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Using narrow beam profiles to quantify focal spot size, for accurate Monte Carlo simulations of SRS/SRT systems

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Abstract. This study investigates the variation of photon field penumbra shape with initial electron beam diameter, for very narrow beams. A Varian Millenium MLC (Varian Medical Systems, Palo Alto, USA) and a Brainlab m3 microMLC (Brainlab AB. Feldkirchen, Germany) were used, with one Varian iX linear accelerator, to produce fields that were (nominally) 0.20 cm across. Dose profiles for these fields were measured using radiochromic film and compared with the results of simulations completed using BEAMnrc and DOSXYZnrc, where the initial electron beam was set to FWHM = 0.02, 0.10, 0.12, 0.15, 0.20 and 0.50 cm. Increasing the electron-beam FWHM produced increasing occlusion of the photon source by the closely spaced collimator leaves and resulted in blurring of the simulated profile widths from 0.24 to 0.58 cm, for the MLC, from 0.11 to 0.40 cm, for the microMLC. Comparison with measurement data suggested that the electron spot size in the clinical linear accelerator was between FWHM = 0.10 and 0.15 cm, encompassing the result of our previous output-factor based work, which identified a FWHM of 0.12 cm. Investigation of narrow-beam penumbra variation has been found to be a useful procedure, with results varying noticeably with linear accelerator spot size and allowing FWHM estimates obtained using other methods to be verified.

1. Introduction

The sensitivity of output factors for small photon fields to the diameter of the linear accelerator's initial electron beam has received increasing attention over recent years, with several authors recognising that the characteristics of small fields can be used for fine-scale optimisation of electron spot parameters used in Monte Carlo simulations of photon beams [1, 2, 3].

Despite the high spatial resolution, near water-equivalence and relative energy independence demonstrated by radiochromic films [4, 5, 6], the use of radiochromic film measurements to aid in the optimisation of the initial electron beam parameters used in Monte Carlo simulations has been minimal [7]. Reported problems with radiochromic film uniformity [8, 9] have led to observed localised inaccuracies in dose measurements [2, 3]. However, it has been shown that the use of repeated measurements, in combination with the use of an appropriate handling, irradiation, scanning and analysis procedure, can produce reliable and informative results [10, 11].

This study aims to demonstrate that the accuracy of the electron focal spot diameter used in a Monte Carlo model of a linear accelerator operating with or without an external microMLC can be

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broadly verified with reference to narrow-beam dose profiles obtained from radiochromic film measurements. This work is therefore expected to assist in the accurate Monte Carlo modelling of both stereotactic radiosurgery and radiotherapy (SRS/SRT) delivery systems and more conventional linear accelerator designs.

2. Method

A Varian Millenium MLC (Varian Medical Systems, Palo Alto, USA) and a Brainlab m3 microMLC (Brainlab AB. Feldkirchen, Germany) were used, with one Varian iX linear accelerator, to produce 6 MV photon fields that were (nominally) 0.20 cm across. Dose profiles for these fields were measured at the isocentre using 5 x 5 cm^2 squares of Gafchromic EBT2 radiochromic film (International Specialty Products, Wayne, USA) that were placed at 3 cm depth in Virtual Water (Standard Imaging, Middleton, USA). To obtain adequate film darkening to provide a measurable result, for the narrow beams used in this study, 500 MU irradiations were used. Each film measurement was repeated three times and the results were averaged. The handing, scanning and calibration of the EBT2 film was completed as previously described [9, 10, 11], with scans obtained before and after irradiation and results analysed using the red channel only. The only deviation from the published procedure was that the scanning resolution was increased from 72 DPI to 150 DPI (resulting in 0.015 cm pixel widths), in order to obtain suitably detailed results.

A series of Monte Carlo simulations were completed, using BEAMnrc and DOSXYZnrc [12, 13], with established, geometrically and dosimetrically accurate models of the Varian iX linear accelerator, Millennium MLC and Brainlab m3 microMLC [14, 15, 16]. The film and water-equivalent phantom were modelled as a simple volume of water with voxels 0.1 cm thick in the beam-axis direction and 0.01 x 0.01 cm^2 across in the lateral directions. For these narrow fields, BEAMnrc runs using 10^9 histories (with a directional bremsstrahlung splitting number of 1000) produced 10^6 particles at the exit plane of the linear accelerator. DOSYZnrc runs of 10^9 histories (with a photon splitting number of 10 and with phase-space particle recycling permitted as necessary) were required to achieve dose calculation results with a statistical precision within 0.5%.

To investigate the effects of source occlusion on the resulting narrow beam profiles, the width of the initial electron beam in the simulations was varied. The BEAMnrc simulations, for the MLC-collimated and microMLC-collinated systems, were completed using electron beam full widths at half maxima (FWHM) of 0.02, 0.10, 0.12, 0.15, 0.20 and 0.50 cm.

3. Results

Figures 1(a) to (d) and table 1 illustrate the results of varying the FWHM of the initial electron beam used in the simulations of the MLC-collimated beam (figures 1(a) and (b)) and the microMLC-collimated beam (figures 1(c) and (d)). Results normalised to the central axis dose (figures 1(a) and (c) show that increasing the FWHM from 0.02 to 0.50 cm resulted increasing photon source occlusion, leading to blurring of the simulated profile widths from 0.24 to 0.58 cm, for the MLC, from 0.11 to 0.40 cm, for the microMLC (also see table 1).

In figures 1(a) to (d), the profiles obtained using electron spot diameters from FWHM = 0.10 to FWHM = 0.15 all closely overlie each other and are all in close agreement with the profiles obtained from the radiochromic film measurements. Data listed in Table 1 confirm that the required electron spot size to be used in simulating these beams clearly falls into the range $0.10 \leq \text{FWHM} \leq 0.15$ cm. This result is consistent across collimation systems and applies in both the radial direction (pictured in figure 1) and the transverse direction (not pictured). This range encompasses the result of our previous diode-based examination of the beam produced by this linear accelerator, which identified an optimal FWHM of 0.12 cm [17].

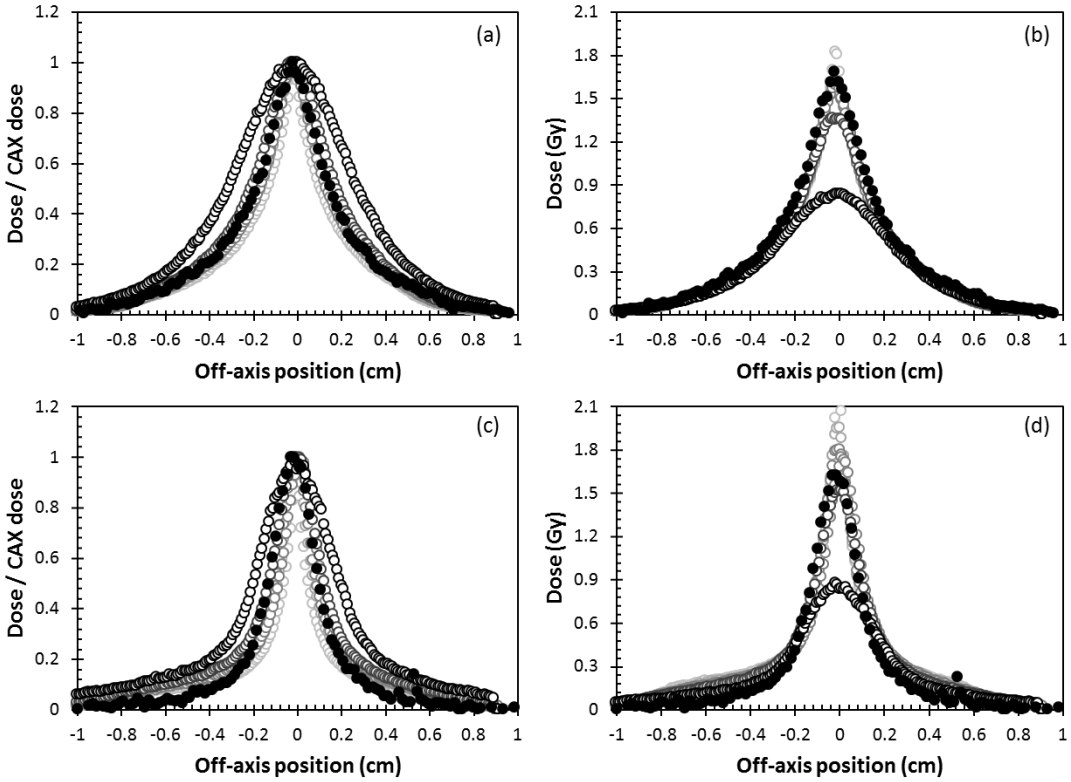

Figure 1. Dose profiles for the MLC-collimated fields (a) normalised to the central axis (CAX) dose and (b) measured and calculated in Gy, and for the microMLC-collimated fields (c) normalised to the CAX dose and (d) measured and calculated in Gy. Filled data points represent dose from film measurement. Open data points represent dose from Monte Carlo simulations using the different FWHM values listed in section 2. The shading of the data points representing the Monte Carlo results increases in saturation with FWHM, from light grey for FWHM = 0.02 cm to black for FWHM = 0.50 cm.

Table 1. Field widths, measured at the 50% isodose (see figure 1(a) and (c)), and central axis doses (see figure 1 (b) and (d)) for narrow fields collimated using MLC and microMLC, simulated using the listed FWHM values. Data shown in italicised bold-face type are from the EBT2 film measurements.

	MLC-collimated fields		microMLC-collimated fields	
FWHM (cm)	Field width (cm)	CAX dose (Gy)	Field width (cm)	CAX dose (Gy)
0.50	0.58 ± 0.01	0.84 ± 1.36	0.397 ± 0.004	0.88 ± 0.01
0.20	0.387 ± 0.004	1.36 ± 0.01	0.253 ± 0.003	1.52 ± 0.02
0.15	0.300 ± 0.003	1.61 ± 0.02	0.199 ± 0.002	1.75 ± 0.02
0.12	0.319 ± 0.003	1.56 ± 0.02	0.185 ± 0.002	1.81 ± 0.02
0.10	0.305 ± 0.003	1.60 ± 0.02	0.164 ± 0.002	1.96 ± 0.02
0.02	0.243 ± 0.002	1.82 ± 0.02	0.113 ± 0.001	2.44 ± 0.02
Film result:	***0.33 ± 0.02***	***1.65 ±0.05***	***0.23 ± 0.02***	***1.63 ± 0.05***

4. Conclusion

The use of radiochromic film to investigate narrow-beam profile variation with electron focal spot size has been found to be a useful procedure, with results varying sufficiently to allow identification of an optimal electron FWHM to within 0.05 cm. This result was consistent, whether a standard MLC or a microMLC was used to collimate the field, and indicates that this procedure could be used to provide independent verification of FWHM estimates obtained using diodes or other dosimeters.

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References

[1] Scott A D J, Nahum A E and Fenwick J D 2009 *Med. Phys*. **36**(7) 3132-3144
[2] Francescon P, Cora S and Cavedon C 2008 *Med. Phys*. **35**(2) 504-513
[3] Cranmer-Sargison G, Weston S, Evans J A, Sidhu N P and Thwaites D I (2011) *Med. Phys*. **38**(12) 6592-6602
[4] Butson M J, Yu P K N, Cheung T and Alnawaf H 2010 *Radiat. Meas*. **45** 836-839
[5] Devic S 2011 *Physica Medica* **27**(3) 122-134
[6] Kim J H, Hill R and Kuncic Z 2012 *Phys. Med. Biol*. **57**(14) N267-N278
[7] Scott A J D, Nahum A E and Fenwick J D 2008 *Med. Phys*. **35**(10) 4671-4684
[8] Richley L, John A C, Coomber H and Fletcher S 2010 *Phys. Med. Biol*. **55**(9) 2601-2617
[9] Aland T, Kairn T and Kenny J 2011 *Australas. Phys. Eng. Sci. Med*. **34**(2): 251-260
[10] Kairn T, Aland T and Kenny J 2010 *Phys. Med. Biol*. **55**(15) L37-L42
[11] Kairn T, Hardcastle N, Kenny J, Meldrum R, Tome W and Aland T 2011 *Australas. Phys. Eng. Sci. Med*. **34**(3) 333-343
[12] Rogers D W O, Faddegon B A, Ding G X, Ma C M, We J and Mackie, T R 1995 *Med. Phys*. **22** 503-522
[13] Kawrakow I and Walters B R B 2006 *Med. Phys*. **33** 3046-3056
[14] Kairn T, Kenny J, Crowe S B, Fielding A L, Franich R D, Johnston P N, Knight R, Langton C M, Schlect D and Trapp J V 2010 *Med. Phys*. **37**(4) 1761-1767
[15] Kairn T, Aland T, Franich R D, Johnston P N, Kakakhel M B, Kenny J, Knight R, Langton C M, Schlect D, Taylor M L and Trapp J V 2010 *Phys. Med. Biol*. **55**(17) N451-N463
[16] Charles P H, Crowe S B, Kairn T, Kenny J, Lehmann J, Lye J, Dunn L, Hill B, Knight R T, Langton C M and Trapp J V 2012 *Phys. Med. Biol*. **57** 6947-6960
[17] Charles P H, Crowe S B, Kairn T, Knight R T, Hill B, Kenny J, Langton C M and Trapp J V 2013 *Phys. Med. Biol*. **58** 4501- 4512