IOP Conf. Series: Materials Science and Engineering **298** (2018) 012022 doi:10.1088/1757-899X/298/1/012022

Verification of relative output factor measurement using Gafchromic films for small-field radiosurgery photon beams.

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Abstract. Accurate dosimetry of small-field photon beams has always been difficult to achieve, due to the steep dose gradient and absence of lateral electronic equilibrium. The purpose of this study was to verify the measurement of relative output factor (ROF), which is one of the dosimetric parameter required for stereotactic radiosurgery (SRS) treatment planning. The ROFs for Radionics circular cone collimators with diameter in the range of 10.0 to 45.0 mm were measured using Gafchromic EBT2 and EBT3 films. The measurements were then compared with the ROFs obtained using a PinPoint ionisation chamber and Monte Carlo (MC) simulation. From the results, the ROFs measured by the ionisation chamber, EBT2, and EBT3 films were good agreement with the MC simulation, with deviations of less than 1.5, 2.6, and 5.0 % respectively. Based on the film dosimetry, the EBT2 film showed in a more reliable measurement for field size ranging from 15.0 to 45.0 mm, compared with EBT3. As a conclusion, based on the special characteristic of the small-field photon beams, ROF measurement using PinPoint ionisation chamber are being favoured, due to its accuracy. However, the EBT2 film can be used as an alternative, when high spatial resolution is required.

1. Introduction

In order for a stereotactic radiosurgery (SRS) treatment planning system (TPS) to be commissioned to work with a medical linear accelerator (LINAC), a large number of measurements using the LINAC will be required, to be entered into the system. One of the parameters to be measured is the relative output factor (ROF). The ROF is a simple way of comparing the output of a LINAC under desired settings, to the output of the same LINAC under reference condition (i.e. field size of 10 x 10 cm^2 at the reference depth inside a water phantom, and source to surface distance (SSD) of 100 cm), with known absolute dose. The ROFs need to be accurately measured for very small field size, as it can be used to tell the TPS how the LINAC output varies as the field size reduces, allowing a more accurate calculation of the dose.

The accuracy of the ROF directly affects the accuracy of the dose delivered in a radiosurgical treatment [1]. Accurate measurement of the ROF for small-field photon beams ($\leq 4 \times 4$ cm^2) used in SRS can be made difficult due to the presence of lateral electronic disequilibrium and steep dose gradients. The ionisation chamber is a standard dosimeter used for measuring the dosimetric parameters of photon beams, such as percentage depth dose (PDD) beam profiles, and ROF. However, for small-field photon beams, several challenges are present, as discussed in the published literatures [2-4]. Various dosimeters can be used as alternative to the ionisation chamber, e.g., diode, diamond detector, thermoluminiscent detector (TLD), metal-oxide-semiconductor field effect transistor (MOSFET), glass rod dosimeter (GLD), radiographic, and radiochromic films. Each dosimeter has its own pros and cons when it is used for the small-field photon beams, as elaborated in the published literatures [5-10]. To date, there is no single detector which can be used on its own, a narrow circular field (with diameter of < 20 mm) [11]. This led to many relying on the Monte Carlo (MC) simulation. Although the MC calculation is still considered as an experimental method, it is often used as a detector-independence reference. The relative performance of each detector can therefore be quantified, as deviation from the MC simulation results.

Therefore, the ROFs of small-filed photon beams can be obtained, through careful comparison between the ROFs estimated by the small volume ionisation chamber, film dosimetry, and MC simulation. This study was conducted to compare the measured ROF using two different types of Gafchromic film (i.e. EBT2 and EBT3) and a PinPoint ionisation chamber, and validated using MC simulation.

2. Material and methods

All irradiations were performed with 6 MV photon beam, using a LINAC (PRIMUS, Siemens Healthineers, Erlangen, Germany) equipped with a multi-leaf collimator (MLC). The LINAC output was calibrated based on the IAEA TRS-398 protocol [12]. The ROF for circular cone collimators (Radionics, Integra Radionics, Massachusetts, USA) with diameters of 10.0, 15.0, 20.0, 22.5, 27.5, 32.5, and 45.0 mm, were measured in this study.

2.1. Measurement of ROF using PinPoint Ionisation Chamber

The measurement of ROF using an ionisation chamber (PinPoint®, PTW, Freiburg, Germany) with vented sensitive volume of 0.015cm^3, was conducted by placing it inside a water scanning system (MP3, PTW, Freiburg, Germany). The ionisation chamber was placed at the centre of a 45.0 mm circular field size, depth of maximum dose (dmax) of 1.5 cm and SSD of 100 cm. the procedure was repeated by replacing the circular cone collimator with that of a different diameter. The ROF for each circular cone collimator was calculated, by calculating the ratio of the charge obtained at dmax (Cw, ic, A), to the charge ontained at similar depth with 10 x 10 cm^2 or reference field size (Cw, ic, ref). The ROFs were calculated using Equation 1, as follows:

$$ROF\ (A) = \frac{Cw,ic,A}{Cw,ic,ref} \quad (1)$$

2.2. Film calibration

Gafchromic EBT2 films (Ashland Inc., Kentucky, USA) were irradiated with 6 MV photon beam, by placing it inside a 30 x 30 x 20 cm3 solid water phantom (RW3, PTW, Freiburg, Germany), at the centre of a 10 x 10 cm2 field size, dmax of 1.5 cm and SSD of 100 cm. Film calibration was carried out by placing the film perpendicular to the beam, for dose ranging from 50 to 500 cGy. Unexposed film was also developed, to obtain the background reading. After 24 hours, the calibrated films were scanned using a flatbed scanner (Epson Expression 10000XL, Seiko Epson Corporation, Nagano, Japan) in landscape orientation. The ratio of film response to the dose delivered was determined in

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pixel value, using a patient plan verification software (Verisoft®, PTW, Freiburg, Germany). Equation 2 was used to convert pixel value to the net optical density (OD). Similar procedure was repeated for the EBT3 film (Ashland Inc., Kentucky, USA). Finally, a calibration curve (dose versus net OD) was generated for each film type, i.e. EBT2 and EBT3 films.

$$Net\ OD = Log\ 10\ \frac{\text{pixel value non irradiate film}}{\text{pixel value irradiate film}} \quad (2)$$

2.3. Measurement of ROF using Gafchromic EBT2 and EBT3 films

Gafchromic films (i.e. EBT2 and EBT3) taken from the same batch as the calibrated films, were irradiated with 6 MV photon beam, by placing it inside the 30 x 30 x 20 cm^3 solid water phantom, at the centre of a 45.0 mm circular field size, dmax of 1.5 cm and SSD of 100 cm. the procedure was repeated by replacing the circular cone collimator with that of a different diameter. The irradiated films were scanned using the EPSON flatbed scanner, at 24 hours post-irradiation and analysed using Verisoft software. The net OD was converted to dose, based on calibration curve. The ROF for each circular cone collimator was calculated, by calculating the dose obtained at dmax, to the dose obtained at similar depth with 10 x 10 cm^2 field size.

2.4. Modelling and simulation

The ROF for the Radionics circular cone collimators were calculated using BEAMnrc and DOSXYZ nrc software components, which are included in the EGSnrc source code (national Research Council Canada, NRCC). The code was installed on a personal desktop computer. The BEAmnrc is a general purpose MC simulation system for modelling of radiotherapic source, while DOSXYZnrc is used to calculate the dose in three dimensional (3D) medium [13]. The simulations were performed in three stages. For the first stage, the BEAMnrc was used to simulate the PRIMUS LINAC head, to obtain the phase space data for the first 20 cm distance after target (right after the projection mirror). This phase space file was used for the subsequent circular and square (10 x10 cm^2) field sizes. In this stage, 50 million particle histories were used.

For the second stage, all circular cone collimators used in this study were simulated. The collimators were simulated as stainless steel materials with a density of 8.03g/cm^3. The geometry of each collimator was simulated based manual measurement, since technical drawing of the component was unavailable. The radionics assembly holder and circular cone collimators were simulated using the BEAMnrc's flattening filter (FLATFILT) component module. The 50 x 50 mm^2 (phase space file was used for second stage) and space files were generated for all cone collimators, at SSD of 80 cm. The energy cut-off values for photon (PCUT) and electron (ECUT) transport were set to 0.01 and 0.70 MeV, respectively. The phase space files generated during the second stage of the simulations were used in the final stage, to calculate the 3D dose distributions in water phantom using the DOSXYZnrc software.

3. Results and Discussion

Figure 1 shows the calibration curves of the EBT2 and EBT3 films, following irradiation with 6 MV photon beam. Both films showed linear response to the dose. Based on the R^2 values, EBT3 showed a more linear response to the dose ranging from 50 to 250 cGy, compared to the EBT2 film. The differences between the films were smaller than ~ 4 %, with almost similar sensitometric curve pattern. In general, the results showed no significant variation in terms of dose response, for both films. However, the variations in sensitivity (net OD per unit dose) may be present, when different batches of film were used. This has been proven in the study done by Butson et al. (2010), where it was concluded that there were variations in the sensitivity between different batches of each film (i.e. EBT2 and EBT3), although both batches possess similar thickness of active layer (~ 28 µm) [5]. Hence, the EBT2 and EBT3 films must be calibrated, every time a set of measurement needs to be performed using films from different batches.

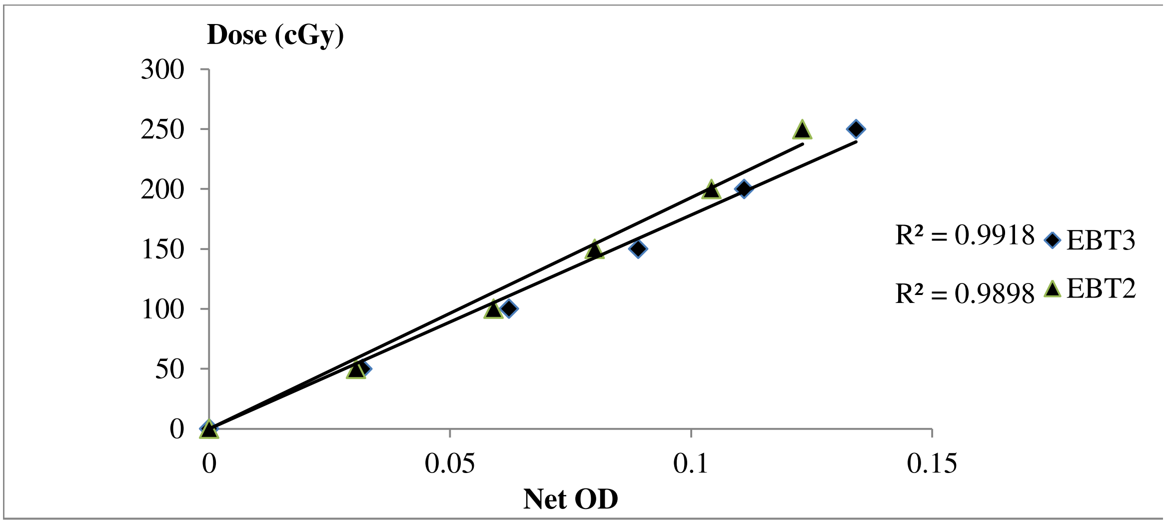

Figure 1. Dose (cGy) versus net OD for Gafchromic EBT2 and EBT3 films.

The comparison between the ROFs measured using the PinPoint ionisation chamber, EBT2 and EBT3 films with respect to the MC calculated ROF, are shown in Table 1 and 2. The ROFs measured using the ionisation chamber were in excellent agreement with the MC calculated ROFs (with less than 1.5 % deviation, except for the 10 mm circular collimator. The accuracy of the ionisation chamber in small-field photon beam measurement was dependent on the resolution of the ionisation chamber. A smaller sensitive volume will contribute to higher resolution. The ROFs measured using the EBT2 and EBT3 films were also found to be in good agreement with the MC-calculated ROFs (with deviations of less than 2.6 and 5.0 %, respectively), except for 10 mm circular collimator. The results were in parallel with the study done by Underwood (2013), which reported the inherent variations in dose measurement of around 2 to 5 % (for both EBT2 and EBT3 films), even with an optimised dosimetric process [14].

Table 1. The ROFs obtained using the films (EBT2 and EBT3), ionization chamber (PP), and MC simulation, for different circular cone diameters.

Cone (mm)	ROF			
	EBT2	EBT3	PP	MC
10.0	0.616	0.625	0.733	0.770
15.0	0.829	0.833	0.827	0.824
20.0	0.859	0.843	0.873	0.879
22.5	0.867	0.850	0.887	0.886
27.5	0.892	0.850	0.896	0.895
32.5	0.887	0.868	0.902	0.902
45.0	0.938	0.905	0.928	0.915

Table 2. The percentage deviations between the ROFs obtained using the films (EBT2 and EBT3) and ionization chamber (PP), relative to the MC simulation, for different circular cone diameters.

Cone (mm)	Deviations (%)		
	EBT2/MC	EBT3/MC	PP/MC
10.0	-20.03	-18.86	-14.73
15.0	0.62	1.10	0.37
20.0	-2.24	-4.06	-0.65
22.5	-2.14	-4.06	0.11
27.5	-0.34	-5.03	0.11
32.5	-1.71	-3.82	-0.05
45.0	2.56	-1.05	1.47

Unlike the ionisation chamber, the self-developed Gafchromic films record doses through indirect measurement. Thus, the films were required to be 'rested' for the first 24 hours following irradiation, before they can be read and analysed. Still, systematic error may be introduced during the measurement, as well as the scanning process. This is because, the flatbed scanner was not specifically made for film dosimetry, and thus, hardware issues may be present, which could results in a dose fluctuation. Human error may also be present during the setup of the experiment, the scanning process and analysis of the films using the dosimetric software. The energy dependence of the films may be another contributor to the variations. Nonetheless, for the 6 MV photon beams used in this study, a relatively small difference in the films response of < 10 % were demonstrated, from 60 KeV to MeV range [15].

4. Conclusion

Gafchromic EBT2 and EBT3 films were shown to be capable of measuring the ROFs for small-field photon beams, due to their features, i.e. lack in lateral electronic equilibrium, high in spatial resolution, and near tissue equivalent. Both films are inexpensive and provide good option for smaller radiotherapy centre that do not own the equipment or personnel, to perform a more complex small-field relative dosimetry. However, the films are limited such that, the read out process needs careful attention, to avoid measurement uncertainties. Therefore, based on the special characteristics of small-field photon beams, the PinPoint ionisation chamber was suggested due to its accuracy. However, the EBT2 film can be used as an alternative, when high spatial resolution is required.

5. References

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Acknowledgments
This study was supported financially by the Short-term Grant (304/PPSK/61313048) of Universiti Sains Malaysia. This work was made possible with the cooperation of the Nuclear Medicine, Radiotherapy, and Oncology Department, School of Medical Sciences, Hospital Universiti Sains Malaysia, and School of Health Sciences, Universiti Sains Malaysia (USM).