A Feasibility Study of IMRT of Lung Cancer Using Gafchromic EBT3 Film

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ABSTRACT

Background: Intensity modulated radiation therapy (IMRT) is an advanced method for delivery of three dimensional therapies, which provides optimal dose distribution with giving multiple nonuniform fluency to the patient. The complex dose distribution of IMRT should be checked to ensure that the accurate dose is delivered. Today, film dosimetry is a powerful tool for radiotherapy treatment Quality Assurance (QA) and a good method to verify dose distribution in phantoms.

Objective: This study aimed to evaluate the accuracy of IMRT treatment planning system, Prowess Panther® software, with Gafchromic EBT3 films in a inhomogeneity phantom.

Material and Methods: The IMRT plan was generated by Prowess Panther® treatment planning system (TPS) version 5.2 on a inhomogeneity phantom, then it was irradiated by ONCOR linear accelerator (Linac) with 6 (MV) photon beam energy. The Gafchromic EBT3 film located between the phantom has measured the dose distribution.To compare between TPS calculated doses and film measured doses, Gamma criteria 3%/3 mm, 4%/4 mm, 5%/5 mm, 6%/6 mm and 7%/7 mm Dose Difference (DD) and Distance to Agreement (DTA), respectively were used.

Results: Gammas passing rates for PTV are obtained 67.5% for 3%/3mm, 78.8% for 4%/4mm, 86.3% for 5%/5mm, 91.2% for 6%/6mm and 94.3% for 7%/7mm and for organs at risk is 72.4% for 3%/3mm, 82.8% for 4%/4mm, 89.8% for 5%/5mm, 93.3% for 6%/6mm and 95.4% for 7%/7mm (respectively DD/DTA). By increasing the range of criteria the capability increased.

Conclusion: The results show that the use of EBT3 film in a inhomogeneity phantoms allows us to evaluate the dose differences between the EBT3 measured dose distribution and TPS calculated dose distribution .Hence, a result Prowess Panther® TPS can be used for IMRT technique treatment.

Keywords

Radiotherapy, IMRT QA, Prowess Panther®, Inhomogeneity Phantom, Lung Cancer, Gafchromic EBT3 Film, Gamma Analysis

Introduction

Radiation therapy is one of the several ways for cancer treatment that uses ionizing radiation to eliminate or shrink tumor [1]. Radiation treatment developed over the past 20 years from two-dimensional (2D) therapy to three-dimensional Conformal Radiotherapy (3D-CRT) to kill the maximum cancer cells with minimum damage to healthy tissues [2]. Unlike 3D-CRT, both the treatment planning and delivery of IMRT are more complicated and less understandable to the users. The intensity-modulated beams are produced with a complex

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motion of the Multileaf Collimators (MLCs). The field of IMRT involves many small and asymmetric fields. The small subfields in an intensity-modulated beam create leaf positioning accuracy much more critical for IMRT compared with 3D-CRT [3].

TPS plays an important role in implementation of IMRT technique. The modern TPS with complicated calculation algorithms in IMRT technique is able to divide each beam into large number of beamlet and calculate their dose accurately [4].

When IMRT is applied, the dose distribution calculated by TPS has to be assessed before the treatment. QA is particularly defined as the systematic actions necessary to ensure that a product or process performs accurately [5]. Several ways are in hand to verify the calculated dose distribution like Electronic Portal Dosimetry (EPID), TLD, two-dimensional Ionization Chamber Systems and Gafchromic film [6]. The selection of dosimeters needs some consideration, such as a radiation technique and field size of the investigated case [7]. Today, film dosimetry is a powerful tool for radiotherapy treatment QA [8] and a good method to verify dose distribution in phantoms. The first suitable radiotherapy film was Gafchormic EBT that was published in 2004 by International Specialty Products (ISP, Wayne, NJ). Instead of Gafchromic EBT film, the Gafchormic EBT2 film with a yellow marker dyed in the active layer was released in 2009 [9]. Gafcromic EBT3 film was the new generation of gafchromic film that was published in 2011. This film was the same as EBT2 film in chemical composition of the active layer [6] except in the response of the scanning side of scanner because of having symmetrical structure [10]. According to manufacturer's note, overlaying an active layer between two similar polyester layers prevented fromformation of Newton's Rings in EBT3 film [9]. In addition, high spatial resolution, insensitivity to visible light, ease of handling and preparation in room light, weak energy dependence make these dosimeters applicable for high dose gradients. Radiochromic dosimeters color change directly without any chemical processes and their image formation occurs by a dye development through a polymerization process [8, 11].

Since IMRT is a complex treatment; therefore, we can use radiochromic dosimeter to measure dose maps obtained from TPS and assess them by analysing programs according to Gamma Index [12]. In this study, to verify IMRT technique before treating, the measured dose from EBT3 film will be compared with calculated dose from TPS.

The TPS Quality assurance program is applied to validate the accuracy of calculated dose [13]. Since the TPS plays an important role in implementation of IMRT technique, thus before using this system, it should have been evaluated to verify that the accurate dose was calculated. As a result, our purpose is to assess the accuracy of Prowess Panther® TPS in IMRT technique in our institute.

Material and Methods

EBT3 film calibration, scanning and analysis

This study used GAFCHROMIC® EBT3 (Lot no. 03071603) in 20.3 × 25.4 cm^2 dimensions. The film was applied according to the methods illustrated in the AAPM TG-55 report [11].

GAFCHROMIC® EBT3 radiochromic film consists of a single active layer with 28 µm thick, including the marker dye, stabilizers, active components and other components giving the film its week-energy dependence. The active layer is between two, 100 µm matt polyester layers and incorporates a yellow dye that enable multi-channel dosimetry and decrease UV/light sensitivity (Figure 1). The EBT3 film structure is symmetric and eliminates the necessity to keep what shape of the film was placed on the scanner.

To obtained calibration curve, EBT3 film was cut in size of 5x5 cm^2 and seven of them

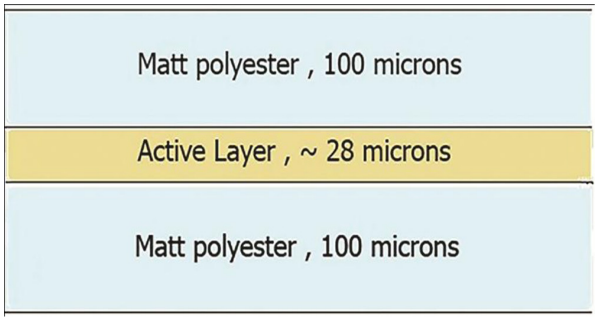

Figure 1: Structure of Gafchromic EBT3 Film.

were selected. Each piece of film was placed under 5 cm thick solid water phantom (PTW, Freiburg, Germany) and 10 cm thick underneath to provide adequate backscatters and field size of 10 × 10 cm^2 and 95 cm Source-to-Surface Distance (SSD) then they were irradiated by an ONCOR linear accelerator (Linac) with 6 MV (*TPR20/10* = 0.67) photon beam energy in the dose range of 50 to 350 cGy (Figure 2). To calibrate the Linac output, it used the IAEA *TRS398* protocol and an ion chamber. Ion chamber placed at 5 cm downstream from the pieces of films and monitor the Linac output during the irradiation process.

After irradiation, the films were kept in 7 black packets in order to protect from fluorescent lights and 48 hours after irradiation exposed and an unexposed film was scanned using a flatbed Microtek ScanMaker 9800XL Plus scanner (Microtek International, Inc. MRS-3200A3L, China). All exposed and one of unexposed films were located with scan ruler in the center of the scanner and they have been scanned in three colors (48 bit RGB) with 300 dpi of scanning resolution in transmission modes with all image corrections switched off. Film pieces are scanned using Microtek ScanWizard Pro (Microtek Inc.) software and saved as tiff file for analysis. For film dosimetry, the film had a maximum absorbency in a wavelength range between 600 to 700 nm that is in the red region of the visible spectrum, as a consequence, the red image was selected [14, 15]. The opinion of using the red channel for radiochromic film dosimetry has been accordingly employed by many authors [16-20]. Films were separated into three colors

Figure 2: Solid water phantoms and EBT3 film that was sandwiched between them in order to obtained calibration curve.

(red, blue and green) by using Image J 1.42 (National Institute of Health, Bethseda, MD) software and the selected red image. The mean pixel values of films were obtained in the center of them with 1.21×1.21 cm^2 Region of Interest (ROI) and then the net optical density (netOD) and the standard deviation (σ) were determined according to the following relations [20, 21]:

$$netOD = log_{10}(\frac{I_{unexp}}{I_{exp}}) \quad (1)$$

$$\sigma_{netOD} = \frac{1}{ln10}\sqrt{\frac{\sigma^2_{I_{unexp}}}{\left(I_{unexp}\right)^2}+\frac{\sigma^2_{I_{exp}}}{\left(I_{exp}\right)^2}} \quad (2)$$

I_{unexp} = mean pixel value of unexposed film, and I_{exp} = mean pixel value of exposed film, and σ_i are the corresponding standard deviation of the pixel values.

Generation of IMRT Treatment Plans and Dosimetric verification

An inhomogeneity phantom (Behyaar Sanaat Sepahan, Isfahan, Iran) was scanned in multi-slice SOMATOM® Spirit® Computed Tomography (CT) simulator (Siemens Medical Solutions USA, Inc., Malvern, PA) with 0.5 cm slice thickness. CT simulator images were transferred to Prowess Panther® TPS, version 5.2 (Prowess® Inc., Concord, CA) via DICOM. The patient plan that has been loaded on the inhomogeneity phantom and the Planning Target Volume (PTV), lung, and spinal cord was contoured. The prescribed dose to PTV was determined 80 Gy in 35 fractions that each section is given 2.8 Gy [22].The planning goals were to achieve 95% of the 100% prescriptive dose to the target volume and keep organs at risk below known tolerance limits. The beam configuration for this IMRT plan was 7 non-coplanar with 4 segments for each field and the gantry angels were 0°,11° ,58° ,83.9° ,149.4° ,205.6° ,309.4°. To optimize IMRT plan, it is necessary to define the dose of PTV volume and tolerance dose of organs at risk. Consequently The goal of the IMRT plan in this study contains following priorities: (1) the prescribed dose has to cover the PTV, to protect the spinal cord, (2) the received dose must be less than 45 Gy, (3) the dose received by the volume of normal lung must be less than 5 Gy (V5) and less than 10 Gy (V10) [23].

The EBT3 film was sandwiched between inhomogeneity phantoms (Figure 3) and irra-

Figure 3: EBT3 film sandwiched between the inhomogeneity phantom for IMRT QA and irradiated with 6MV ONCOR linear accelerator.

diated IMRT in a step-and-shoot method. The irradiated film was scanned after 48 hours in 48-bit RGB mode (16 bits per color) and separated into three colors (red, blue and green) with Image J software and the red image was selected.

The calibration curve was used in film analyze program (PTW-Freiburg, Germany) to convert the pixel values of the film that was sandwiched in inhomogeneity phantom into doses. The comparison was done between the measured and calculated dose distribution using Verisoft (PTW, Freiburg, Germany) software. The software uses the gamma analyses method to carry out the comparison[24]. To compare between calculated and measured dose distribution, gamma criteria of 3% DD / 3 mm DTA, 4% DD/4 mm DTA, 5% DD/5 mm DTA, 6% DD/6 mm DTA, 7% DD/7 mm DTA was used .It was performed by the suppression of the dose below *10%* of maximum dose of calculated volume [5].

Results

The EBT3 films calibrated curve (Figure 4) was formed according to a dose of 50 to 350 cGy range and obtained OD from Eq (1). The calibration curve data were fitted with a third order polynomial (R^2=0.9995) and the standard deviation that obtained from Eq (2) is 0.04%.

For obtained gamma index with Verisoft software we drew ROI for PTV and organs, then analyzed them separately. The Gamma analysis criteria that compare IMRT plan and film were 3% DD / 3 mm DTA and 4% DD / 4 mm DTA, and 5% DD / 5 mm DTA and 6% DD / 6 mm DTA and 7% DD and 7 mm DTA. Dose profiles and gamma histogram with 3% DD–3 mm DTA and 4% D-4mm DTA and 5% DD-5mm DTA and 6% DD-6mm DTA and 7% DD-7mm DTA criteria of comparison results between calculated doses in TPS and measured by EBT3 film in inhomogeneity phantoms were shown (Figure 5).

Dose map of EBT3 film and TPS calculated data were compared. Gamma analysis compares values of calculated and measured dose distribution that it is shown in (Table 1).

Discussion

The aim of this study was to assess the accuracy of Prowess Panther® treatment planning system at IMRT technique. Because of the

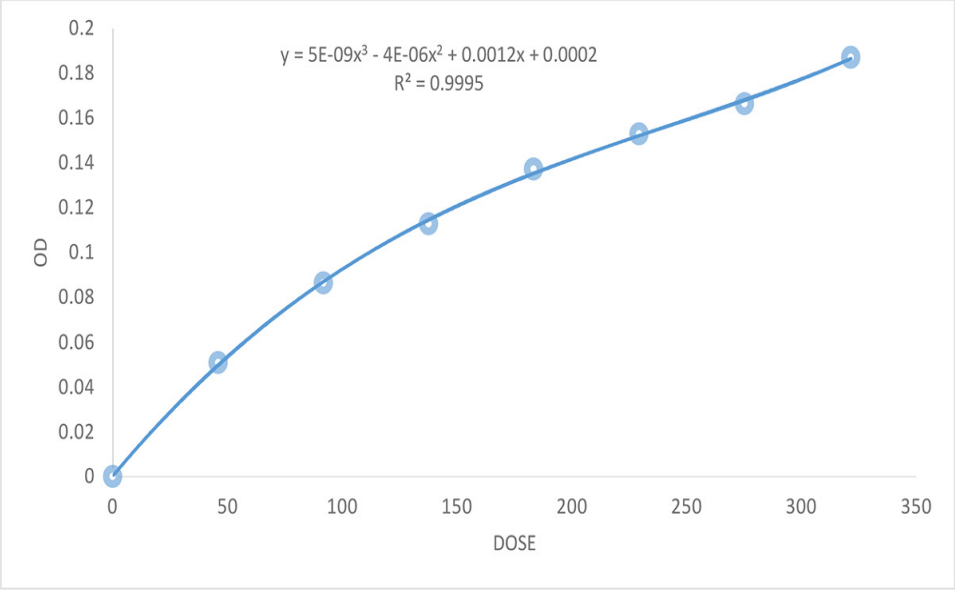

Figure 4: calibration curve of EBT3 films that were between solid water phantoms.

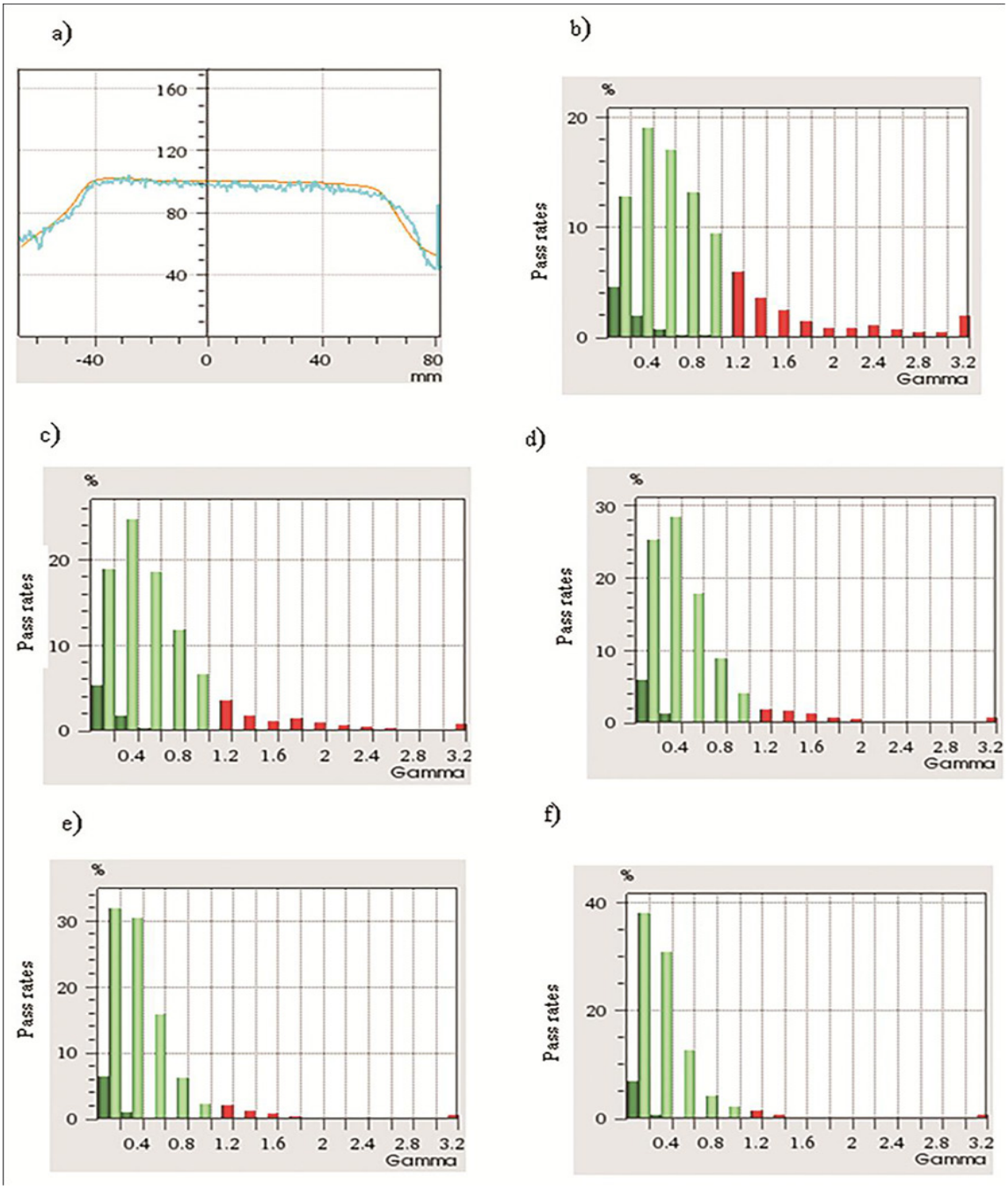

Figure 5: histogram of gamma analysis. a) Profile of comparison between film and TPS ,blue line is film measurement , b) 3%/3mm, c) 4%/4mm, d)5%/5mm, e)6%/6mm, f)7%/7mm, dose difference (DD) and dose to distance agreement (DTA) respectively.

complex nature of IMRT treatments, the treatment plan should be assessed before treating patients. To reach this purpose, QA process was done with lung IMRT treatment plan that was generated with Prowess Panther® TPS and Gafchromic EBT3 film dosimetry. Calculated and measured dose distributions were compared and the results in the same gamma analyzes tolerance level ($\Gamma<1$) for PTV and organs were found between 67.5% to 94.3% and

Table 1: Gamma passing rates, at various criteria (3% DD / 3mm DTA, 4% DD / 4mm DTA, 5% DD / 5mm DTA, 6% DD / 6mm DTA, 7% DD / 7mm DTA) for the Γ index. Data obtained with comparison between measured dose with EBT3 and calculated dose with TPS for PTV and organ at risk (spinal cord and right lung).

	Gamma passing rates				
Target	Point with Γ<1 (%) [3%-3mm]	Point with Γ<1 (%) [4%-4mm]	Point with Γ<1 (%) [5%-5mm]	Point with Γ<1 (%) [6%-6mm]	Point with Γ<1 (%) [7%-7mm]
Right lung (PTV)	67.5	78.8	86.3	91.2	94.3
Organ at risk (left lung, spinal cord)	72.4	82.8	89.8	93.3	95.4

72.4% to 95.4%, respectively.

We used different gamma criteria, 3%/3mm, 4%/4mm, 5%/5mm, 6%/6mm and 7%/7mm DD/DTA, respectively. It was shown that if we increase the criteria, the compatibility between TPS and film will increase and this was the same as the study that was done by Nalbant Nalbant et al. [6]. Their study was done for 10 prostate IMRT plans produced with Eclipse 8.9 (version8.9, Varian, Palo Alto, CA, United States) TPS. The comparison of EBT3 film dose distribution that was sandwiched between RW3 parallel slabs of water phantom (PTW-Freiburg, Germany) and TPS was done. Gamma analyses were obtained with Verisoft program (PTW-Freiburg, Germany). The compatibility of TPS and film dosimetry systems increased from 3%/3mm to 5%/5mm DD/DTA, respectively criteria.

The uniformity of Gafchromic film is variable film by film and the different regions in one specific film, according to Researched conducted by Sankar et al. [25]. They tested the clinical usability of Gafchromic EBT films with IMRT plans that were generated by ADAC Pinnacle planning systems. Gamma values were obtained with RIT113 software and the results showed variable values from 68.11% to 99.89% for 3% DD / 3 mm DTA criteria, because of variation in film uniformity. They stated that EBT film had a good sensitivity and t is suitable to determine the clinical dose. However, in order to have better result, we should get a small ROI, because in small areas of film uniformity variety is not heavy.

while radiochromic films were scanned by a flatbed scanner, they will be affected by the scanner parameters including different light scattering due to scanner light over scan areas as a result, this leads to the non-uniform response of the film [26]. Nonuniformity of the scanner is due to the source of light and/or scattering of light. Several studies have been done in this area, including GS Sim et al [27] in order to verify the dosimetry of a 3D conformal radiotherapy treatment with EBT2 Film. In their study, the plan of a one-year-old pediatric anthropomorphic phantom (CIRS, VA) contained lung and spinal cord was created by the Eclipse treatment planning system (TPS), version 8.9 (Varian Medical Systems). To compare between the EBT2 film and TPS plan, they used MATLAB 2008b (The MathWorks Inc., Natick, MA) by using gamma index with 7%DD and 7mm gamma criteria. The result of the gamma criterion showed the discrepancy between the measured and calculated dose. They said it may happen due to scan bed nonuniformity. The other group that used different flatbed scanners observed the effect [28, 29].

In this work, the results of comparison between measured and calculated dose distribution for 7%/7 mm and 6%/6mm DD/DTA

criteria were an optimum criteria, it demonstrated that the compatibility between film measurement doses and TPS calculated doses was more than 90%. About the other criteria, When we compared the result obtained for 3%/3mm, 4%/4mm DD/DTA, criteria with the similar study were conducted by Carla Sini et al. [30] that they had done IMRT QA in thorax phantom with EBT3 film and their result demonstrated 72% of points were satisfactory for 3% DD/3 mm DTA acceptance criteria; the agreement improves with 4% DD/ 4mm DTA, that 81% of points were satisfactory for the acceptance criteria that had been demonstrated approximately the same result to our study.

Conclusion

IMRT QA requires 2D dosimetry systems that have high resolution and are able to measure accurate doses. In this study, EBT3 film was used to evaluate IMRT plan. The measured doses of EBT3 film were compared with TPS calculated doses. It was observed that the result obtained for 6%/6mm and 7%/7mm DD/DTA, criteria is more compatible than the other criteria between film measurement and TPS calculated dose. Compatibility between film measurement and TPS predicted is reduced for the criteria to 3%/3mm, 4%/4mm, 5%/5mm DD/DTA, respectively and it may cause for film uniformity variation or nonuniformity of the source of light and/or scattering of light. It is suggested that the dose distribution achieved in a smaller area, due to the film uniformity in the smaller area has smaller variation and it places the film in central of the scanner bed so as to reduce the effects of the nonuniformity from the scanner light. The results show that the use of EBT3 film in inhomogeneity phantoms allows us to evaluate dose differences between the EBT3 measured dose distribution and TPS calculated dose distribution .Thus, Prowess Panther® TPS can be used for IMRT technique treatment.

There are different methods to evaluate TPS that film dosimetry is one of them and it is impossible to state that the film dosimetry is the only suitable method to assesse TPS. We selected this method due to the existing facility in our institute.

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Conflict of Interest

The authors declare that there is no conflict of interest in this study.

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