the characteristics between the two films; however, complete scanning orientation independence was only characteristic of the EBT3 film [29]. When using modern radiation techniques (such as IMRT and VMAT), verifying the dose distribution calculated by the planning system prior to the initiation of the treatment is a quality assurance requirement. As a consequence, self-developing films have an ever growing role in the dosimetric verification of radiotherapy treatment plans, due to their precision and the lack of requirement for expensive and space demanding equipment. The aim of this study was to gain experience with self-developing EBT3 films and to assess their utility in the clinical practice for the dosimetric verification of dynamic techniques and for in vivo dosimetry.

**Patients and Methods**

**Assessment of Physical Properties of the Films**

In this study, the EBT3 film irradiated to a known dose was analyzed with Image J, FilmQA Pro, Verisoft, and Filmcal film analysis software products since the 4th min after irradiation for 30 consecutive days. We first prepared a calibration film series by using 6 Gafchromic EBTR3 films (4 x 10cm, Ashland Specialty Ingredients, Wilmington, DE, USA) exposed to different doses (0Gy, 1Gy, 2Gy, 3Gy, 4Gy, 5Gy). The film used as the subject of our study itself was 10 x 10cm, and the dose delivered was 4Gy. To allow recovery from the mechanical injury and material loss due to the interruption of polymer continuity secondary to having been cut to size, the films were stored in a dark box in constant temperature for 24h after cutting. The irradiation was conducted in a 30 x 30cm solid water phantom (PTW, Freiburg, Germany) with a source to surface distance (SSD) of 100cm, at d = 1.5cm depth of dose maximum, with a photon energy of 6MV, and at a 300MU/min dose rate, by the use of the dualenergy Varian Clinac DHX 2300C Millennium 120leaf MLC linear accelerator, with a field size of 10 x 10cm2. An Epson Expression 11000XL Photo scanner (Seiio Epson Corp., Nagano, Japan) was used to digitize the films through the 30 day period.

After switching the scanner on, we let it warm up for 15min before use. According to the manufacturer’s recommendation, only images produced during the second and third digitization were...
saved and analyzed. The film and the calibration series were placed at exactly the same region of the scanning surface, parallel with the sides. The electronic images (tiff format, 72dpi, professional mode, landscape position, color correction turned off) were analyzed with 4 film analysis software products:

a) FilmQA Pro 3.0.4864.35322,
b) Image J 1.46r,
c) Mephysto PTW Film Cal 2.11and

d) Mephysto Verisoft.

The films were stored in a dark box under constant temperature between readings. During the analysis with FilmQA Pro and Image J software products, blue and green color values were evaluated separately as well.

Subjects of Analysis (Figure 1).

![Figure 1: The analyzed areas on the calibration and the examined films using FilmQA Pro and Image J.](image)

a) In the case of the calibration series, the 2 x 2cm squares of the 3 regions of interest (i.e., ROI_Left, ROI_Center, ROI_Right) were located 1cm from the sides of the 4 x 10cm films on the right side, in the middle, and on the left side of the films.

b) In the case of the 10 x 10cm film examined, the ROI corresponded to a 8 x 8cm field 1-1cm from the sides of the film.

The Use of the Mephysto PTW Film Cal 2.11 Software

Subjects of Analysis

a) In the case of the calibration series, the 4 x 10cm films used were divided into 3 equal parts and samples were obtained from the middle of each part, i.e., from the ROI_L, from the ROI_C, and from the ROI_R. The optical density (OD) values obtained were averaged.

b) The examined 10 x 10cm film was divided into 9 equal parts and the samples were obtained from the middle of each part to determine the OD: the values obtained from the sampling points in the upper right corner, lower right corner, upper left corner, lower left corner, and the total of 5 regions the middle were averaged.

The Use of the PTW Verisoft 2.11 Software

The transverse CT slice of the 40 x 40cm water phantom exported from the XiO Release 4.7 TPS planning system were used. The parameters of radiation were: 6MV photon energy, 10 x 10cm² field size, 1.5cm depth (A data). The OD results obtained with the Mephysto PTW Film Cal 2.11 software were used as calibration series. A ROI of 8 x 8cm (1cm from the sides in all directions) was analyzed on the film studied (B data).

Clinical Application

Dosimetric Verification of Dynamic Techniques in a Phantom

Quality Assurance of IMRT and VMAT Radiation Techniques in the Daily Routine: Series of CT scans with a slice thickness of 3 mm were performed on the head and neck phantom in vertical and horizontal positions (Figure 2) using a Siemens Emotion 6 scanner. IMRT and VMAT treatment plans were generated using the Eclipse version 13.6 planning system for both series. The 20 x 22cm films were placed at the isocenter level within the head and neck phantom. The phantom was irradiated in vertical and horizontal positions as well. The results were analyzed by the ImageJ software and were compared with the dose values calculated by the planning system.

![Figure 2: Head and neck phantom with film in vertical and horizontal positions.](image)

In Vivo Dosimetry During the Treatment of Real Patients

The 1 x 5cm films were covered with Styrofoam of 2mm in thickness to avoid mechanical injury to the film and to prevent direct contact with the patients. After giving informed consent, the patients bit on the Styrofoam during a treatment. The locations of the amalgam dental fillings and the films were the maxillary right canine, the mandibular right first premolar, and both maxillary incisors in the cases of the first, second, and third patient, respectively. The treatment of the patients was conducted consecutively, and the calibration series were taken prior to the treatment of the first patient with a Varian Truebeam accelerator (the irradiation was conducted in a 30 x 30cm solid water phantom...
(PTW) with an SSD of 100cm, at d = 1.5cm depth of dose maximum, with a photon energy of 6MV, and at a 300MU/min dose rate, with a field size of 10 x 10cm2. The dose values of the calibration series were 0Gy, 0.5Gy, 1Gy, 1.3Gy, 1.7Gy, 2Gy, and 2.5Gy.

Results
Physical Properties of the Films

Using the values corresponding to samples obtained from different regions of the calibration series (i.e., ROI_L, ROI_C, and ROI_R) did not result in significant differences in the evaluated data of the examined film; therefore, only the series derived from samples from the center (ROI_C) were used for further analyses. The film began the stabilization process after its irradiation and oscillated around 4 Gy after a while. The temporal evaluation of the film revealed that the relative difference between the measured and calculated doses decreased after the first couple of hours and increased again after a few days, independently of the analyzer software used. The comprehensive analysis demonstrated the optimal time interval for the scanning and analysis of the films to be between 24 and 48 h after irradiation (Figure 3). Within this interval, the mean relative differences (%) obtained by the different software products are included in (Table 1).

Table 1: The mean relative differences (%) obtained by the different software products.

| The mean relative differences (%) | Relative difference (%) |
|----------------------------------|-------------------------|
|                                  | Mean        | SD       |
| FilmQA Pro                       |             |          |
| Red                              | 0.025       | 0.119    |
| Green                            | -0.121      | 0.051    |
| Blue                             | -0.016      | 0.074    |
| ImageJ                           | 0.167       | 0.229    |
| FilmCal                          | 0.326       | -0.193   |
| Verisoft                         | 0.409       | -0.096   |

Dosimetric Verification of Dynamic Techniques in a Phantom

The films were irradiated on the basis of plans generated by the use of two different techniques and were compared to the dose distribution exported from the planning system. The scanned absolute dose maps were compared to the calculated ones. Verisoft film analysis software was used for the analysis. The results of the gamma analysis using the 3%/3mm acceptance criteria were as follows, with the prescribed dose of the IMRT and VMAT treatment plans at isocenter being 1.8Gy:

In the case of IMRT treatment in horizontal position: 1.74Gy (-3.3%) (Figure 4) whereas in vertical position: 1.81Gy (0.5%) (Figure 5). In the case of VMAT treatment in horizontal position: 1.78Gy (-1.1%) (Figure 6) whereas in vertical position: 1.83Gy (1.7%) (Figure 7). The extent of point-to-point matching of the measured dose distribution and the one calculated by the planning system slightly differed between the vertical and horizontal phantoms (IMRT: 92.5% vs 90.8%; VMAT: 98.7% vs 96.5%), which can be at least in part attributable to the fact that the axes of the fields were parallel with the film in the horizontal position.
In Vivo Dosimetry in Real Patients

a) In the first patient, the dose on the surface of the amalgam filling according to the planning system was 1.29 Gy. The measured value was 1.32 Gy (2.3%).

b) In the second patient, the dose on the surface of the amalgam filling according to the planning system was 1.71 Gy. The measured value was 1.73 Gy (1.2%).

c) In the third patient, the dose on the surface of the amalgam filling according to the planning system was 1.71 Gy. The measured value was 1.73 Gy (1.2%).

Discussion

Self-developing films play an ever-growing role in radiotherapy dosimetry. They do not require extra facilities, and their evaluation can be performed by the use of film analysis computer software products. The active layer of the EBT films consists of low-atomic-number elements; hence these films have water-equivalent properties, with their radiological characteristics being close to those of water and are hence appropriate as an alternative to water phantom dosimetry. As opposed to ionization chambers, the film is energy and dose rate independent within the MV photon energy range; therefore, according to our experience, this tool can be reliably used to verify radiotherapy treatment plans including the IMRT and VMAT techniques. The measurement results were within 5% [30] therefore, they proved to be excellent for quality assurance verification procedures. The comparative analysis was performed by using 4 different film analysis software products. All 4 software products were found suitable for the calibration and evaluation of the films, and to compare the dose maps exported from the planning system with those developed on the film.

Ionization chambers, due to their physical size, cannot provide reliable and precise results for the verification measurements of very small fields. An advantage of a self-limiting film over a semiconductor detector matrix is its better resolution, which enables a more precise gamma analysis, hence providing precise results even in the case of small fields. To our experience, this wide range energy independence makes the self-developing film an ideal tool in dosimetry, especially in cases where the delivery of high doses is intended. For the same reason, this tool provides precise results in small-field stereotactic radiotherapy as well [31]. We recommend the use of films in cases where the possibility to place a chamber is limited (by size). Ionization chambers need to be calibrated prior to the first use and every 3 years. Films are not associated with such additional expenditures.

Conclusion

All 4 analysis software products examined were found suitable for the calibration and evaluation of the films. As the EBT3 self-developing film is energy- and dose rate independent over the MV photon energy range, it can be reliably used for the verification of radiotherapy treatment plans in the case of IMRT and VMAT techniques.

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