Journal of
Applied Sciences

ISSN 1812-5654

ANSInet
an open access publisher
http://ansinet.com

Journal of Applied Sciences 14 (17): 1952-1958, 2014
ISSN 1812-5654 / DOI: 10.3923/jas.2014.1952.1958

Measurement and Comparison of Skin Dose Distribution in Water Phantom Exposed to 6 MV Photon Beam

A. Aydarous
Department of Physics, Faculty of Science, Taif University, Al-Hawiah, Taif, Saudi Arabia

Abstract: The build-up dose in an area like skin is very difficult to determine due to contributions from electron contamination which cannot be accounted for by the ionization chamber. Precise measurements in the build-up region are important to prevent tumors and cervical lymph. The Treatment Planning Systems (TPS) lack dose accuracy in the stated region. This study focuses on utilizing EBT2 Gafchromic Dye films to determine dose in the build-up region from a 6 MV photon beam generated from a VARIAN linear accelerator. This technique was also used to measure the depth-dose profile for each irradiation setting. The measured skin doses were then compared against the predicted values from the TPSs. EBT2 films along a beam axis prove to generate good and continuous sensitometric curves (depending on the scanner resolution) and show better agreement over other irradiation settings when films are at the isocentre or perpendicular to the incoming beam. Good agreements (~3%) in the percentage depth dose, at depths greater than 2 cm, were shown between the TPS, EBT2 and ROOS chambers. At the tail of the curve where the dose is low, the percent dose difference analysis would show higher values (from 8 to 10%). Results also show that in order to obtain very precise measurements, care must be taken during the irradiation and scanning of EBT2 films. Reasons for disagreement between different dosimetric techniques and features of differing scanning systems for analyzing EBT2 films were discussed.

Key words: Skin dose, Gafchromic EBT2 film, build-up dose

INTRODUCTION

Measurement of skin dose is required when dealing with beta rays, electrons and low energy photons. Obtaining accurate dose measurements near the surface of the body is a challenge because biological effects of radiation largely vary with skin depths (Roland *et al*., 2008). In the 59th publication of the International Commission on Radiological Protection (ICRP), the commission identified a depth of 7 mg cm^{-1} as the depth where most of the radiosensitive layer of the skin is located. The ICRP recommended that for routine radiation protection purposes, the skin dose should be evaluated as an average over an area of 1 cm^2 at a depth of 7 mg cm^{-1} (ICRP, 1991; Kwan *et al*., 2008).

In order to measure skin dose by ionization chambers, dose integration is required at each position. This dose integration makes the measurement very time-consuming (Devic *et al*., 2004). High dose gradient areas, such as skin, require a dosimetry technique with a high resolution feature. The parallel plate ionization chamber provides accurate dose measurements but it does not offer high spatial resolution due to the wide diameter of its plates. Extrapolation thermoluminescence dosimeters (TLDs) provide better spatial resolution but require batch calibration and provide only point by point data (O'Shea and McCavana, 2002; Abdelhalim *et al*., 2008). Most surface dose measurements from radio therapeutic machines are derived from the Treatment Planning Systems (TPSs) measurements. TPS data is constructed from CT images. The voxel size of the CT image is larger than skin dimension. This makes it difficult for the TPS to accurately define the skin and consequently, leads to inaccurate quantification of the skin dose (Roland *et al*., 2008). The TPSs used in many radiotherapy departments predict, to certain accuracy, the dose in the build-up region via algorithms. There are some attempts to used Monte Carlo to calculate the dose in the build-up region, however, such methods use some approximations which lead to inaccurate determination of the dose in this region accurately (Roland *et al*., 2008).

Electron contamination plays a major role in the increasing of dose in the build-up region. The electron contamination is generated from the interaction of the high energy photons with the LINAC head, patient and surroundings (Paelinck *et al*., 2005). Precise knowledge of measuring superficial dose or skin dose becomes vital when patients are undergoing external radiotherapy or radiochemotherapy for the head and neck. In radiotherapy treatment, the field size, shape and treatment planning techniques used, play a major role in the magnitude of the skin dose (Paelinck *et al*., 2005). With these challenges, it is difficult to accurately measure the skin dose and the shortage of skin dose data that account for a patient undergoing radiation therapy.

Gafchromic Dye film is capable of measuring surface dose and provides a two-dimensional dose map that cannot be obtained with the ionization chamber or TLD. Both the slimness of Gafchromic film and being tissue equivalence make the film a promising technique for measuring skin dose (Fuss *et al*., 2007; Soares, 2006).

The aim of this study is to investigate the ability of Gafchromic EBT2 films to measure build-up dose in water phantom by using 6 MV high energy photon beams. The EBT2 measurements will be compared with the (ROOS) ionization chamber. These techniques will also be used to measure the depth-dose profile for each irradiation setting. The measured skin doses will then be compared against the predicted values from the TPSs. This study also encourages the validation of 2D dose distributions between the calculated dose and the EBT2 measurements.

MATERIALS AND METHODS

Gafchromic EBT2 films: The EBT2 dosimetry film has been specifically designed for the measurement of absorbed dose in both high-energy photon beams and in regions of steep dose gradients due to their high spatial resolution. The Gafchromic™ dye film, type EBT2, consists of a 30 μm thick (density = 1.2 g cm^{-3}) active dye layer. This active layer is sandwiched between 2 sheets of transparent polyester, layers of 50 and 175 μm thick, respectively (density = 1.35 g cm^{-3}). The total thickness is ~0.285 mm. Numerous improvements have been added to EBT2 films including a yellow marker dye which is incorporated into the active layer in an effort to make the film response independent of small thickness. The EBT2 film is claims to be less sensitive to room light than the original EBT product (ISP, 2010). The EBT2 film has a threshold dose of ~1 cGy but also depends on the reading out system. The Gafchromic dosimetry technique is nearly energy independent from about 50 keV into the MV. In addition, the technique is self-developing, relative ease of use and ease of analyzing data.

EBT2 dose measurements: All measurements were made from the 50 μm sheet side. This means that the effective depth of measurement, scaled by density, is 11.625 g cm^{-2}. When exposed to ionizing radiation, the color of the active layer turns to a shade of green which requires no processing to stabilize. The darkness of the exposed film increases with an increase in dose. The Optical Density (OD) of the film can be related to absorbed dose over a dose range up to ~50 Gy.

These films are insensitive to light and may be handled without the need for a darkroom. By measuring the optical density of the exposed films using densitometers, spectrophotometers, or flatbed scanners, these films can be used directly for dosimetric measurements.

EBT2 films calibration: The film dose response was calibrated for 6 MV photon beam in accordance with recommendations found in the TG-55 document (Niroomand-Rad *et al*., 1998). Two sets of calibrated Gafchromic™ EBT2 films from 2 batches (Lot #: A06221004) were prepared with a size of 2×2 cm. Each film was marked in the corner of the 50 μm side to define its orientation. Films were exposed to a 6 MV photon beam over a dose ranging from 5 to 1000 cGy produced by a Varian Linear accelerator (Linac). The films were placed around the central axis of the beam at the depth of dose maximum (Z_{max} = 1.5 cm). The absorbed dose from the Linac was measured using a calibrated ionization chamber. A 30×30 cm^2 field size at 100 cm Source-surface Distance (SSD) was used for irradiations. A number of tissue-equivalent material (15 cm), placed below film pieces, was used to provide full backscatter.

Scanning protocols: The EBT2 films were analyzed using 4 different scanning systems: A UV-Visible spectrophotometer (JASCO V-670) (UV-Vis), a digital densitometer (Model 07-443), a Epson Expression 10000XL transmission flatbed scanner and a Cannon commercial flatbed scanner (CanoScan LiDE 110). The scanner spectral response should match or come close to the absorbance response of the film in order to obtain best results. Figure 1 illustrates the UV-Vis spectral response of the active layer of EBT2 after exposure to 0.5 and 2.1 Gy from a 6 MV photon beam. The peak absorption of the active component is at about 636 nm with a secondary peak at about 587 nm. The peak of 420 nm results from the presence of the yellow marker dye.

The Epson Expression 10000XL scanner is a transmission color image flatbed scanner with a xenon gas, cold cathode fluorescent lamp and Charged-coupled

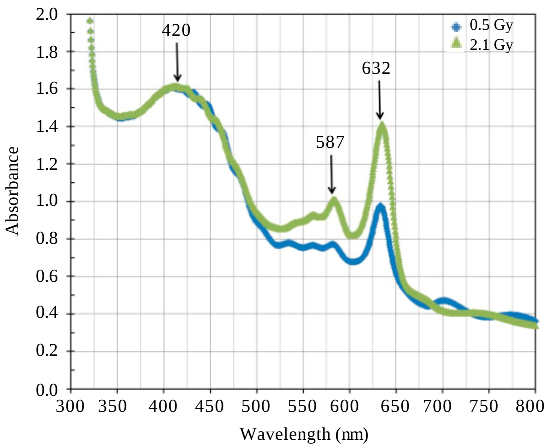

Fig. 1: Absorption spectra of EBT2 film irradiated by 6 MV photon beam for 0.5 and 2.1 Gy

Device (CCD) line sensor. The digital resolution of the Epson scanner is 16-bit per color giving a theoretical minimum detectable transmittance of 1/65535. The scanner's Pixel Value (PV) for each color is converted into an OD value using the following equation:

$$\text{OD} = -\log_{10} (\text{PV}/65535) \qquad (1)$$

This equation gives a maximum optical density of 4.82. A control set of films, not exposed to radiation, were used to monitor any change in the film OD due to temperature and ambient light.

The digital densitometer (Model 37-443) is a compact hand-held unit. It is designed to measure the principle (671 nm) absorption spectrum peak of Gafchromic films. The digital densitometer provides accurate and reproducible readings of optical density for Gafchromic dosimetry and its media can be obtained directly, accurately and reproducibly.

The Cannon flatbed scanner is an inexpensive, commercial scanner. This device is capable of providing a high resolution image, upto 1950 dpi, 8 bit per color. The transmitted raw intensity values were obtained using the scanner software. This device is capable of scanning upto 20 films at the same time which is not possible with other devices like a densitometer and a spectrophotometer. The theoretical minimum detectable transmittance is 1/256 (0.4% transmittance) and the transmittance has a maximum optical density of $\log_{10}$ (1/0.004) = 2.41. The image files produced are analyzed using RADODS software (Aydarous *et al*., 2008).

In order to optimize the evaluation results and minimize the errors, special properties of the film have to be considered, they are as follow:

- Film's orientation has to be fixed and known
- Edges of the scanned area should be avoided
- Time between irradiation and scanning should be constant

ROOS ionization chamber (PTW-Freiburg, 2004): The ROOS ionization chamber is a detector to be used for relative dose measurements in high energy photon and electron fields. The detector is hemispherically shaped, approximately 12 mm in diameter and has a flat bottom for easy positioning. Surface measurements can be performed by taping the detectors to the patient's skin. The *in vivo* semi-conductor probe response may vary with energy, SSD, filed size, wedge filter, incidence angle, dose per pulse, temperature, accumulated dose and patient thickness. These variations may vary from detector to detector, therefore, it is important to calibrate the detector under the conditions of the current clinical application before use.

Treatment planning system: Treatment plans for conformal and IMRT techniques have been simulated for a RANDO phantom using a 3D TPS (CadPlan, Varian). Virtual simulations have been performed using a CT-simulator. The CT scan data and plan parameters were exported in a usual way to the treatment planning system. The treatment plans were delivered on a Varian Clinac 2300 (C/D) linear accelerator, using a 6 MV photon beam. The build-up dose was measured in a regular square, 30×30 cm^2.

RESULTS AND DISCUSSION

Reproducibility and uniformity check: The reproducibility of the irradiation procedure was investigated by exposing 7 EBT2 films to 2.18 Gy photon on different days. This step is important in order to make sure that the irradiation source is stable and the irradiation procedure is consistent. Table 1 presents the optical density of each irradiated film scanned by the Epson scanner at the same settings. The coefficient of variation of the mean optical density is less than 3% which is the same accuracy attained by the ionization chamber. The uncertainty in the measured optical density was evaluated using the Epson scanner for the repeat scanning of uniformly exposed calibration films selected from the red and green color regions (Table 2). A film of 3 Gy was

Table 1: Repeated irradiation of 2.18 Gy photons and read out by the Epson flatbed scanner

Parameters	Values
Dose (Gy)	2.18
Color	Red
Film No.	O.D
1	0.532
2	0.530
3	0.540
4	0.524
5	0.560
Mean	0.537
SD	0.014
CV (%)	2.590

Table 2: Repeated scanning of irradiated EBT2 film using Epson scanner

Parameters	Values			
Dose (Gy)	5			
Color	Red		Green	
Scan No.	O.D	C.V (%)	O.D	C.V (%)
1	1.33	2.50	0.347	0.37
2	1.32	2.46	0.347	0.37
3	1.32	2.43	0.348	0.38
4	1.32	2.48	0.347	0.37
5	1.32	2.58	0.346	0.41
6	1.31	2.45	0.347	0.38
7	1.31	2.48	0.346	0.39
8	1.31	2.51	0.346	0.40
9	1.32	2.41	0.347	0.36
10	1.31	2.39	0.347	0.36
Mean	1.32		0.347	
CV (%)	0.55		0.180	

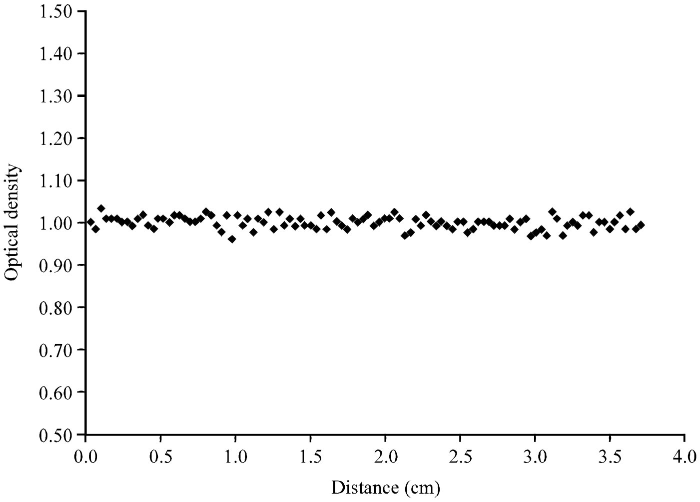

Fig. 2: Uniformity of the Epson CCD, optical density profile across a uniformly exposed EBT2 film

scanned 10 times using a resolution of 300 dpi and scanning area of 1 cm^2. The uncertainty obtained from repeat scans is generally less than 1.0%.

The film uniformity has been evaluated by measuring the OD profile across a uniformly exposed film as shown in Fig. 2. The variation was insignificant and the uncertainty was less than 1.3%. Experiments to investigate a front back flipping effect did not show any change in optical density value and optical density profile.

Sensitometric curve: A calibration curve was used to convert the optical densities to dose. Since determining the dose response of Gafchromic EBT2 is a very critical step in utilizing these films in dose determination, the effect of dose rate, film's position and beam orientation on EBT2, dose response was investigated. A set of 36 EBT2 films (2×2 cm^2) was prepared for this purpose. The irradiation of these films was performed separately and perpendicular to the beam axis. The doses ranged from 2.18 to 10.91 cGy. The dose rate was increased as the dose to the film increases. At each dose point, 2 films were placed at dose maximum (1.5 cm). All films were read out after at least 24 h. This time delayed post-irradiation is necessary for the films to stabilize.

The films were scanned on the Epson Expression 10000XL transmission flatbed scanner at a resolution of 300 dpi in color scale and saved as a TIFF file. Optical density was averaged over about 1×1 cm^2 in the central part of the film. A calibration curve was then constructed using a third-order polynomial fit to the data. Figure 3 shows the dose response of the EBT2 films for red, green and blue colors. The dynamic range for the red and green colors starts from 0.20-10 Gy. The maximum optical density was shown for the blue color. This indicates that the highest sensitivity of the EBT2 film is for the blue color and for a dose range from 0.5-10 cGy. It is likely that the sensitometric curves can be extended beyond 10 Gy. Similarly, the same films were also scanned using the other scanning systems. Figure 4-6 show the dose response of the EBT2 films scanned by the UV-visible spectrophotometer (JASCO V-670) (UV-Vis), digital densitometer (Model 07-443), and Cannon commercial flatbed scanner (CanoScan LiDE 110), respectively.

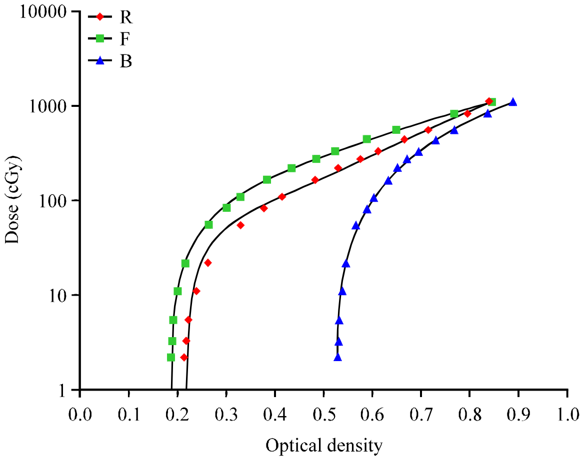

Fig. 3: Calibration curves of EBT2 films irradiated by 6 MV photons and read out using Epson Expression 10000XL scanner

Build-up dose measurements: The dose in the build-up region was investigated using two different methods. In the first method, 33 EBT2 films were placed at different depths of water phantom (surface to about 29 cm). Each film was positioned in the isocentre, perpendicular to the incoming beam. All films were irradiated simultaneously using 6 MV photons, at constant dose rate and given 500 MU at the dose maximum.

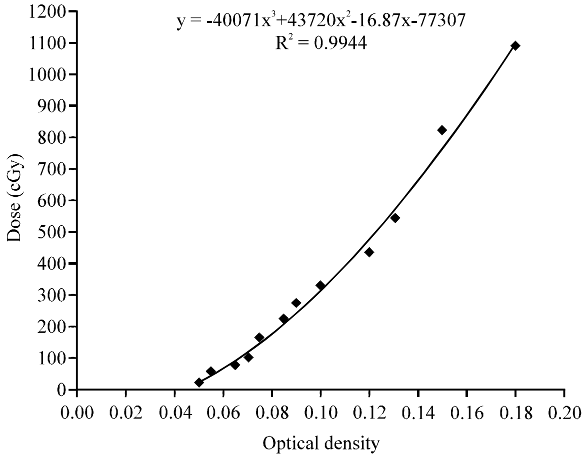

Fig. 4: Calibration curves of EBT2 films read out using Digital Densitometer (Model 07-443)

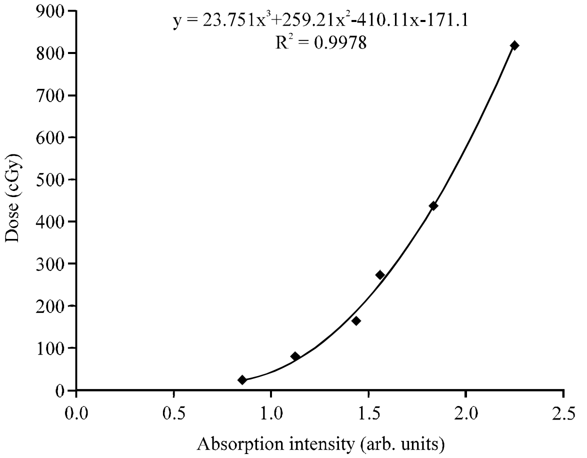

Fig. 5: Calibration curves of EBT2 films read out using UV-Visible spectrophotometer (JASCO V-670) (UV-Vis)

In the second method, a strip of Gafchromic EBT2 film (20×3 cm^2) was irradiated to a 6 MV photon beam and SSD of 100 cm parallel with the central beam axis (Fig. 7). The film was irradiated to 500 MU. The film was positioned in such a way that the edge of the film was perfectly aligned with the edge of the phantom. Measurements were repeated at least 3 times to minimize statistical fluctuations. The films were scanned in the transmission mode using the red banner of thevisible spectrum and a resolution of 72 dpi. Figure 8 shows the Percentage Depth Dose (PDD) for the three techniques. Generally, there is good agreement within 5% for PDD greater than 2 cm.

Comparative relative measurementsbetween the ROOS chamber and the TPS were performed to verify the EBT2 dose measurements. The purpose of this comparison is to investigate how good EBT2 measurements are in measuring the superficial dose (Fig. 9). Reference source not found. shows the percentage depth dose for EBT2 films along beam axis,

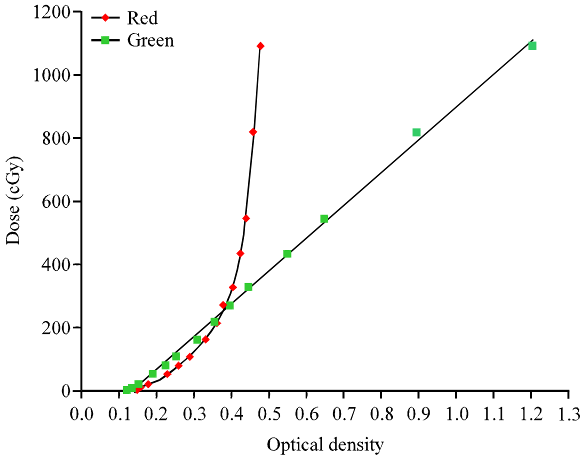

Fig. 6: Calibration curves of EBT2 films read out using Cannon Commercial Flatbed scanner (CanoScan LiDE 110)

Fig. 7: A strip of Gafchromic EBT2 film (20×3 cm^2) irradiated to 500 MU from 6 MV photon beam parallel with the central beam axis

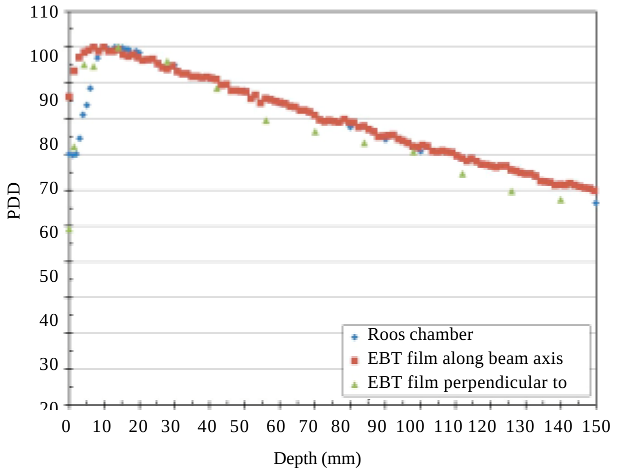

Fig. 8: PDD for ROOS chamber, EBT film along beam axis and EBT film perpendicular to beam axis

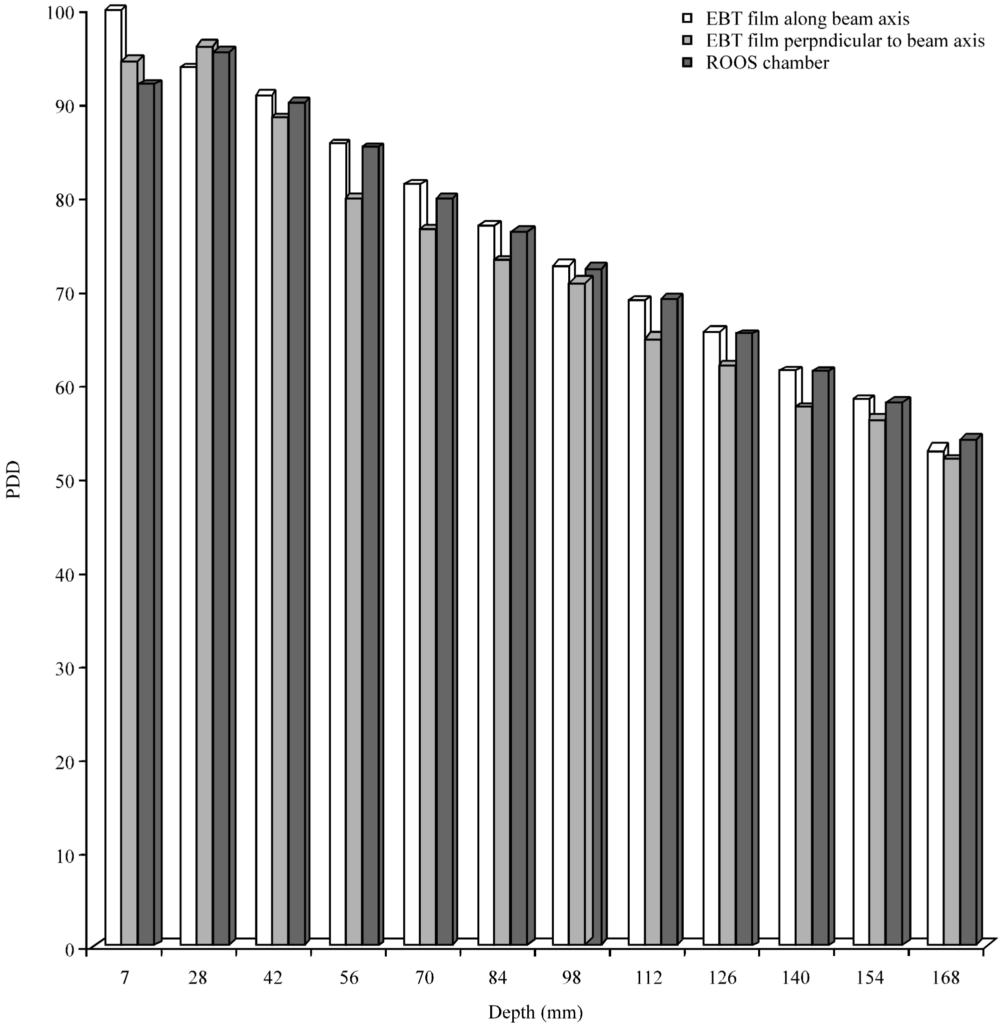

Fig. 9: Comparison of percentage depth dose for selected depths for EBT films along beam axis, EBT film perpendicular to beam axis and ROOS chamber

EBT2 film perpendicular to beam axis and ROOS chamber. In the build-up region (<1.5 cm), EBT film along beam axis shows the highest PPD at about 8% higher than the ROOS chamber. In the deeper depths (>1.5 cm), the ROOS chamber results are the highest. Generally, no significant differences were observed in PDD between the EBT films along beam axis results, the ROOS chamber and the TPS predictions (less than 2%). Placing one strip of EBT2 film along the beam axis minimized any experimental uncertainty that may have occured due to changing films as in the case of using 33 films.

CONCLUSION

The purpose of this study was to measure the build-up dose using EBT2 films through 2 different methods. The percentage depth dose from the TPS prediction, ROOS chamber and EBT2 shows good agreement at depths greater than 2 cm. At the tail of the curve, where the dose is low, the percent dose difference analysis would show higher values (from 8 to 10%). Measurement of dose with EBT2 along beam axis shows good agreement with the ROOS chamber and TPS predictions. The PDD difference found between the EBT2 film along a beam axis and the EBT film perpendicular to a beam axis are within 5%. This is about 2.5% higher than the repeated irradiation measurements. A reason for this disagreement may be attributed to several factors: A scanner non-uniformity effect, the non-uniformity of the EBT2 film and irradiation procedures. It can be concluded that the depth-dose measurement using the method of EBT2 film perpendicular to beam axis is more appropriate and more accurate. The perpendicular method gives more dose points than other methods, depending on the resolution used.

REFERENCES

Abdelhalim, M.A.K., R.O. Al-Darwish and M.S. Al-Ayed, 2008. Assessment of patient doses levels during X-ray diagnostic imaging using TL dosimeters and comparison with local and international levels. Trends Med. Res., 3: 72-81.

Aydarous, A., M.W. Charles and P.J. Darley, 2008. Dose distribution measurements and calculations for dounreay hot particles. Radiat. Prot. Dosimetry, 128: 146-158.

Devic, S., G. Hegyi, T. Vuong, T. Muanza and E.B. Podgorsak, 2004. Comparative skin dose measurement in the treatment of anal canal cancer: Conventional versus conformal therapy. Med. Phys., 31: 1316-1321.

Fuss, M., E. Sturtewagen, C. de Wagter and D. Georg, 2007. Dosimetric characterization of Gafchromic ebt film and its implication on film dosimetry quality assurance. Phys. Med. Biol., 52: 4211-4225.

ICRP, 1991. Biological basis for dose limitation in the skin. ICRP Publication 59, Pergammon Press, UK. http://www.icrp.org/publication.asp?id=ICRP+Publication+59

ISP, 2010. Gafchromic EBT2 dosimetry film manual. White Paper, International Specialty Products, Wayne, New Jersey, USA.

Kwan, I.S., A.B. Rosenfeld, Z. Qi, D. Wilkinson and M.L.F. Lerch *et al*., 2008. Skin dosimetry with new MOSFET detectors. Radiat. Meas., 43: 929-932.

Niroomand-Rad, A., C.R. Blackwell, B.M. Coursey, K.P. Gall and J.M. Galvin *et al*., 1998. Radiochromic film dosimetry: Recommendations of AAPM radiation therapy committee task group 55. Med. Phys., 25: 2039-2154.

O'Shea, E. and P. McCavana, 2002. Review of surface dose detectors in radiotherapy. J. Radiother. Pract., 3: 69-76.

PTW-Freiburg, 2004. User manual *in vivo* semi-conductor probe. PTW Freiburg GmbH, Germany, pp: 24.

Paelinck, L., C. de Wagter, A. van Esch, W. Duthoy, T. Depuydt and W. de Neve, 2005. Comparison of Build-up dose between Elekta and Varian linear accelerators for High-energy photon beams using radiochromic film and clinical implications for IMRT head and neck treatments. Phys. Med. Biol., 50: 413-428.

Roland, T.F., S. Stathakis, R. Ramer and N. Papanikolaou, 2008. Measurement and comparison of skin dose for prostate and head-and-neck patients treated on various IMRT delivery systems. Applied Radiat. Isotopes, 66: 1844-1849.

Soares, C.G., 2006. Radiochromic film dosimetry. Radiat. Meas., 41: S100-S116.