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NOTE

Megavoltage x-ray skin dose variation with an angle using grid carbon fibre couch tops

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Abstract

It is well known that a skin dose from high-energy x-ray radiation varies with the angle of beam incidence or the presence of a radiotherapy linear accelerator couch top material. This note investigates changes produced to the skin dose from a Varian carbon fibre grid couch top at differing angles of incidence for 6 MV x-rays as is often the case clinically. Results have shown that the skin dose can easily be measured using an EBT Gafchromic film whereby the delivered skin dose can be quantified to a high level of spatial resolution, not easily achieved with other skin dose detectors. Results have shown a significant increase in the skin dose specifically at the point of a cross-sectional carbon fibre grid. Values in % of the skin dose increased from approximately 27% (an open area within a 10 cm × 10 cm field) up to 55% (same field size) at the centre of the carbon fibre mesh strip (0° incidence). This is compared to 19% of the skin dose for an open field of a 10 cm × 10 cm beam without the couch material present. At larger angles similar effects occur with values changing from 52% to 75% (60°, 10 cm × 10 cm) in the open area and under the grid, respectively. This produces a wave effect for the skin dose. The average skin dose magnitude increases with the angle of incidence of the beam, ranging from 37.5% to 66% from 0° to 60° (10 × 10 cm), respectively. The symmetric wave nature of the skin dose profile skews to deliver an increased dose on the posterior side of the carbon fibre grid as the angle of incidence increases. Simulated fractional dose delivery on a phantom has shown that over 30 fractions the wave nature of the delivered skin dose is minimized due to the random nature of most patient positioning on the treatment couch. However, some variations are still present as the ratio of the open to grid area is approximately 4:1 and the dose spread is not necessarily completely averaged during a typical fractionated radiotherapy treatment. As such, if the treatment type results in a more rigorously positioned

patient on the treatment couch, the wave nature of skin dose delivery may need to be taken into account.

Introduction

Skin dose can vary quite considerably with the use of high-energy x-ray clinical radiotherapy. Many of these changes can be attributed to variations in electron contamination and phantom scatter. Large variations are observed for changes in beam parameters such as field size, the use of beam modifying devices and the beam angle of incidence (Butson *et al* 1996, Zhu and Palta 1998, Hounsell and Wilkinson 1999, Damrongkijudom *et al* 2007) or for changes in the material which may be in a direct or indirect path of the radiation beam in question. It has been shown that the skin dose can be adequately measured with the EBT Gafchromic, radiochromic film (Devic *et al* 2006).

Radiotherapy couch tops are designed in various ways to produce different characteristics to match certain treatment criteria. Although couch tops are made to be relatively x-ray translucent, they still affect the x-ray characteristics even at high energies (McCormack *et al* 2005, Higgins *et al* 2001, Poppe *et al* 2007). The type investigated in this note is the Varian grid carbon fibre Exact™ couch top insert. This couch top's design is intended to reduce the delivered dose to a patient's skin when posterior beams are used, and to allow visual alignment of patients from a posterior view. The carbon fibre grid accounts for approximately 20% of its surface areas and as such is relatively open. It also has a thin Mylar sheet over it for patient comfort. One of the major parameters affecting the skin dose is the amount of material placed in the beams path which increases photon scatter. In essence the areas covered by the carbon fibre material will increase the dose delivered directly behind it whilst the areas with just Mylar will have a reduced delivered dose. Varying the beam angle of incidence will inevitably change the way the skin dose is delivered through the couch top material. The authors investigated a similar carbon fibre and tennis string couch tops in 2002 (Butson *et al* 2002) at normal incidence and found significant variations in the skin dose. This note furthers this work and investigates the skin dose delivered through the Varian Exact™ carbon fibre couch top and its variability with an angle of beam incidence. In this note we define the skin dose as a dose measured at an effective depth of 0.15 mm. This is also the effective point of measurement for the EBT Gafchromic film. We also briefly investigated the effects of fractionated treatment on skin dose delivery through the treatment couch.

Materials and methods

Measurements were made using a Varian 2100C linear accelerator, 6 MV x-rays and a fixed SSD of 100 cm. Similar patterns in skin dose delivery are expected at other SSDs although it is acknowledged that the magnitude will change mainly due to effects of electron contamination contributions. The Varian grid carbon fibre insert is constructed using a carbon fibre square grid, with dimensions of 17 mm^2. The ribbing is 1.8 mm in width and 3 mm thick. A 0.62 mm thick Mylar sheet is placed over the ribbing for patient comfort.

Point dose measurements were performed using an Attix parallel plate ionization chamber (Gerbi 1993) with Rawlinson corrections applied (Rawlinson 1992) for comparison to EBT Gafchromic film dose assessment (Butson *et al* 2005). The Attix chamber measurements were made with half a layer of the EBT Gafchromic film over the active volume to simulate the same effective depth of measurement as the EBT for comparison. The profile and two-dimensional map measurements were made using the EBT Gafchromic film. This was performed by placing the detectors on a solid water slab phantom (Constantinou *et al* 1982) (30 cm × 30 cm × 30 cm) during irradiation. The grid couch top was placed over the detectors for the analysis of the dose delivered through its material. Measurements of the dose for 6 MV x-rays were performed with field sizes ranging from 5 cm × 5 cm up to 40 cm × 40 cm. The beam angle of incidence was varied from 0° to 60° in steps of 15°. The results are quoted as percentages of the maximum dose delivered at Dmax.

The EBT Gafchromic film (ISP Technologies Inc., batch number 35322-0031) was used and handled as outlined in TG-55 (Niroomand-Rad *et al* 1998). During storage and film analysis the temperatures were kept at 22 °C ± 4 °C, thus reducing the effects of temperature-dependent evolution of the absorption spectra of the film (Meigooni *et al* 1996). The EBT Gafchromic film is constructed with multiple layers of active polymer and polyester protective coatings, which allow the film to be easily handled and minimize the effects from ultraviolet exposure (Butson *et al* 2003, 2004). The effective atomic number of the EBT film is $Z_{\text{eff}} = 6.98$ (ISP Corp. 2007) compared to water $Z_{\text{eff}} = 7.3$, a comparatively close match compared to other radiochromic film types and radiographic film. It provides a low-energy dependence (Butson *et al* 2006) and has an overall water equivalent thickness of approximately 300 μm, thus making the effective depth of measurement 0.15 mm. All films were analysed using a PC desktop scanner and ImageJ software on a PC workstation for at least 24 h after irradiation to minimize effects from post-irradiation colouration (Cheung *et al* 2005). The scanner used was an Epson Perfection V700 photo, dual lens system desktop scanner using a scanning resolution of 150 pixels per inch. The images produced were 24 bit RGB colour images. These images were analysed with the full RGB components (Butson *et al* 2005). Net reflective optical densities (RODs) (film fog levels were subtracted from the results) for all films were calculated to find the dose delivered to the film. The net reflective optical density was converted into dose measurements using a second-order polynomial calibration equation. Calibrations of the Gafchromic film were performed in standard conditions (100 cm SSD, 10 cm × 10 cm field size) using doses ranging from 0 Gy to 3 Gy in 0.25 Gy steps. Results are calculated by comparing experimental reflective optical densities with the calibration optical densities. This method produces an uncertainty of the measured dose of ±4% (2SD) in the range of doses measured.

Results and discussion

Figure 1 shows percentage skin dose profiles measured across a 10 cm × 10 cm x-ray beam which is incident at angles of 0°, 30°, 45° and 60°. Figure 1(b) shows the skin dose profiles expanded for clarity of the magnitude and shape of skin dose deposition. Results show a significant variation in the skin dose depending on the position under the grid couch top material. A similar pattern is seen (although different in magnitude) for all field sizes ranging from 5 cm × 5 cm up to 40 cm × 40 cm as shown in figure 2. A wave-like dose profile is produced whereby a higher dose is delivered directly under the carbon fibre material compared to the open area where only the Mylar sheeting interacts with the incident beam. For the 0° beam at a 10 cm × 10 cm field size, the peak skin dose was measured as 55% where as the minimum or trough dose was 27%. When these values are averaged across the dose profile an average value of 37.5% of the skin dose is found. These min/max values are 35% and 60% for 30° incidence, 42% and 65% for 45° and 52% and 70% for 60° incidence, respectively, at a 10 cm × 10 cm field size. As the angle of incidence increases the dose profile length

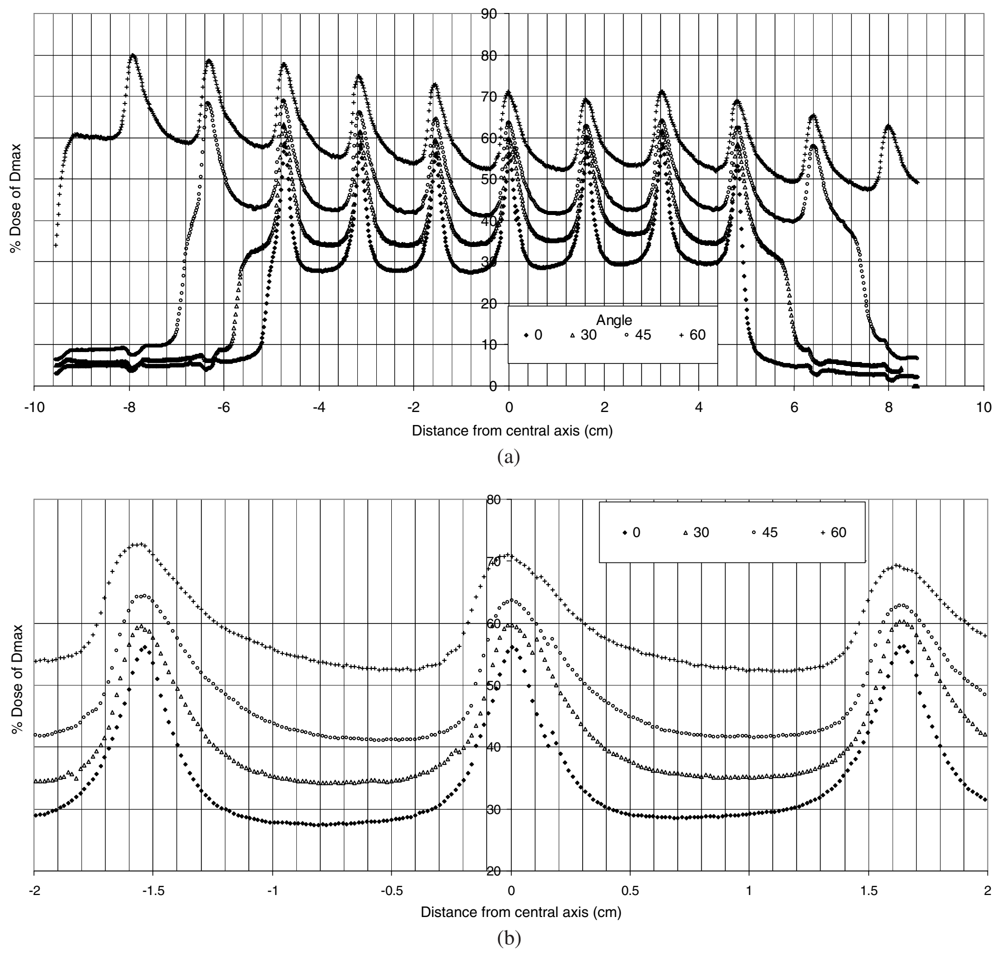

Figure 1. Skin dose profile for a 10 cm × 10 cm 6 MV x-ray underneath a Varian grid carbon fibre couch top at various angles of beam incidence. Complete profiles shown in (a) with a magnified section to highlight the shape of the skin dose deposition shown in (b).

increases due to the geometric projection of a 10 cm × 10 cm field size on the phantom at a different angle of incidence. This relationship can be expressed via the geometry with an expanding profile length proportional to the angle of incidence using a sine relationship. As such the field widths become 10 cm, 12 cm, 15 cm and 20 cm, respectively, for 0°, 30°, 45° and 60° incidence. Of interest in the peripheral regions is the slightly reduced skin dose under the carbon fibre grid which is a result of attenuation of electron contamination at this site causing reduced dose deposition. This can be seen in figure 1(a) at approximately −8 cm distance for example. Closer examination of the skin dose profiles parallel to the angular movement reveals a reduction in magnitude of percentage skin dose as the distance increases from the source and vice versa. For example, using the 60° beam, the peak dose closest to the source is approximately 80% whereas the furthest peak dose measured is approximately 64%. This is due to the combination of the inverse square effect on radiation as well as changing characteristics of electron contamination production and deposition. Another interesting effect seen as the angle of incidence increases is the skewing of the peak skin dose symmetry away

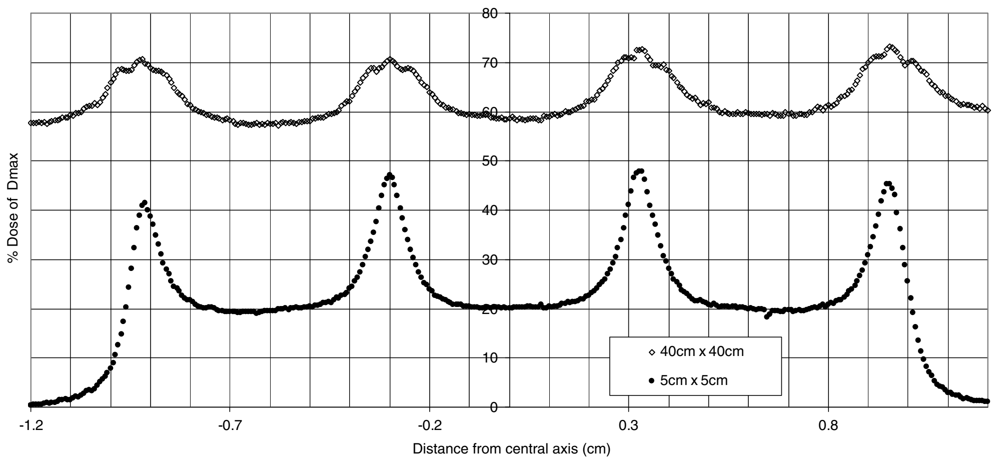

Figure 2. Skin dose profile for a 5 cm × 5 cm and 40 cm × 40 cm field at 0° incidence to show the variation in magnitude of the wave pattern and also its similar nature.

Table 1. Comparison of the skin dose from the grid carbon fibre couch top for a 6 MV x-ray energy with varying field sizes at a 0° angle of incidence.

Field size (cm × cm)	Open field (Attix) (%)	Couch top (skin dose at 0.15 mm depth) Trough (%)	Peak (%)	Average (%)	Average (Attix) (%)
5	12 ± 1	19 ± 3	47 ± 4	30 ± 2	32 ± 2
10	19 ± 1	27 ± 4	55 ± 4	38 ± 2	36 ± 2
20	31 ± 1	40 ± 4	66 ± 4	49 ± 2	48 ± 2
30	41 ± 1	51 ± 4	74 ± 4	60 ± 3	58 ± 2
40	45 ± 1	58 ± 4	81 ± 3	64 ± 3	62 ± 2

from the beam source. Instead of symmetric peaks as seen for the 0° incident beam, an increased dose deposition occurs on the 'exit' side of the carbon fibre material. Obviously as the angle of incidence increases the electrons produced within the 1.8 mm wide carbon fibre grid are scattered beyond their production site downstream and deposited along the skin surface on the exit side. This effect is of course enhanced as the angle increases.

Tables 1 and 2 show the results for trough, peak and average skin doses for field sizes ranging from 5 cm × 5 cm up to 40 cm × 40 cm at 0° as well as with varying angles of incidence. As can be seen, the field size increases the skin dose generally as an average as well as both trough and peak values. Also shown is the skin dose measured with an Attix chamber at the central axis for an open beam and with the couch top material. The average skin dose using EBT estimates the skin dose using the entire field at each angle of incidence. Average dose results from EBT measurements become larger than the Attix chamber results as the angle increases, e.g. by 1% to 4% of Dmax using a field size of 10 cm × 10 cm. This is assumed to be due to a proportionately higher percentage of skin dose delivered at SSDs closer to the treatment head.

Figure 3 shows an example of a profile from a randomly positioned skin dose pattern delivered to a phantom using a 30 fraction treatment to simulate the effect on patients from the grid carbon fibre couch top. In our institution the grid top is mainly used for chest or abdominal

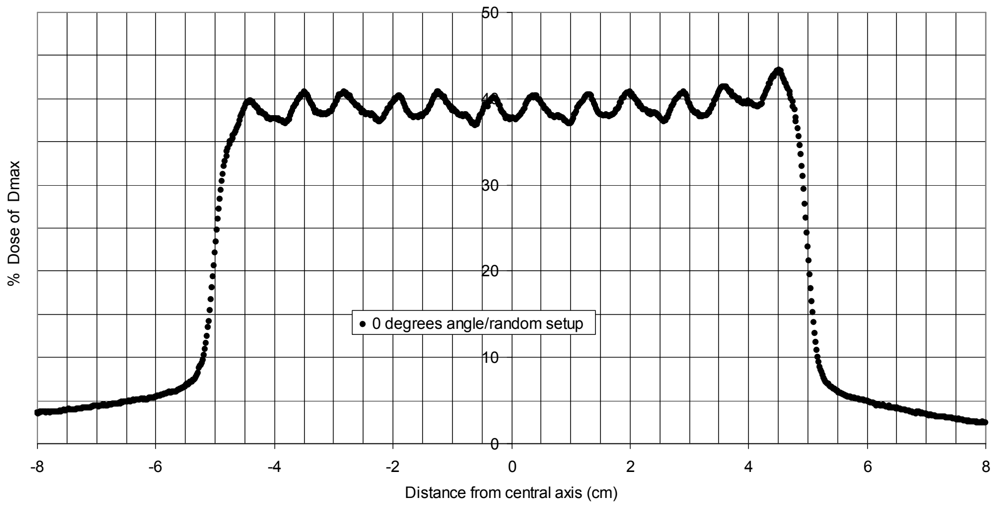

Figure 3. An example of fractionated skin dose delivery through the Varian grid carbon fibre couch top at a 0° angle of incidence. Thirty fractions were delivered with the film positioned randomly underneath the couch each time.

Table 2. Comparison of the average skin dose with a field size and angle of incidence at a 6 MV x-ray energy.

Angle	Field size (cm × cm)					
(°)	5	10	20	30	40	(Attix Avg (10 × 10))
0	30 ± 2	38 ± 2	49 ± 2	60 ± 3	64 ± 3	36 ± 2
15	33 ± 2	41 ± 2	53 ± 2	63 ± 2	68 ± 3	38 ± 2
30	37 ± 2	44 ± 2	58 ± 4	67 ± 3	73 ± 3	41 ± 2
45	44 ± 3	52 ± 3	66 ± 4	73 ± 4	80 ± 3	49 ± 2
60	57 ± 4	66 ± 3	77 ± 4	84 ± 5	89 ± 4	62 ± 2

treatments where the patients initially position themselves on the couch before alignment. In this way, their position relative to the grid pattern is often randomly chosen. Clinically there is a minimal rotational variation in setup as the patient is normally aligned ‘straight’ on the couch for reproducible alignment. As such the movements described are normally translational rather than rotational variations. Results show that the wave effect is removed substantially by the random nature of the positioning over the 30 fractions of dose. The variations are however not totally removed. This test was performed 10 times with variations similar to figure 3 seen each time. The average minimum to maximum skin dose variation (between troughs and peaks) over the ten measurements was found to be 5% ± 2% (1SD) for our randomly positioned couch top at 0° incidence, as compared to 28% for a single irradiation. The average skin dose delivered from our random experiment using a 10 cm × 10 cm field at 0° incidence was measured as 39% ± 4% as compared to 37.5% for the single field using the same configuration. With the grid size of the couch top in question, approximately 80% of the area is open and 20% (4:1 ratio) represents the carbon fibre material, thus multiple fractions are required to spread the dose evenly. If however the patients are positioned more accurately with the use of some holding device such as a head mask, the patient’s skin may align itself on a daily basis with the carbon fibre grid and produce a skin dose accumulative effect. A similar effect may be seen for smaller fraction regimens. This may need to be taken into account in a clinical environment.

Conclusion

The Gafchromic EBT film has adequately measured the skin dose and highlighted the effects of the beam angle incidence on the skin dose for a grid carbon fibre-type treatment couch. An increase in the angle of incidence increased the skin dose with a wave-type nature in the dose deposition. Phantom results have shown that the wave nature of skin dose delivery with this type of couch is minimized through a fractionated treatment, where random patient positioning allows the skin dose waves to average out over a course of treatment, but may not entirely remove the dose peaks.

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References

Butson M J, Cheung T, Yu P K and Webb B 2002 Variations in skin dose associated with linac bed material at 6 MV x-ray energy *Phys. Med. Biol.* **47** N25–30

Butson M J, Cheung T and Yu K N 2004 Radiochromic film: the new x-ray dosimetry and imaging tool *Australas. Phys. Eng. Sci. Med.* **27** 230

Butson M J, Cheung T and Yu K N 2005 Absorption spectra variations of EBT radiochromic film from radiation exposure *Phys. Med. Biol.* **50** N135–40

Butson M J, Cheung T and Yu K N 2006 Weak energy dependence of EBT Gafchromic film dose response in the 50 kVp–10 MVp X-ray range *Appl. Radiat. Isot.* **64** 60–2

Butson M, Mathur J, Perez M and Metcalfe P 1996 6 MV x-ray dose in the build up region: empirical model and the incident angle effect *Australas. Phys. Eng. Sci. Med.* **19** 74–82

Butson M J, Yu K N, Cheung T and Metcalfe P E 2003 Radiochromic film for medical radiation dosimetry *Mater. Sci. Eng.* R **41** 61–120

Cheung T, Butson M J and Yu P K 2005 Post-irradiation colouration of Gafchromic EBT radiochromic film *Phys. Med. Biol.* **50** N281–5

Constantinou C, Attix F H and Paliwal B R 1982 A solid water phantom material for radiotherapy x-ray and gamma ray beam ray calculations *Med. Phys.* **9** 436–41

Damrongkijudom N, Butson M and Rosenfeld A 2007 Extrapolated surface dose measurements using a NdFeB magnetic deflector for 6 MV x-ray beams *Australas. Phys. Eng. Sci. Med.* **30** 46–51

Devic S, Seuntjens J, Abdel-Rahman W, Evans M, Olivares M, Podgorsak E B, Vuong T and Soares C G 2006 Accurate skin dose measurements using radiochromic film in clinical applications *Med. Phys.* **33** 1116–24

Gerbi B J 1993 The response characteristics of a newly designed plane-parallel ionization chamber in high-energy photon and electron beams *Med. Phys.* **20** 1411–5

Higgins D M, Whitehurst P and Morgan A M 2001 The effect of carbon fiber couch inserts on surface dose with beam size variation *Med. Dosim.* **26** 251–4

Hounsell A R and Wilkinson J M 1999 Electron contamination and build-up doses in conformal radiotherapy fields *Phys. Med. Biol.* **44** 43–55

ISP Corp. 2007 www.ispcorp.com

McCormack S, Diffey J and Morgan A 2005 The effect of gantry angle on megavoltage photon beam attenuation by a carbon fiber couch insert *Med. Phys.* **32** 483–7

Meigooni A, Sanders M, Ibbott G and Szeglin S 1996 Dosimetric characteristics of an improved radiochromic film *Med. Phys.* **23** 1883–8

Niroomand-Rad A, Blackwell C, Coursey B, Gall K, Galvin J, McLaughlin W, Meigooni A, Nath R, Rodgers J and Soares C 1998 Radiochromic film dosimetry: Recommendation of AAPM radiation therapy task group 55 *Med. Phys.* **25** 2093–115

Poppe B, Chofor N, Rühmann A, Kunth W, Djouguela A, Kollhoff R and Willborn K C 2007 The effect of a carbon-fiber couch on the depth-dose curves and transmission properties for megavoltage photon beams *Strahlenther. Onkol.* **183** 43–8

Rawlinson J A 1992 Design of parallel plate ion chambers for build up measurements in megavoltage photon beams *Med. Phys.* **19** 641–8

Zhu T C and Palta J R 1998 Electron contamination in 8 and 18 MV photon beams *Med. Phys.* **25** 12–9