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NOTE

Measurement of effects of nasal and facial shields on delivered radiation dose for superficial x-ray treatments

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Abstract
Kilovoltage x-ray beams are used for the treatment of facial cancers when located on the patient's skin or subcutaneous tissue. This is of course due to the sharp depth dose characteristics of these beams delivering much lower doses at depth, than high energy x-ray beams. When treatment is performed, lead shields are often used within the nasal passage, or behind the lips and ears. These shields affect the backscattering patterns of the x-ray beams producing perturbations to upstream dose thus reducing delivered dose to the tumour. Experimental results using radiochromic films have shown that up to 10.5% ± 1.9% reduction in tumour dose can occur for field sizes less than 5 cm circle diameter for x-ray beams of 50 to 150 kVp. These results were confirmed using EGSnrc Monte Carlo techniques. Clinically more than 70% of treatments used fields of diameters less than 3 cm where the reductions were up to 6% ± 1.3%. Using a 1 cm diameter field, which can be used for skin cancer treatment on the nose, reductions up to 2.5% ± 1.3% were seen. Thus corrections need to be applied for dose calculations when underlying lead shields are used clinically in kilovoltage x-rays. The size of the reduction was also found to be dependent on the depth of the shield which will normally clinically vary from approximately 0.5 cm for nasal shields or behind eye lobes and up to approximately 1 cm for lips or cheek areas. We recommend that clinics utilize data for corrections to delivered dose in kilovoltage x-ray beams when lead shields are used in nasal passages, behind lips or behind ears for dose reduction. This can be easily and accurately measured with EBT2 Gafchromic film.

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Introduction

Dose delivered using a kilovoltage energy x-rays beam comprises a large quantity of backscatter radiation (Kim *et al* 2010, Das and Chopra 1995, Ma and Seuntjens 1999). These values calculated for our clinical x-ray beams of field sizes 10 cm diameter were found to be 20%, 26%, 32%, 36%, 37%, 39% and 33% for 50 kVp, 75 kVp, 100 kVp, 125 kVp, 150 kVp, 200 kVp, 250 kVp beams, respectively (IPEMB 1996, Aukett *et al* 2001). As such, this represents a significant quantity of the beam's dose. This value of dose deposition is subsequently dependent on the material directly behind the tissue in question. Thus, if a lead shield is used during superficial and orthovoltage treatment, these quantities may be affected causing differences in delivered dose to the tumour in question.

Lead is well known to absorb both forward and backscattered x-rays and has the potential to reduce the dose delivered to an area directly above it in kilovoltage x-rays (Saiful Huq *et al* 1992, Lanzon and Sorell 1993, Hill *et al* 2007). As such, when a lead shield is used to reduce dose delivered to a region at depth, there is also a potential to reduce dose to the tumour as well.

Monte Carlo modelling by Hill *et al* (2007) has shown that this effect can be both energy and field size dependent. Results have shown that for larger field sizes, e.g. 8 cm circular field, the magnitude of this reduction at a position 0.5 cm in front of the shielding can be reduced by up to 14% at 100 kVp. Clinically, this may relate to a treatment such as an ear with shielding placed directly behind it. Other smaller field sizes also produce reductions in Monte Carlo modelled dose such as a 2 cm diameter field at 0.5 cm distance with a 135 kVp beam producing a 2% reduction in calculated dose. Whilst Monte Carlo modelling can provide an accurate assessment of lead shielding effects, it is a complex task to set up the necessary spectral and computational models required to simulate clinical beams.

A simple and effective method for measurement of dose reductions can be performed utilizing EBT2 Gafchromic film whereby the clinical medical physicist can measure and calculate dose reductions caused by lead shields for their clinics. This note utilizes this technique and shows values measured for dose reductions caused by lead shields located at depths of 0.5 and 1 cm for x-ray energies from 50 to 150 kVp compared to Monte Carlo modelled results.

Materials and methods

A Gulmay[4] D3300 orthovoltage machine was used to deliver x-ray exposures, at 50, 75, 100, 125 and 150 kVp energies. The given radiation exposure levels are based on absorbed dose to water calibrations performed with a Farmer thimble-type ionization chamber according to the IPEMB protocol for kilovoltage x-rays (IPEMB 1996, Aukett *et al* 2001). The phantom material used was an RMI[5] solid water phantom (Constantinou *et al* 1982) of dimensions 30 cm × 30 cm × 30 cm. Hill *et al* (2005) examined the radiation absorption equivalency of RMI solid water to water and found a match within 1% over the energy range 75–300 kVp. Ma and Seuntjens (1999) also highlighted the fact that tissue and water do not deviate significantly (less than 1%) in their mass energy absorption coefficients. Thus solid water can provide an adequate simulation of tissue. 0.5 cm thick lead sheets were introduced into the solid water phantom at depths of 0.5 and 1 cm to simulate the positioning of lead shields behind a treatment site like a lip, ear or the nose ala. This is shown in figure 1. Thus,

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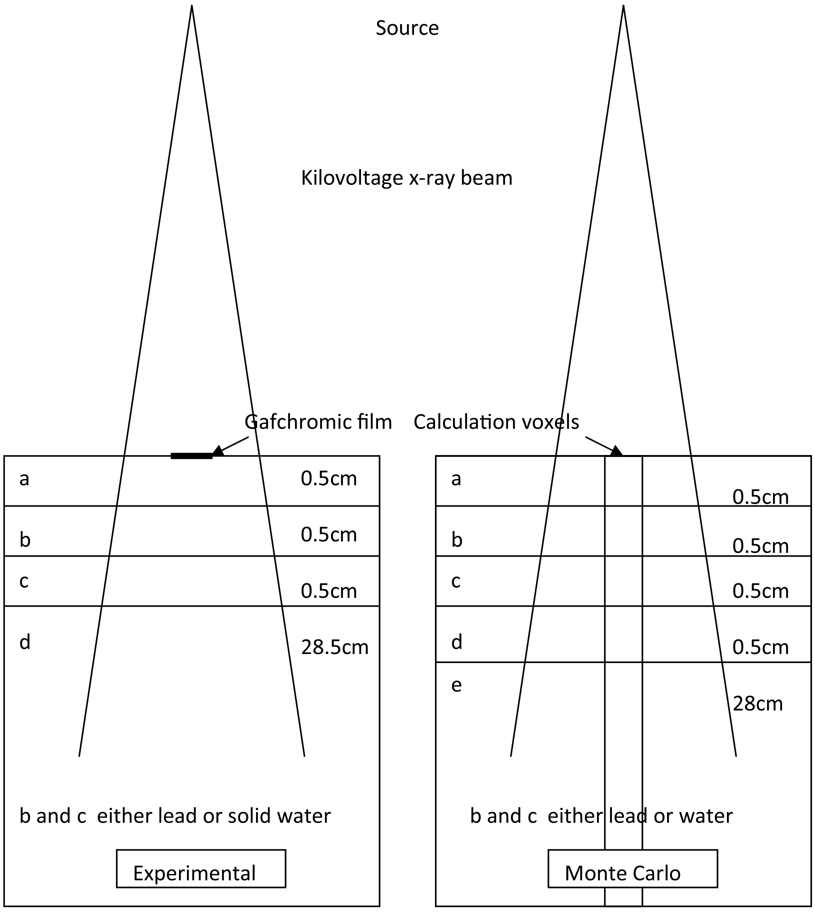

Figure 1. Experimental and Monte Carlo setup comparison.

either region b or c could be replaced by lead for each experiment type with other regions kept as solid water. The depths of 0.5 and 1 cm were chosen following the clinical evaluation of lip, ear and ala thicknesses. Comparisons were made for dose measured at the surface, with and without the lead shield in position. The ratio defines the change in delivered dose caused by the shield. The effects of lead shields were tested using EBT2 Gafchromic film for sizes ranging from 1 cm diameter to 5 cm diameter for x-ray energies ranging from 50 to 150 kVp in 25 kVp steps.

EBT2 Gafchromic film was used to measure changes in dose at the phantom surface (Butson *et al* 2007, Nakano *et al* 2012) caused by the effects of lead shields at depths of 0.5 and 1 cm. EBT2 Gafchromic was used and handled as outlined in TG-55 (Niroomand-Rad *et al* 1998) and the Medical Radiation dosimetry with radiochromic film report series (Butson *et al* 2003). EBT2 provides a low-energy-dependent measurement (Arjomandy *et al* 2010, Cheung *et al* 2006, Butson *et al* 2010b) and will thus have a minimal effect from spectral changes caused by the lead shields. This is unlike other kilovoltage designed Gafchromic film where their spectral sensitivity has been enhanced at these lower energies (Cheung *et al* 2004). Film pieces used were 3 cm × 3 cm. All films were analysed using a PC desktop scanner and Image J software on a PC workstation at least 24 h after irradiation to minimize effects from post-irradiation colouration (Cheung *et al* 2005, Devic 2011). The films when not in use are kept out of fluorescent and solar light sources to reduce effects from UV radiation (Paelinck *et al* 2007, Butson *et al* 2010a). The scanner used was an Epson Perfection V700 photo, dual lens system desktop scanner using a scanning resolution of 150 pixels per inch. No software corrections were used for analysis. The images produced were 24 bit RGB colour images. The films were examined in reflectance mode with a matt white backing paper to minimize the scanner nonuniformity and improve the accuracy (Butson *et al* 2011). In reflectance mode, reflective optical densities (RODs) for all films were calculated to evaluate the uniformity response in landscape and portrait directions. ROD is defined as

$$\mathrm{ROD} = \log(65536/P_t), \tag{1}$$

where P_t is the pixel value of the reflected intensity through the EBT2 film.

The films when scanned were always positioned in the same manner to eliminate differences in results caused by film polarization effects (Butson *et al* 2006, 2009, Desroches *et al* 2010). For data analysis the outer 1 cm edge of the scanned film results was removed. This was performed to minimize any effects on scanner results from film edges or cutting damage (Yu *et al* 2006). Results given are the average for five scans of each film piece. Experiments were repeated five times for analysis using different films with results shown as the average of five experiments. Using these techniques a measurement accuracy of ± 3% (2SD) could be achieved at kilovoltage x-ray energies.

Results have also been compared to Monte Carlo modelling (Rogers 2006, Verhaegen and Seuntjens 2003, Rogers *et al* 2000, Kawrakow 2000). The Electron Gamma Shower (EGSnrc) version 4.2 has been utilized to simulate kilovoltage x-ray beams on a water phantom which can also have 0.5 cm lead shields positioned at depths of 0.5 and 1 cm (i.e. either region b or c in figure 1). All other regions were simulated as water. The DOSRZ code was used to calculate the dose delivered at x-ray energies of 50, 75, 100, 125 and 150 kVp which matched our clinical x-ray beams (Poludniowski *et al* 2009). Photon and electron cutoff parameters were set to PCUT = 0.002 MeV and ECUT = 0.521 MeV for all calculations. The kilovoltage x-ray beam spectrums were calculated using the XRAYBEAM code, based on an algorithm determined by Birch and Marshall (1979) and the work by Poludniowski *et al* (2009). Utilizing the input spectrums determined, EGSnrc depth dose simulations were performed and spectra slightly modified until results were found to match measured depth dose to 15 cm depth within an accuracy of 2% at all depths. Cylindrical coordinates were used with the inner cylinder radius of 0.5 cm. This allowed for simulations of field sizes down to 1 cm diameter to be performed. The thickness of each cylinder was 1 mm within the first 2 cm followed by 5 mm thickness for the next 28 cm. 500 million histories were performed for each simulation. To simulate the effects of lead shields at depth (Ali and Rogers 2008, Verhaegen 2002), voxels at a depth of either 5 to 10 mm or from 10 to 15 mm were changed to lead and the simulations repeated. This was equivalent to a lead shield placed at a depth of 0.5 or 1 cm below the water level. Measurements and simulations were performed for circular field sizes ranging from 1 cm diameter up to 5 cm diameter. Comparisons were made in surface dose for water only and lead shield in place to compare clinical Dmax doses.

Results and discussion

Table 1 gives results for normalized dose at the surface measured when the lead shield is placed behind the field in question at a depth of 0.5 cm as measured with EBT2 Gafchromic film. This depth relates to the average minimal thickness of the side of the nose before the nostril cavity (ala), a lip or an ear lobe where lead shields are commonly used for kilovoltage

Table 1. EBT2 Gafchromic film, clinically measured results for 0.5 cm depth lead shields. Ratio of surface dose with lead at 0.5 cm compared to water.

Field size	x-ray beam energy (kVp)				
Circle (cm)	50	75	100	125	150
1	0.977 ± 0.017	0.976 ± 0.013	0.979 ± 0.016	0.988 ± 0.013	0.995 ± 0.018
2	0.968 ± 0.016	0.965 ± 0.013	0.963 ± 0.017	0.956 ± 0.013	0.959 ± 0.019
3	0.956 ± 0.014	0.954 ± 0.012	0.944 ± 0.016	0.940 ± 0.014	0.955 ± 0.017
4	0.942 ± 0.015	0.942 ± 0.013	0.921 ± 0.016	0.922 ± 0.013	0.942 ± 0.016
5	0.921 ± 0.016	0.922 ± 0.014	0.902 ± 0.017	0.896 ± 0.014	0.922 ± 0.015

Table 2. Monte Carlo simulation results for 0.5 cm depth lead shields. Ratio of surface dose with lead at 0.5 cm compared to water. 500 million histories.

Field size	x-ray beam energy (kVp)				
Circle (cm)	50	75	100	125	150
1	0.976 ± 0.009	0.978 ± 0.008	0.980 ± 0.009	0.983 ± 0.008	0.987 ± 0.008
2	0.967 ± 0.008	0.963 ± 0.007	0.959 ± 0.007	0.960 ± 0.006	0.968 ± 0.009
3	0.955 ± 0.009	0.946 ± 0.008	0.938 ± 0.008	0.937 ± 0.007	0.949 ± 0.009
4	0.938 ± 0.008	0.927 ± 0.006	0.915 ± 0.006	0.917 ± 0.009	0.933 ± 0.010
5	0.917 ± 0.008	0.906 ± 0.008	0.897 ± 0.007	0.903 ± 0.009	0.917 ± 0.008

Table 3. Difference in Monte Carlo simulations and clinical measurements (%).

Field size	x-ray beam energy (kVp)				
Circle (cm)	50	75	100	125	150
1	−0.1	0.2	0.1	−0.5	−0.8
2	−0.1	−0.2	−0.4	0.4	0.9
3	−0.1	−0.8	−0.6	−0.3	−0.6
4	−0.4	−1.0	−0.6	−0.5	−0.9
5	−0.1	−1.0	−0.5	0.7	−0.5

x-ray treatment. Column 1 describes the circular field size (cm). Each treatment energy tested is given in the following column from 50 up to 150 kVp in 25 kVp steps. Results show the effects of the lead shield on surface dose with larger reductions in delivered dose seen as field size increases for all energies tested. This is specifically caused by the reduction in backscatter which is a function of field size causing the larger reductions at larger field sizes. This is a well-known fact. Table 2 shows the same results calculated for field sizes of 1–5 cm circles for energies 50–50 kVp in 25 kVp steps using Monte Carlo techniques. With the use of 500 million histories per calculation, uncertainty in simulated results was found to be within 1% using depth dose comparisons. By direct comparison, table 3 is created which shows the difference in clinically measured and Monte Carlo simulated results for the effects of lead shields at 1 cm depth. As can be seen, all values agree within 1% showing good agreement between measured values using EBT2 film and Monte Carlo simulations.

Table 4 provides similar results for clinical measurements made with EBT2 with the lead shield placed at a depth of 1 cm. This relates to the maximum thickness for tissue of the ala, lips or earlobes. Table 5 shows results for Monte Carlo simulations with the same field sizes and energy beams with the lead shields placed at 1 cm depth for comparison. Table 6 shows the percentage difference in the clinically measured and Monte Carlo results for lead shields at 1 cm depth.

Table 4:. EBT2 Gafchromic film, clinically measured results for 1.0 cm depth lead shields. Ratio of surface dose with lead at 1.0 cm compared to water.

Field size	x-ray beam energy (kVp)				
Circle (cm)	50	75	100	125	150
1	0.981 ± 0.014	0.978 ± 0.016	0.982 ± 0.019	0.981 ± 0.016	0.991 ± 0.018
2	0.977 ± 0.015	0.970 ± 0.014	0.975 ± 0.019	0.968 ± 0.014	0.975 ± 0.016
3	0.972 ± 0.014	0.965 ± 0.014	0.965 ± 0.017	0.954 ± 0.015	0.962 ± 0.018
4	0.962 ± 0.016	0.961 ± 0.013	0.957 ± 0.019	0.944 ± 0.012	0.951 ± 0.018
5	0.949 ± 0.015	0.943 ± 0.015	0.932 ± 0.016	0.935 ± 0.015	0.945 ± 0.018

Table 5. Monte Carlo simulation results for 1.0 cm depth lead shields. Ratio of surface dose with lead at 1.0 cm compared to water. 500 million histories.

Field size	x-ray beam energy (kVp)				
Circle (cm)	50	75	100	125	150
1	0.985 ± 0.008	0.986 ± 0.009	0.986 ± 0.009	0.989 ± 0.010	0.992 ± 0.009
2	0.977 ± 0.007	0.975 ± 0.007	0.977 ± 0.008	0.980 ± 0.008	0.983 ± 0.010
3	0.969 ± 0.010	0.965 ± 0.009	0.965 ± 0.009	0.967 ± 0.009	0.974 ± 0.010
4	0.960 ± 0.009	0.954 ± 0.010	0.949 ± 0.007	0.952 ± 0.010	0.961 ± 0.008
5	0.953 ± 0.008	0.942 ± 0.006	0.929 ± 0.008	0.934 ± 0.010	0.949 ± 0.007

Table 6. Difference in Monte Carlo simulations and clinical measurements (%).

Field size	x-ray beam energy (kVp)				
Circle (cm)	50	75	100	125	150
1	0.4	0.8	0.4	0.8	0.1
2	0.0	0.5	0.2	1.2	0.8
3	−0.3	0.0	0.0	1.3	1.2
4	−0.2	−0.7	−0.8	0.8	1.0
5	0.4	−0.1	−0.3	−0.1	0.4

As can be seen, a similar pattern occurs in measured and modelled results with larger field sizes producing larger reductions in dose at the surface. The maximum reduction effect occurs between energies of 100 and 125 kVp in both experimental and Monte Carlo modelled results. The maximum variation found for these experiments with the lead at 1 cm depth between clinical measurements and modelled simulations was 1.3% found at 125 kVp.

These results have two clinically significant outcomes. Firstly, EBT2 Gafchromic film, which is a relatively accurate, simple and effective measurement tool, can be used to evaluate dose reductions caused by lead shields in kilovoltage x-ray beams. The comparison and similarities of results with Monte Carlo models show that clinically measured results can be effectively used to correct dose calculations for superficial x-ray treatments like the nose (nasal shields), lips or ears. Secondly, with field sizes of 5 cm diameter, up to 10% reduction in surface dose can occur from the use of a lead shield at a depth of 0.5 or 1 cm to protect underlying tissue. Thus, we recommend that clinical measurements are performed to produce clinical correction data to account for dose reductions caused by these lead shields. These results have shown that EBT2 Gafchromic film is an effective and accurate tool to perform this task and medical physicist can easily create their own institution's data to improve the accuracy of kilovoltage x-ray therapy treatment.

Conclusion

Accurate experimentally measured results for dose reductions caused by lead shields at kilovoltage x-ray energies can be performed by simply using EBT2 Gafchromic film. This has been verified by comparison to Monte Carlo simulations. Up to 10% reductions can occur for clinical field sizes of 5 cm circle diameters and energies from 50 to 150 kVp. As such, recommendations are to correct for such reductions clinically and these can be easily and accurately measured with the use of EBT2 Gafchromic film.

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