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Comparison of the EBT2 calibration responses in 4MV LINAC at Water and Solid Water Materials

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ABSTRACT

Currently, cancer has gained a larger dimension and become a global public health problem. Radiotherapy (RT) performs the treatment by RT Linacs. Such linear accelerators must undergo a strict dose quality control. Water or solid water phantoms can be used with this intuit. In recent years, radiochromic films with equivalent tissue composition have been widely used as dosimeters in the medical field. The present proposal was to analyze the two distinct dosimeter responses in water and solid water phantoms at a 4MV beam spectrum. Solid water and water phantoms and EBT2 Radiochromic films were set in two distinct calibration processes. Films were exposed to a set of absorbed doses established by distinct monitor units (MU) specified in a RT-center. Mathematical correlations between the level of red-intensity from digitized films and the absorbed dose for both methods were established. The coefficients of the polynomial function of the calibration curve were determined by the Origin software. The uncertainty of both processes was analyzed. The efficiencies of the two calibration processes were set up. The adjustment of the calibration curve provided the coefficients of the second-order equation that relates the dose absorbed with the optical density in the film. The uncertainties regarding the calibration performed in water and solid water and the dose-error accuracy were in agreement with the literature. Both water and solid water were effective in calibration and can be used in routines of quality-control measurements.

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The results showed that EBT2-radiochromic films are suitable to for dose-calibration in RT.

Keywords: radiochromic film, dosimetry, calibration processes.

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1. INTRODUCTION

The word cancer, in general, is used to designate a set of more than one hundred diseases that have in common the disordered growth of cells [1]. In the last decades, cancer has gained a larger dimension, becoming a world public health problem. According to data from the World Health Organization (WHO), by 2030, more than 21 million cases of cancer can be expected and more than 13 million deaths due to population increase and its inevitable aging [1, 2].

Radiotherapy is one of the therapeutic modalities of the neoplasias. RT employs high doses of radiation in the patient aiming the eradication of the malignant and occasional benign neoplasms. The aim of this treatment modality is to deliver a precise dose to the tumor volume with minimal damage to neighboring tissues [3].

The present technologies have improved the diagnosis and treatment of malignant tumors. However, the equipment used must undergo a strict quality control, since a technical mismatch in the hardware can have severe consequences for the patients.

RT quality assurance includes procedures that aim providing accurate prescribed doses in the target volume and in the ogans at risk, and minimum exposure to the workers involved. Such procedures are necessary because small deviations may cause changes in the tumor dose-response sigmoidal curves [4].

Calibration can be defined as a process that establishes the relationship between the values achieved by a measurement instrument and the corresponding value of the quantity being measured [5].

In the TRS-398 document, published by the International Atomic Energy Agency [6], water is the recommended reference standard for determining the absorbed dose for high energy photon beams, since the radiation effects are equivalent in human tissue in this energy magnitude. Phantoms of solid water should not be used in reference dosimetry for high energy photon beam; however, it has often being used in routine measures linked to quality assurance.

In recent years, radiochromic films have been widely used as dosimeters in the medical field. These films have an equivalent tissue composition of 42.3% C, 39.7% H, 16.2% O, 1.1% N, 0.3% Li and 0.3% Cl [7, 8, 9]. Developed by International Specialty Producct (ISP), radiochromic films are relatively inexpensive tools compared to other technologies available for dose measurements and can be used in most technologies available in radiotherapy, covering a wide dose range of 1 cGy to 40 Gy [10].

In this context, the goal of this study was to compare and evaluate the efficiency of the two calibration processes. The measurements were performed by radiochromic films in two distinct environments, in water and solid water; both performed in the Linear accelerator (LINAC) model Clinac 6x SN11 of 4MV. In both processes, mathematical relationships between the level of film darkening and the absorbed dose were generated, compared and analyzed.

2. MATERIALS AND METHODS

2.1 - EBT-2 Radiochromic Film Calibration in Water Phantom

Three groups, each containing ten segments (3.0 x 3.0 cm^2) of EBT-2 films (batch: # if10070902B) were irradiated in a 4 MV linear accelerator for the calibration process. The calibration technique was carried out by means of an acrylic box filled with water, said water phantom. Such a phantom has the external dimensions of 40 x 40 x 40 cm^3 and a pulley with a movable support that varies its height in mm along the box. A 5 x 5 x 100 mm^3 horizontal rod was used to attach and position the films during calibration. This material acts as a clamp for fixing the film. The radiation exposure was also measured with an ionization chamber following the calibration procedure of the monitor units (MU) in the LINAC, prior the irradiation of the films, resulting the normalized deep dose profile (DDP) in function of the maximum value found in the electronic equilibrium position. A value of a MU was specified as 1cGy.min^{-1}.

The film´s depths were: 1 cm, 3.5 cm, 5.5 cm, 6 cm, 8.5 cm, 11 cm, 12.5 cm, 14 cm, 16 cm and 22 cm. In each deepness three distinct films were irradiated and mean and standard deviation were evaluated. The absorbed doses in the films were calculated by multiplying the applied MU by the percentage of dose in the DDP at a field of 10 x 10 cm with a distance surface source (DFS) of 80 cm. The applied doses ranged from 0 to 450 cGy. Film´s segments were handled in the calibration; irradiation and reading in non-light room to further reduce the effects of ambient light.

2.2 - EBT-2 Radiochromic Film Calibration in Solid Water Phantom

Three groups, each containing ten segments (3.0 x 3.0 cm²) of EBT-2 films (batch: # if10070902B) were also irradiated in the 4 MV linear accelerator in the solid water for the calibration process. Three solid water plates, one with dimensions of 30 x 30 x 4 cm^3 and two with dimensions of 30 x 30 x 1 cm^3 of the Standard Grade Solid Water Gammex 457 (2017) were used. The films were irradiated in the central region of the beam with a field of 10x10 cm² with SSD of 80 cm. In each irradiation, three different films were exposed and mean and standard deviation were evaluated. The absorbed doses were established by varying the MU values at 4 cm depth in order to fulfill the dose range of 0 to 450 cGy.

2.3 - Digitizing and Processing of Calibration Data

The dosimeters exposed in the water and solid water phantoms were digitized in the HP Scanjet G4050 flatbed scanner, operating in transmission mode with all correction tools turned off. The films were digitized 24 h after their exposure to ensure stability in the degree of browning of the films. All the digitized parameters were performed following the suggestions provided by Devic et. al. [11, 12] and Thompson et al. [13].

The six groups of films with 10 segments were digitized separately, similar to slides placed in the center of the scanner, using the following settings: 300 pixels per inch (ppi, pixels per inch) in RGB mode (Red, Green, Blue) with 48 bits, 16 bits per color saved in TIFF format.

After the digitizing process, the images of the films were transferred to the ImageJ program [14], and separated into each color component of the RGB channels. The mean intensity of each irradiated film was measured in the red channel with ROIs of 2 cm², avoiding the edges.

The optical density (*OD*) was associated with the absorbed dose as follows [11]:

$$OD = \mathrm{Log}_{10}\,(I_0/I) \ , \tag{1}$$

in which I_0 is the intensity of the red component in the non-irradiated film and I is the intensity of the irradiated film [7]. The standard deviations of the optical densities of the exposed and unexposed film segments were calculated, as described by Devic et al. [11, 12] and Thompson [13], as follows:

$$\sigma(OD) = \frac{1}{ln_{10}}\sqrt{\frac{\sigma(RGB_{ni})^2 \ + \ \sigma(RGB_{rv})^2}{OD(RGB_{ni}) - \ OD\ (RGB_{rv})^2} + \frac{\sigma(RGB_i)^2 + \ \sigma(RGB_{rv})^2}{OD(RGB_i) - \ OD\ (RGB_{rv})^2}} \tag{2}$$

in which σ and OD of RGB_{ni} are respectively the standard deviation and the optical density of the non-irradiated film; σ and OD of RGB_{rv} are the standard deviation and optical density of the overexposed film, respectively, in a veiled radiographic film; and σ and OD of RGB_i are the standard deviation and the optical density of the irradiated film, respectively, all in the red component [11, 12, 13].

After evaluating the dose and the optical density in the ten calibration films, a calibration curve was constructed according to Devic et al. [11]. The following mathematical function was applied:

$$D_{fit} = a + b \cdot OD + c \cdot OD^{n} \,, \tag{3}$$

in which *a*, *b* and *c* are the coefficients provided by the mathematical adjustment, *OD* is the optical density, *n* is the index of the equation and D_{fit} is the correlated dose .

2.4 - Uncertainty assessment of the measured dose

The uncertainty related to the calibration curve was calculated according to Chiu-Tsaoa and Chan (2009) [15], following the expression:

$$\sigma_{D,fit} = \frac{u_a^2 + (OD)^2 u_b^2 + (OD)^6 u_c^2}{D_{fit}} \qquad , \tag{4}$$

where u_a, u_b and u_c are respectively the uncertainties of the parameters *a*, *b* and *c* of the calibration curve, D_{fit} is the mathematical adjustment function. All these parameters were extracted from the calibration curve, given by Eq.3.

3. RESULTS AND DISCUSSION

Both dosimetric calibration curves at 4 MV were generated in the water and solid water phantoms. Devic et al. [11] recommended that the best value of *n* be chosen, so that the values of the coefficients *a*, *b* and *c* hold the smallest possible uncertainties. In this work, both curves had the value of *n* equal to *2.5*.

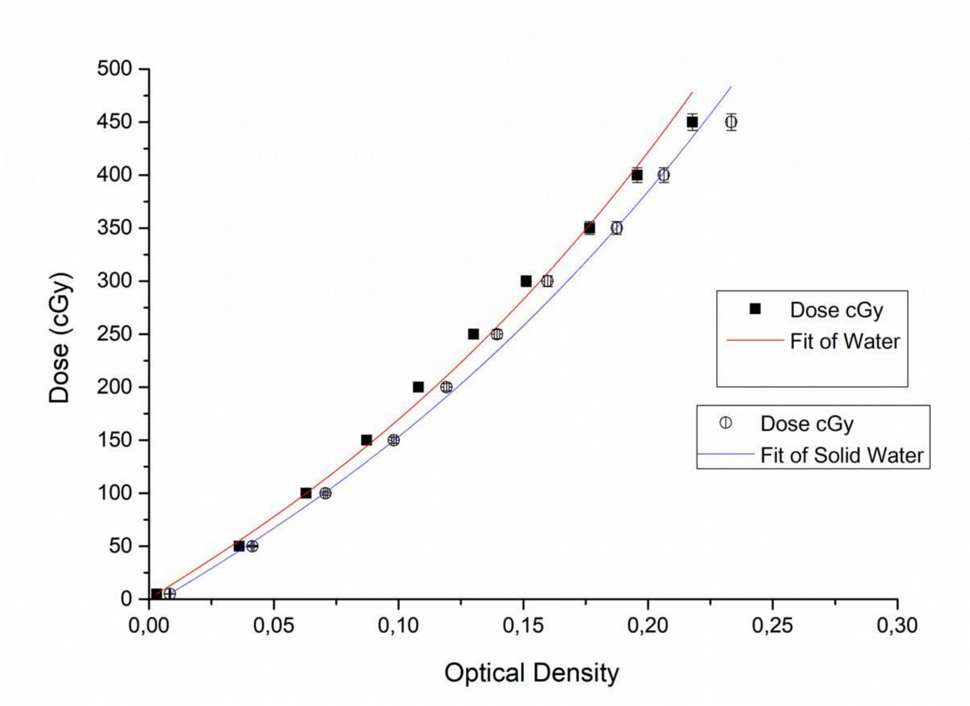
The coefficients of the polynomial function of the calibration curves were determined by the Origin software [16]. The obtained values are shown in Table 1.

Table 1: Coefficients of the polynomial function of the calibration curve

Water		Solid Water Phantom	
a	+ 0.54 ± 0.39	***a***	- 6.71 ± 0.60
b	+ 1464.41 ± 69.06	***b***	+ 1403.32 ± 61.66
c	+ 7166.84 ± 1254.70	***c***	+ 6175.29 ± 983.24
R^2	0.995	R^2	0.997

The adjustment of the calibration curves provided coefficients that allowed suitable equations that related the absorbed dose with the optical density in the dosimeters. Figure 1 depicted the graphical representation of Eq.2 for the two calibrations [16].

Figure 1: *Calibration math curves of the EBT-2 film exposed to a 4MV beam in a water and solid water phantom.*



The circular symbols are the mean value of the ODs of each film in the solid water, while the square symbols are the mean value of the OD of each film in the water phantom, and the solid lines are the polynomial functions applied at each curve.

The uncertainty regarding calibration in solid water was 0.23% and the uncertainty related to calibration in water was 1.88%, according to Chiu-Tsaoa and Chan [15].

Hugtenburg et al. [17] suggest that the dosimetric accuracy should be within 5% for a successful clinical outcome, whereas the IAEA [18] recommends an accuracy of 3%. In this work, the applied doses were equivalent in the two experiments. The dosepercentage differences from the two protocols have not exceeded 3%.

Water is the recommended reference standard for the determination of the absorbed dose in the IAEA document TRS 398 [6], since it is the homogeneous material that most matches the human tissue composition, thus it is expected that the absorption and scattering properties of the radiation in water are similar to human tissue [19]. The use of solid water phantoms for reference dosimetry is not recommended; however, such phantoms have often been used in routine quality control measures. In this work, we show that the differences found are not relevant in their use in dose versus optical density calibrations.

The use of radiochromic films in dose measurements in both water and solid water was satisfactory. No color or chemical property changes were found in the films submerged in the water, if 5 mm from the border of the film is discarded during the digitized process [20].

4. CONCLUSION

The protocol of generation of calibration curves that represent a mathematical relation between the level of darkening of the red-component and the absorbed dose in the radiochromic film was shown to be effective. No chemical or color changes were found in the water submerged films, respecting the boarder limits. Both water and solid water phantom proved an effective tool for calibration. Both can be used in the routine of the quality control measurements.

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