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Lepton contamination and photon scatter produced by open field 18 MV X-ray beams in the build-up region

Martin J. Butson[a,b,*], Tsang Cheung[a], Peter K.N. Yu[a]

[a] Department of Physics and Materials Science, City University of Hong Kong, Kowloon Tong, Hong Kong
[b] Department of Medical Physics, Illawarra Cancer Care Centre, Crown St., P.O. Box 1798, Wollongong, NSW 2500, Australia

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Abstract

18 MV X-ray beams used in radiotherapy have skin sparing properties as they produce a dose build-up effect whereby a smaller dose is delivered to the skin compared to dose at depth. Experimental results have shown that variations in the build-up dose significantly contribute to lepton contamination produced outside of the patient or the phantom in question. Monte Carlo simulations of 18 MV X-ray beams show that the surface dose contribution from in-phantom scatter alone is approximately 6% of the maximum dose. The contribution to dose from lepton contamination is found by comparison of Monte Carlo phantom photon scatter dose only and experimental data. Results show that the percentage contributions to dose from lepton contamination are approximately, 65%, 90% of dose at 0.05 mm (basal cell layer), 52%, 79% at 1 mm depth (dermal layer) and 15%, 26% at 10 mm depth (subcutaneous tissue) for 10 cm × 10 cm^2 and 40 cm × 40 cm^2 fields, respectively. © 2002 Published by Elsevier Science Ltd.

Keywords: Build-up effect; Photon beams; Skin dose

1. Introduction

When cancer patients undergo radiation therapy, various skin reactions have been noticed. Early stage effects include Erythema and in some cases desquamation (Turesson and Thomas, 1989). Occasionally late effects such as Telangectasia may occur. Fibrosis can occur in the subcutaneous tissue if the dose is too high. Low skin dose is normally not the treatment aim. However, when doses to these regions are greater than tolerance levels for individual patients the amount of skin dose must be taken into account when establishing the treatment criteria. 18 MV X-ray beams are used in radiotherapy due to their high penetration properties and sometimes due to their skin sparing properties. Contributions to dose in the build-up region come from in-phantom photon scattered electrons and from lepton contamination, or electrons/positrons produced outside the phantom in question (Hounsell and Wilkinson, 1999; Beauvais et al., 1993; Nilsson, 1985; Zhu and Palta, 1998; Hannallah and Zhu, 1996). This note compares theoretical Monte Carlo calculations of the dose produced only in the phantom to experimentally measured build-up doses. By comparison of these quantities, the contribution to dose in the skin and build-up region from each interaction component can be determined for various treatment configurations.

2. Materials and methods

Measurements were performed on a Varian 2100C medical linear accelerator at 18 MV peak energies. Photon beam measurements were made using an Attix Model 449 parallel plate ionization chamber (Rawlinson et al., 1992) in a solid water (Constanitinou et al., 1982) stack phantom. The

* Corresponding author. Department of Medical Physics, Illawarra Cancer Care Centre, Crown St., P.O. Box 1798, Wollongong, NSW 2500, Australia. Tel.: +61-2-422-25709; fax: +61-2-422-65397.
E-mail address: mbutson@guessmail.com (M.J. Butson).

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Table 1
Photon spectrum for simulated 18 MV X-ray beam

Energy (MeV)	Relative fluence
0.1	0.026
0.2	0.045
0.3	0.064
0.4	0.082
0.5	0.099
0.6	0.115
0.8	0.146
1.0	0.173
1.25	0.203
1.5	0.230
2.0	0.271
3.0	0.316
4.0	0.324
5.0	0.306
6.0	0.274
8.0	0.191
10.0	0.112
15.0	0.005
20.0	0.000

Attix chamber has dimensions of 6.0 cm diameter and 1.4 cm height and is made from solid water. The active collection volume is cylindrical with a diameter of 1.3 cm and a separation of 1 mm. The front window consists of a 0.025 mm, 4.8 mg/cm^2 Kapton conductive film. The chamber was connected via a triaxial cable to a Keithley model 2540 electrometer at 300 V bias voltage. Percentage dose build-up curves were measured on the central axis for various beam configurations from the surface to 40 mm depth in 1 mm increments and at 0.05 mm depth. Measurements were performed with radiotherapy field sizes ranging from 5 cm $\times$ 5 cm up to 40 cm $\times$ 40 cm which was considered most typical of treatment fields. All measurements were performed at a source to surface of phantom distance (SSD) of 100 cm. Monte Carlo simulations were performed with an 18 MV spectrum shown in Table 1 which was shown to match the dose versus depth characteristics of our linear accelerator to within 2% at depth beyond the position of maximum dose deposition. The code used was electron gamma shower 4 (EGS4), which is integrated into an ADAC [1] "Pinnacle-3" radiotherapy treatment planning system. Dimensions of voxles used to score dose were 2 cm $\times$ 2 cm and 1 mm thick. This dimension of voxels was used as it closely simulates the dimensions of the Attix parallel plate ionization chamber used for experimental measurement of the build-up dose characteristics whilst still providing a larger enough voxel to minimize errors in calculation. An electron cut-off energy (E-cut) value, below which electrons are considered to deposit all their remaining energy at the last site of interaction was set to 0.531 MeV. This value includes the rest energy of the electron (0.511 MeV). The photon cut off energy (P-cut) at which the photon deposits all its remaining energy was set to 20 KeV. Hundred million histories were used. Field sizes used ranged from 10 cm $\times$ 10 cm up to 40 cm $\times$ 40 cm. Variations in percentage build-up dose at each depth for all field sizes were less than 2% in this configuration. The simulated phantom used was a 50 cm cube of water with vacuum located around it in all directions. Thus, all interactions calculated were due to in-phantom only photon interactions.

[1] ADAC Pty Ltd: Milpitas, CA, USA.

3. Results and discussion

Fig. 1 shows the Monte Carlo derived build-up dose curve for a 18 MV X-ray spectrum which matches the dose versus depth characteristics of our clinical beam to within 2% at depths down to 30 cm. The Monte Carlo simulation only produces fluence and the dose produced within the water phantom. Thus, no electrons produced outside the phantom are simulated or scored for dose. Thus, no knock-on leptons or secondary photons are simulated by interactions produced outside the phantom from any other sources of lepton contamination. The build-up curve produced is a direct result of in-phantom photon interactions only. Simulations were performed with field sizes ranging from 10 cm $\times$ 10 cm up to 40 cm $\times$ 40 cm. Results showed that there was no significant difference, larger than statistical errors, in percentage dose build up for all field sizes. The fact that for all field sizes, the same photon spectrum was used may contribute to this. However, changes in results at depth matched clinical results for percentage dose versus depth. The position of maximum dose was found to be approximately 32–40 mm depending on statistical variations. Percentage surface dose was found to be 6% $\pm$ 2% of maximum. Results shown on the curve are the interpolated and for surface dose, the extrapolated results taken from the scored fluence in the 1 mm thick voxels. That is, the effective point of measurement in each voxel was taken as the midpoint value for depth. Results were calculated in this way so that a comparison between Monte Carlo and experimental results could be made.

Fig. 2 shows the experimental build-up curves measured for the 18 MV X-ray beam at various field sizes ranging from 5 cm $\times$ 5 cm up to the maximum field size of 40 cm $\times$ 40 cm. Surface dose increases from 7% of maximum to 44% of maximum with field size. All measurements were taken with an SSD of 100 cm. The depth of maximum dose deposition (D_{max}) was found to vary considerably, with D_{max} ranging from 33 mm at 5 cm $\times$ 5 cm down to 27 mm for a 40 cm $\times$ 40 cm field size. Experimental results measured includes all in-phantom photon scatter as well as lepton contamination and extra photon scatter produced outside of the phantom. Sources of lepton contamination include areas such as the treatment head and the air column directly above the phantom. Of course, both lepton contamination and extra photon scatter play a bilateral role in dose deposition.

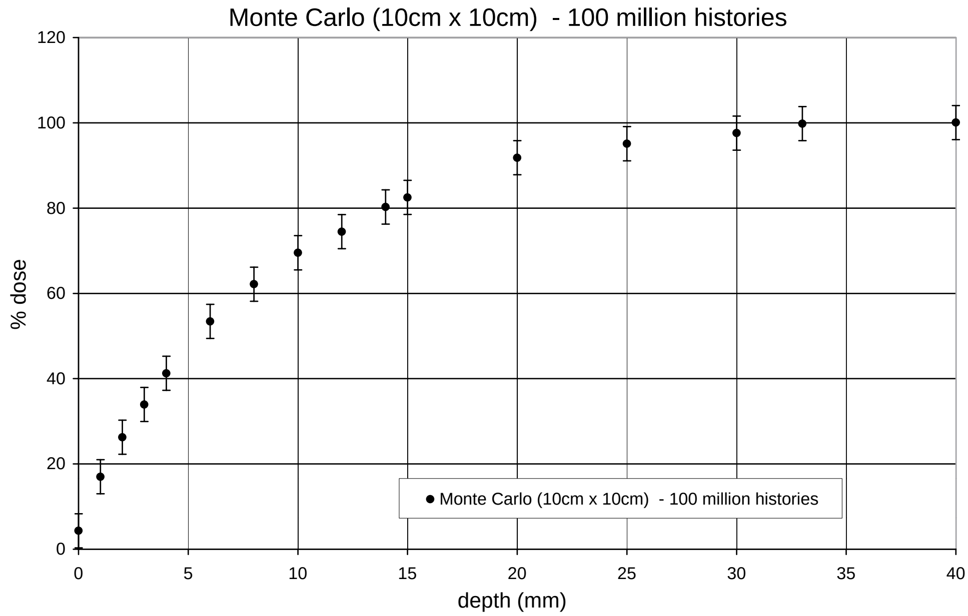

Fig. 1. A Monte Carlo simulation of the build-up dose for an 18 MV X-ray beam. 100 million histories were scored with voxel dimensions 2 cm × 2 cm × 1 mm thick.

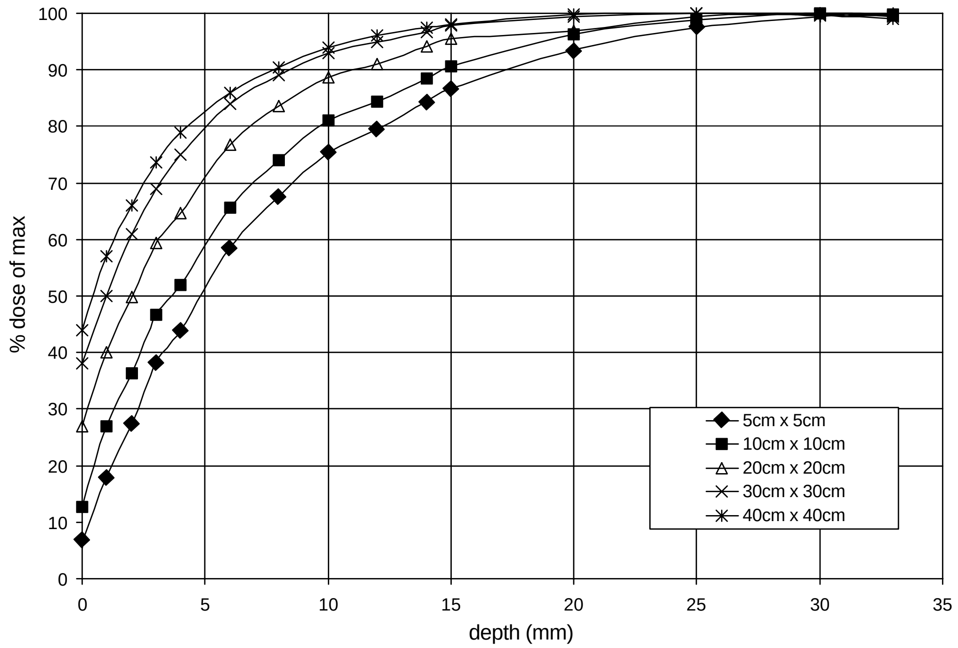

Fig. 2. Experimental measurements of open-field 18 MV X-ray beams in the build-up region for field sizes ranging from 5 cm × 5 cm up to 40 cm × 40 cm.

Lepton contamination can cause extra photon interactions outside the phantom, and vice versa. It seems that the main source of extra dose deposition in the build-up region is due to lepton contamination with a definite range. This is mainly due to the fact that the Monte Carlo simulations matched experimental results beyond D_{max} consistently with all field sizes and with the same photon spectrum. Thus, if there was a major contribution to changes in dose in the build-up region from changes in the photon spectrum, we would expect this beyond the D_{max} region as well.

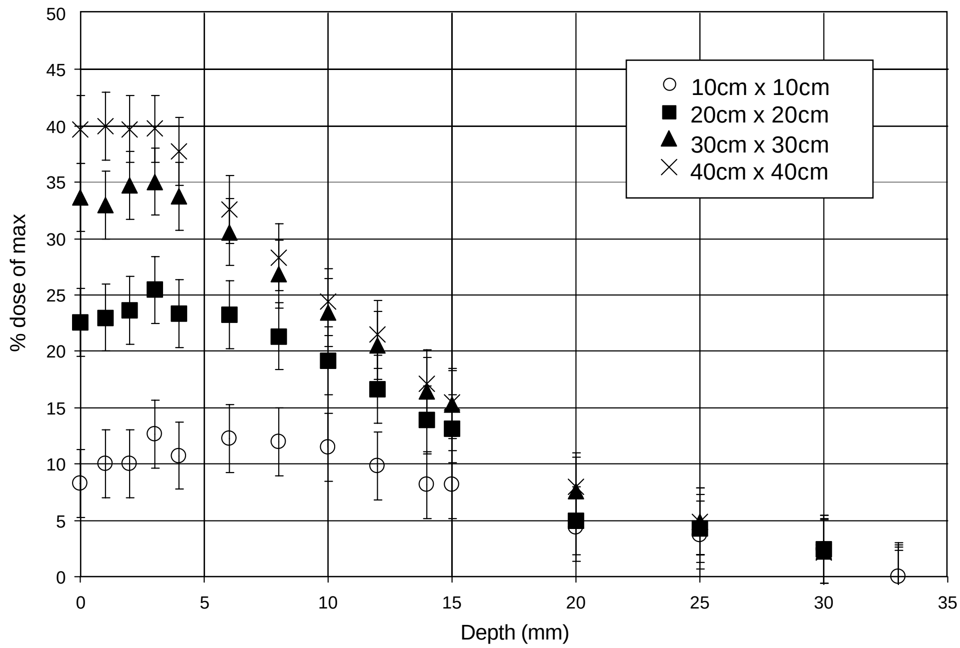

Fig. 3. The contribution to dose in the build-up region by lepton contamination and extra photon scatter produced outside the phantom.

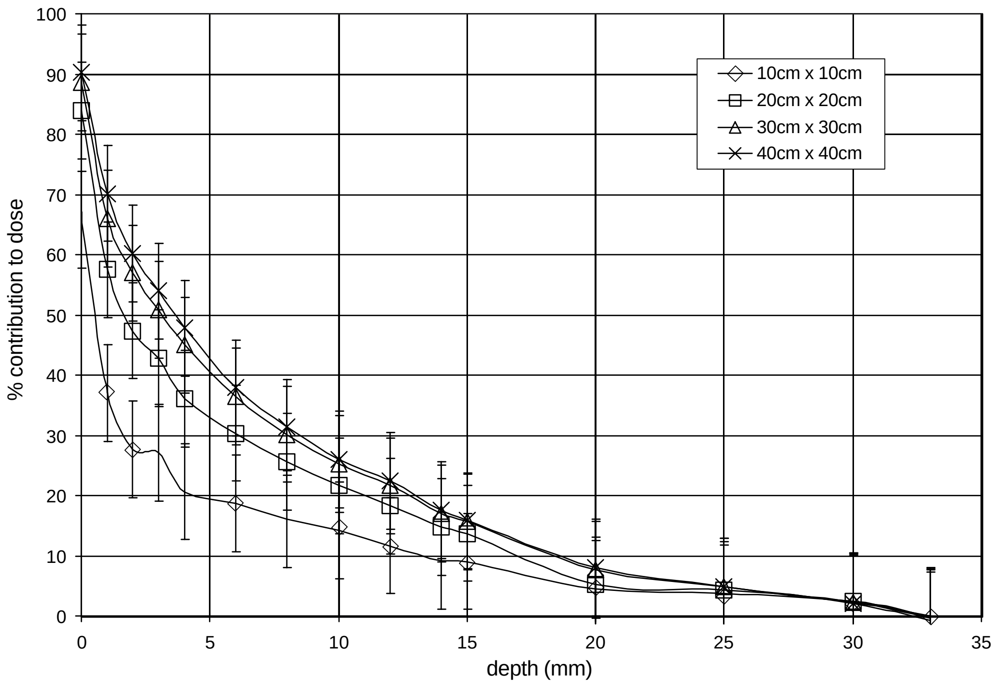

Fig. 4. The percentage contribution to dose at each depth by lepton contamination at various field sizes.

By comparison with the Monte Carlo derived build-up curve and the experimental results, we can produce a measure of dose deposition in the build-up region due to lepton contamination and extra photon scatter. A direct subtraction from experimental data of percentage dose for Monte Carlo build-up is shown in Fig. 3. As can be seen, the percentage of maximum dose delivered by lepton contamination increases with field size. There seems to be a relatively constant amount of dose within the first 4 mm of water for all field sizes with surface doses ranging from 8% up to 40% for beams with field sizes of 10 cm × 10 cm to 40 cm × 40 cm. These results are unlike 6 MV beams (Butson et al., 1996) where a considerably larger percentage dose was seen at the phantom surface compared to dose at depth. That is, the 18 MV X-ray beam produces a relatively harder spectrum of electron contamination (compared to a 6 MV X-ray beam) whose percentage contributions at larger depths are considerably more. By comparison of these percentage dose values with just in-phantom photon dose, a graph of the percentage contribution to dose can be created which shows the extent of the dose deposition by each component at depth. This is illustrated in Fig. 4. Results show the percentage contribution by lepton contamination as a percentage of total dose at each depth. As can be seen, for larger field sizes, nearly all dose at the surface (90%) is caused by lepton contamination. For smaller field sizes this value drops to 67% (10 cm × 10 cm) which is still a significant contribution to surface dose. As photon interactions increase in the build-up region, the contribution to dose from lepton contamination decreases considerably.

4. Conclusion

The build-up characteristics of an 18 MV X-ray beam have been studied using Monte Carlo techniques and experimental data. Results show that the main component for dose deposition at the surface is lepton contamination with up to 90% of contributions being delivered by this interaction.

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