

## Technical Note

# Dosimetric evaluation of electron beams on scalp using EBT2 films and rando phantom

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(Received 25 July 2017; revised 2 December 2017; accepted 3 December 2017; first published online 8 January 2018)

## Abstract

**Background:** In radiotherapy, electron beam irradiation is an effective modality for superficial tumours. Electron beams have good coverage of tumours which involve the skin, however there is an issue about electron scattering and tissue heterogeneity. This subsequently demands dosimetric analysis of electron beam behaviour, particularly in the treatment of lesions on the scalp requiring the application of treatment to scalp curvatures. There are various methods which are used to treat scalp malignancies including photons and electrons, but, the later needs precise dosimetry before each session of treatment. The purpose of the study was to undertake a detailed analysis of the dosimetry of electron beams when applied to the curved surface of the scalp using Gafchromic® EBT2 films.

**Methods and materials:** A rando phantom and Gafchromic® EBT2 films were used for dosimetric analysis. A gafchromic calibration curve was plotted and an in-treatment beam dosimetric analysis was carried out using dosimetry films placed on the scalp. Electron behaviour was assessed by introducing five electron fields in particular curvature regions of scalp.

**Result:** There was an acceptable dose range through all five fields and hotspots occurred in the curved borders. In our study, skin doses and doses at the field junctions, with no gaps, were between 78–97% and 80–97%, respectively.

**Conclusions:** Electron beams are a good modality for treating one flat field, but in the special topography of the scalp, whole scalp treatment requires precise field matching and dosimetry. In undertaking this detailed dosimetric analysis using a rando phantom and Gafchromic® EBT2 films, it is concluded that this method requires further detailed analysis before using in clinics.

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**Keywords:** Electron beams; Gafchromic® EBT2; scalp malignancy; scalp treatment

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## INTRODUCTION

Radiation therapy is a treatment of choice for the treatment of superficial malignancies such as

cutaneous lymphoma, melanoma, angiosarcoma, mycosis fungoides, Kaposi's sarcoma, sebaceous carcinoma, basal and squamous cell carcinoma, that may extend into the entire scalp region and

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forehead. In these patients, irradiation of the total scalp may be necessary to treat these superficial tumours, particularly when surgical excision is not possible or is not the treatment of the choice.<sup>1</sup> The goal of total scalp irradiation is to deliver a uniform dose throughout the target area while minimising dose to the brain and optical structures. This requires measuring the dosimetry of the electron fields before the radiotherapy session, due to the convex surface of the calvarium and the close proximity of the scalp to the adjacent normal brain tissue. In addition, fields must encompass any multifocal spread of the lesion. In this situation, dose delivery is technically challenging and therefore the goal of scalp uniform irradiation is difficult to achieve. In this regard, various irradiation techniques concerning the treatment of scalp malignancies have been suggested in the medical literature. These include a lateral electron–photon technique, a helmet-shaped mould incorporating the use of high dose-rate (HDR) brachytherapy,<sup>2</sup> a linear accelerator based intensity-modulated radiation therapy and helical tomotherapy.<sup>3</sup> Another study verified three different modalities include helical tomotherapy, lateral photon–electron (LPE) therapy and volumetric-modulated arch therapy showed there is best conformity for helical tomotherapy and the LPE plan showed the worst, despite the similar homogeneity indexes.<sup>4</sup>

The traditional electron beam technique can deliver a relatively high dose to the scalp and a relatively low dose to the underlying brain tissues. Nevertheless, electron beams may cause labour intensive treatment set up with numerous electron beam junctions.<sup>5,6</sup> In the conventional combined electron–photon modality technique, an adequate target volume dose can be accomplished, with improved dose uniformity by virtue of overlapped fields whilst sparing dose to the normal brain tissues and eyes. This makes the treatment set up less tedious and less time consuming but incidence of beam angle and field matching remain a problem.<sup>7,8</sup> Photon intensity-modulated radiotherapy (IMRT) is an effective and feasible approach to treat extensive scalp malignancies.<sup>9</sup> Non-coplanar beams could increase dose homogeneity and planning target volume coverage and might reduce dose particularly to the optic chiasm.<sup>10</sup> Electron beam

treatment for scalp tumours can be an easy and effective treatment for palliative intent in elderly patients with squamous cell carcinoma, because good results can be achieved even without considering the dose at field junctions.<sup>11</sup>

The use of HDR brachytherapy can achieve the most conformal treatment and treatment delivery is well tolerated which is delivered in less treatment sessions in contrast to external radiotherapy.<sup>12</sup> This technique could be clinically convenient for treatments requiring a lower prescription dose and for patients who cannot lie on the treatment couch.<sup>12</sup> However, due to the dose fall-off characteristics of <sup>192</sup>Ir source, the HDR modality produces a 58–242% dose gradient within the target volume. Moreover, the underlying brain tissues and optical structures received the highest doses with the HDR brachytherapy technique when compared with IMRT and 3DCRT.<sup>2,12</sup> The IMRT technique constitutes a promising and possible way to treat extensive scalp lesions and provides superior target coverage of the treatment volume with the most homogenous as well as conformal dose distribution within the target.<sup>9</sup> The dose to the brain tissue and lens are slightly higher in the IMRT plan, although this is clinically satisfactory. The IMRT is sensitive to set up uncertainty and can involve long treatment times in an uncomfortable position.<sup>8</sup> Most recently, helical tomotherapy has shown that it can be used to treat the scalp with tangential beamlets. Despite the concern that the tomotherapy planning system can over estimate the calculated superficial doses for head and neck treatments, this modality eliminates the need for bolus as well as avoiding field matching problems and the need to use of more than one modality.<sup>8,13</sup>

Although electron beams have multiple issues during treatment delivery such as lateral scattering, they have a sharp fall-off of dose and good coverage for skin tumours. Symmetry and flatness of an electron beam depend on beam flattening system design and equipments are used for beam collimation. Electron field uniformity would be defined by the specific set-up which is recommended by the IAEA TRS-398 and AAPM TG-51 protocols in a specified area of the beam at determined depth.<sup>14,15</sup> The reference

depth used for this determination has traditionally been at or close to the depth of maximum dose.<sup>16</sup>

Uniformity across the electron field, which is compulsory for quality assurance, is another statement of symmetry and flatness. It determines dose variation over 80% in a plane, parallel to the surface of the phantom and perpendicular to the central axis in a standard field size at 10-cm depth. This variation in every point of measurement in 10 cm depth is accepted around 3% of measurement in central axis.

We can calculate flatness and symmetry from the following Equation (1)<sup>17</sup>:

$$\begin{aligned} \text{Flatness (\%)} &= D_{\max}/D_{\min} \times 100\% \\ \text{Symmetry (\%)} &= \\ & [D(x, y)]/[D(-x, -y)] \times 100\%. \end{aligned} \quad (1)$$

The purpose of this study was to assess the dosimetry of electron beams when they are applied to scalp in contrast to 3DCRT (photon modality). This was clinically useful because we currently have no IMRT in our centre, and also beneficial to providing a new approach for analysing dose distribution and informing the best way to treat successfully scalp malignancy.

In this study, we measured the beam profile and percentage depth dose (PDD) using GAFCHROMIC® EBT2 films (International Specialty Products, Wayne, NJ, USA) for 6 MeV variation measurements by using abutting non-coplanar electron fields, measured in skin and the influences of bone heterogeneity challenged by, utilising an anthropomorphic phantom (RANDO, Alderson Radiation Therapy phantom).

## METHOD AND MATERIAL

### Calibration and verification

This study analysed Gafchromic® EBT2 films employed for dosimetry goals, which have a low sensitivity to light, independence to energy 100 keV–6 MV. Handling of film was based on the recommendations of the AAPM TG55 report,<sup>14</sup> these films include a yellow dye marker that is known to active a layer that has less

sensitivity to light. Films were analysed by using a colour scanner which is designed to scan colour films in the red, green and blue bands of the visible spectrum. Once a red, green and blue (RGB) scan has been obtained, the user can extract the information from the red colour channel where the active component in EBT2 film produces its maximum response through the RGB mode (in red channel) because the wavelength of scanner is about 632 nm that is well matched to the maximum spectral in EBT2 film. Also for preventing Newton rings occurring, flat board Microtek 9800XL (Microtek lab Inc., Moraine, OH, USA) scanner was utilised. The scanner systems have the advantage of shortening the time to read the film.

Nominally changes between the two sides of film, top and right of each film, lead to create a small cutting or marking the film, based on the company recommendation to achieve a uniform response in scan, during the scan of film.<sup>18</sup>

During work with gafchromic films care has to be taken to avoid fingerprints and dust.

To make a calibration curve, 33 pieces of film were prepared in size of  $1.5 \times 2.0 \text{ cm}^2$  (Figure 1) 24 hours before exposure. Based on ISP protocols<sup>19</sup> scanning process (by Mikroteck scanner) should be done 24 hours after irradiation. Scan of films (tiff image) were analysed with Image J software produced by America's Health Research Centre.<sup>20,21</sup>

In order to determine beam profile and PDD, radiation was measured in a slab phantom, at central axis and with a  $10 \times 10 \text{ cm}$  electron applicator. All results were normalised to 100.

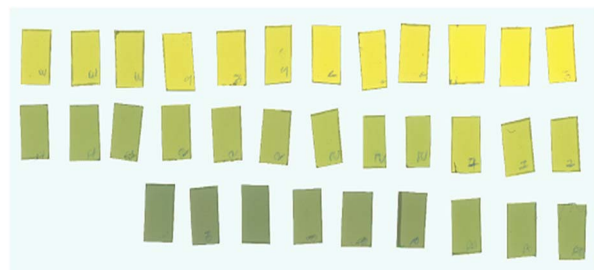


Figure 1. EBT2 films for calibration.



Figure 2. Film for profile and percentage depth dose.

A Varian Clinac 2100C (Varian Medical Industry Palo Alto, CA, USA) as linear accelerator machine was utilised in Imam Khomeini Hospital. The accelerator is capable of generating electron energies in the range of 6, 9, 12, 18 and 20 MeV and photon energies 6 and 18 MV.

The calibration curve was plotted based on the optical density [Equation (2)] and certain step doses were irradiated onto the films (dose steps: 0, 0.5, 1, 2, 3, 5 Gy) (Figure 1).

Other data, including PDD and profile curve dose were attained and then were compared with the calibrated films (Figure 2) and plane parallel chamber (Figure 3).

$$\text{netOD} = OD_{\text{exp}} - OD_{\text{unexp}}$$

$$\text{netOD} = \log_{10} \frac{I_{\text{unexp}} - I_{\text{exp}}}{I_{\text{exp}} - I_{\text{backg}}} \quad (2)$$

Film features include a wide-dose range (0–8 Gy), energy independence, low sensitivity to natural light and high uniformity.<sup>22</sup> These features encouraged us to use Gafchromic® EBT2 films.

Another step was taken to make PDD and profile curves of the 6 MeV electron field using measurements by analysing the pieces of film after irradiation.

A plane parallel chamber was utilised as a reference dosimeter. This type of dosimeter should be used for beam qualities  $R_{50} < 4 \text{ g/cm}^2$  ( $E_0 < 10 \text{ MeV}$ ). The reference point for plane parallel chambers is taken to be on the inner surface of the entrance window, at the centre of the window.<sup>23</sup> Dosimetry was measured at the point of interest (0.5, 1.4, 2.4 cm) in the water phantom. Well-guarded plane parallel ionisation chambers are designed to minimise the scattering



Figure 3. Set up of film to achieve profile and percentage depth dose (energy 6 MeV, Varian Linac accelerator, SSD = 100 cm, FSD = 10 × 10 cm).

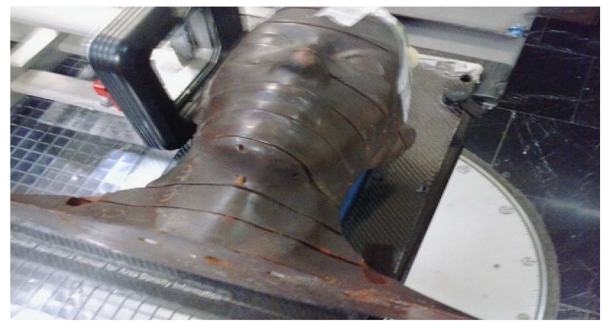


Figure 4. Set up of Rando phantom.

perturbation effect. In addition to this the effective point of measurement is the inner surface of entrance window, at the centre of the window.<sup>23</sup>

### Phantom irradiation

For simulating treatment set up an Alderson Rando phantom (Machlett, Springdale, CA, USA) was utilised, which is tissue equivalent to the human scalp (Figures 3 and 4). Five fields without any gaps between junctions was drawn onto the phantom to cover the whole of the scalp. To avoid field overlap or a gap, every field was modified by gantry, couch angle and shielding. In the temporal lobe region, two lateral fields with a gantry degree 90–270° were used. In the occipital region, a prone position was selected for the phantom with non-coplanar technique (couch 90°). By reducing the number of fields selected, both set up errors and hot or cold spots during transformations was reduced. Points of interests were field's match lines and curvature of scalp.

**RESULTS**

The calibration curve in EBT2 gafchromic films was plotted with two data; dose and optical density. The latter is measured after scanning the irradiated film. Measurements were extracted from the irradiation of 33 piece of films three times to provide a correct statistical measurement [Equation (2)] and at certain doses displayed in Figure 5. Different steps of dose to films produce different optical densities ranged between (0 and 0.3), background irradiation was calculated using non-irradiated films. In order to have a proper utilisation of the calibration curve, data assessed by EXCLE and the following Equation (3) was applied

$$D(\text{cGy}) = 642 \cdot 857 - \left( 714,286 \sqrt{0 \cdot 0000007988 - 0 \cdot 0000028 \times OD} \right) \tag{3}$$

There was an acceptable range between data extracted from films and the chamber. This ensures films are reliable for use in dosimetry. In other words, we can use such films for absolute dosimetry with repetition of film measurements.

According to the graphs<sup>6-8</sup> there are acceptable results between film EBT2 and the plane parallel chamber. In the three depths of measurement there was a negligible difference of about 2%. Conformity and symmetry of Gafchromic® EBT2 had been approved before selecting them for dosimetry in the phantom (Figure 6).

In the second part of this study, we measured the beam dosimetry using five different fields

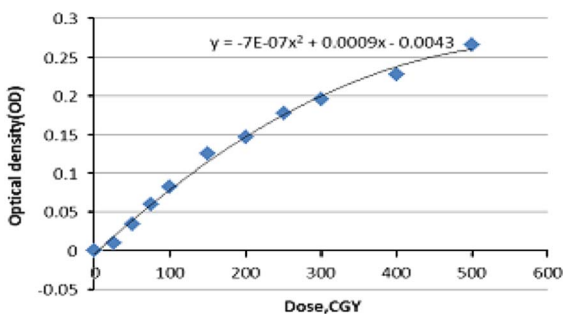


Figure 5. Calibration curve (SSD = 100 cm, field size = 10 × 10 cm gantry rotation = 0).

without using bolus on the phantom, this produced a dose range of 78–97% of maximum dose. There is a prediction of surface phantom dose by using 6 MeV energy. In other words, gafchromic films on the slab phantom had been tested before using anthropomorphic phantom which has shown the surface dose on slab was 50 cGy. So we predicted the surface dose will be in a range of 50 cGy with the time of 100 MU. In the occipital region, because of topographic shape of phantom and type of irradiation the dose was ~78 cGy. Field borders needed shielding to prevent overlap of dose and we found border doses varied sharply (Table 1) and calculated doses were between 74 and 97 cGy, this demonstrates that electron beams produce hotspots and lateral scattering in the field borders (Figures 7 and 8).

In the frontal lobe field, variation of dose is constant and monotonous nearly; the range of variation was around ±6% but in the junctions; there was a conspicuous range of 74–97 cGy.

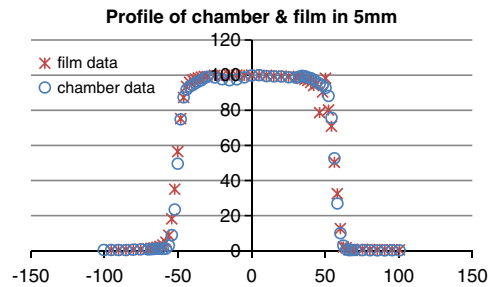


Figure 6. Profile of parallel plane chamber and gafchromic EBT2 (energy: 6 MeV, depth: 5 mm, field size: 10 × 10 cm).

Table 1. Dose variation and pixel values (PV) and optical density (OD) in a part of film in the border

Mean PV	Max PV	Min PV	X (inch)	Y (inch)	OD	Dose (CGy)
53,481	53,481	53,481	0.364	2.64	0.071141	97.22727
52,778	52,778	52,778	0.364	2.773	0.076888	78.15041
54,611	54,611	54,611	0.364	2.871	0.06206	74.68164
54,958	54,958	54,958	0.364	2.978	0.05931	80.42293
54,386	54,386	54,386	0.364	3.084	0.063853	83.11321
54,122	54,122	54,122	0.364	3.182	0.065967	84.89036
53,949	53,949	53,949	0.366	3.298	0.067357	82.50971
54,181	54,181	54,181	0.366	3.387	0.065494	84.14936
54,021	54,021	54,021	0.367	3.511	0.066778	84.5402
53,983	53,983	53,983	0.364	3.618	0.067084	83.15417
54,118	54,118	54,118	0.364	3.724	0.065999	82.80618
54,152	54,152	54,152	0.364	3.822	0.065726	82.27481
54,204	54,204	54,204	0.364	3.938	0.065309	88.80286

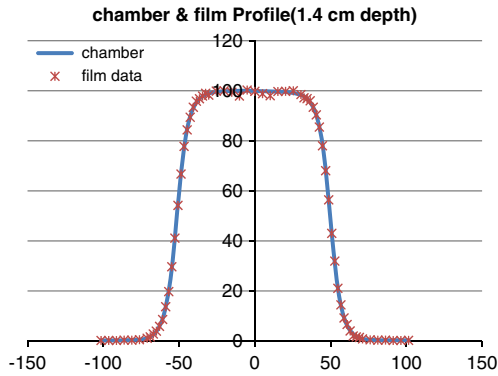


Figure 7. Profile of parallel plane chamber and gafchromic EBT2 (energy: 6 MeV, depth: 14 mm, field size: 10 × 10 cm).

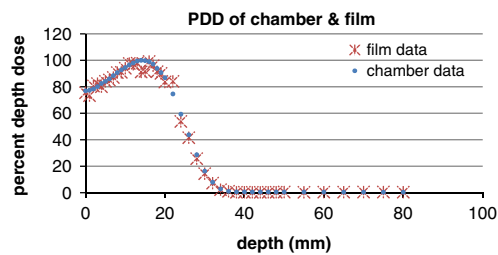


Figure 8. Percentage depth dose (PDD) of parallel plane chamber and gafchromic EBT2 (energy: 6 MeV, field size: 10 × 10 cm).

**DISCUSSION**

In the treatment of the scalp region using electron beams, scalp curvatures lead to an air space between the applicator and the surface of skin, which produces electron lateral scattering, and subsequently we observe a decline in  $D_{max}$  around the treatment field. Another prominent factor that should be considered is the oblique factor which is important when the radiation angle is more than 60°. In this situation, there is a space between the applicator and phantom. It means dose would be increased by increasing the perpendicular line between the applicator and scalp. One point to be highlighted is the scalp tissue heterogeneity which influences the electron dose in the scalp surface.

Heterogeneity of tissue, especially with low density, causes the absence of electron equilibrium which impacts on the dosimetry. In this case, the selection of gafchromic film is a good choice because of its high spatial resolution, flexibility in recording dose and is user friendly.

Electron irradiation demonstrated dose distributions depending on field curvatures and air gap between scalp and the applicator. In other studies, such as in the application of six electron fields with a 3 mm gap between each field, results displayed a variation of ~50–70% despite shifting the fields in the middle of the given total dose.<sup>3</sup> In our technique, dose between field gaps was modified by using 3 mm gaps in the sagittal plane and removing gaps in the coronal plane. Results indicate a 10–50% variation [Equation (1)].

In other techniques, such as using electron and photon beams with or without overlapping there was 80–110 and 85–103% variation in dose in the borders respectively.<sup>4</sup> All techniques mentioned above utilised 6 mm of bolus.

In our study, the dose variation in field junctions when there are no gaps between fields was 74–97% (Table 1). Our methods have the enormous privilege of saving time and reducing errors due to the removal of gaps between treatment fields. In the treatment of scalp lesions, the brain is considered to be an organ at risk (with a maximum tolerance of a TD 55 Gy). A scalp tumour such as a basal cell carcinoma, which requires a treatment dose of 60 Gy, make a demand on a modified technique to decrease the brain dose. In electron beam technique, in order to achieve a rapid fall-off dose to reduce the complication of over irradiating brain tissue and achieve a good coverage of the tumour, requires careful beam positioning. This requires precise dosimetry and planning with good immobilisation. Therefore, electron treatment in scalp malignancy needs further studies.

**CONCLUSION**

Dose uniformity throughout the fields demonstrates scalp treatment using electron beams is a good method for treating cancer. However, hotspots arising in the field borders indicate that electrons display complicated dosimetric behaviour and requires accurate dosimetry before treatment, this can be achieved by using Gafchromic® EBT2 films. In conclusion, electron beams are a good modality for treating one flat field, in the special topography of scalp, whole

scalp treatment requires a precise field matching and dosimetry.

## Acknowledgements

The authors thank the fellow doctoral students for their feedback, cooperation and of course friendship. In addition, the authors express their gratitude to the staff of Cancer Institute of Imam Khomeini Hospital for the last minute favours.

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