Original

Evaluation of Therapeutic Properties of a Low Energy Electron Beam Plus Spoiler for Local Treatment of Mycosis Fungoides: A Monte Carlo Study

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ABSTRACT

Background: When using low-energy electron beams for the treatment of skin lesions, such as Mycosis Fungoides (MF), a beam spoiler is used to decrease electron therapeutic depth (R_{90}) while increasing the surface dose.

Objective: The aim of this study was to evaluate the characteristics of a 5 MeV electron beam when using a spoiler for the local treatment of MF skin lesions by Monte Carlo (MC) simulation.

Material and Methods: In this experimental study, a Siemens Primus treatment head and an acrylic spoiler, positioned at the end of applicator, were simulated using BEAMnrc, an EGSnrc user code. The modelled beam was validated by measurement using MP3-M water tank, Roos parallel plate chamber and Semi flex Chamber-31013 (all from PTW, Freiburg, Germany). For different spoiler thicknesses, dose distributions in water were calculated for 2 field sizes and were compared to those for the corresponding open fields.

Results: For a 1.3 cm spoiler, therapeutic range changed from 1.5 cm (open field) to 0.5 cm and 0.4 cm for 10 × 10 cm^2 and 20 × 20 cm^2 field sizes, respectively. Maximum increase in penumbra width was 2.8 and 3.8 cm for 10 × 10 cm^2 and 20 × 20 cm^2 field sizes, respectively. Maximum increase in bremsstrahlung contamination was %2 in both field sizes.

Conclusion: R_{90} decreased exponentially with increase in spoiler thickness. The effect of field size on penumbra was much larger for spoiled beam compared to the open beam. The results of this research can be applied to optimize the radiation treatment of MF patients in our hospital.

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Keywords
Penumbra, Spoiler, Electrons, Monte Carlo Method, Radiotherapy

Introduction

Electron beam therapy (EBT) plays an important role in cancer treatment [1]. Due to its remarkable advantages over photon beams, i.e. high surface dose and rapid dose fall-off beyond maximum depth, electron beams are commonly used for the treatment of superficial malignancies [2, 3]. Penetration depth of electron beams is determined by selecting appropriate energy and for each energy, therapeutic properties of electron beams are determined by measuring per-

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centage depth dose curves (PDD) and dose profiles in a water phantom. The properties determined from PDD curves include depth of maximum dose (d_{max}), therapeutic depth or the depth that %90 of dose is delivered, percentage of surface dose, the depth that %50 of dose is delivered or R_{50} and percentage of dose which is caused by X-ray contamination, all with respect to dose at d_{max}. However, dosimetric penumbra width is determined using dose profiles [4].

MF is one of the superficial tumors that can be treated with low-energy electron beams. This disease is the most common type of primary cutaneous lymphoma and includes about %50 of all cases of cutaneous lymphoma [5]. Total skin electron beam irradiation (TSEI) is considered as the most effective treatment for this malignancy [6]. In TSEI, electron beams with an energy range of 2-9 MeV are used. In this energy range, dose decreases rapidly in lower depths and since photon contamination is low, superficial lesions up to depth of 1cm can be effectively treated without damaging bone marrow. In TSEI, patient is positioned at distance of 3 m from the electron source and at different angles in order to cover the entire surface of the body by treatment field [4].

For treatment of scalp, perineum, feet and other parts of skin with folds, the patient is located at source-to-skin distance (SSD) of about 100 cm and is treated with local electron fields [7]. Depending on depth of superficial lesions and the lowest electron energy available, it may be necessary to use a layer of beam attenuator or spoiler to reduce electron energy. A beam spoiler is composed of a sheet of a low atomic number material, typically Lucite or acrylic, which is placed in the path of beam to reduce penetration depth of beam and increase its surface dose [4, 8]. When the primary beam passes through the spoiler, secondary electrons are produced and these electrons change the dose distributionin depth [9]. Several studies have been reported on the application of spoiler in order to increase the surface dose in photon beam radiation therapy [9-11]. McKenzie et al. used a plastic spoiler in order to match two adjacent electron fields [11]. Hernández et al. studied the application of aluminum spoilers for increasing surface dose of a 6 MeV electron beam [12]. So-Yeon Park et al. compared dosimetry characteristics of a 4 MeV electron beam without spoiler to a 6 MeV electron beam with spoiler [13]. In general, it has been shown that although low-energy electron beams have appropriate depth dose distribution for the treatment of superficial lesions, their use is restricted by their low surface dose percentage [14]. Surface dose can be increased using a tissue equivalent bolus. However, using bolus on sloped surfaces and partly bloused fields can cause remarkable dose perturbations and may also produce cold and hot spots below the edge. An alternative is to use an electron beam spoiler to decrease the electron therapeutic depth while increasing the surface dose [12, 15]. Studies have revealed that for every treatment unit and for each spoiler material, it is necessary to determine the optimum spoiler thickness by considering the energy of electron beam, depth of tumor and tumor lateral expansion. The aim of this study was to study the application of water equivalent spoilers for electron beam treatment of different stages of MF using local treatment fields. To achieve this goal, MC simulation method was used to calculate dose distributions in a water phantom resulting from different thicknesses of spoiler.

Material and Methods

In this experimental study, a Siemens Primus medical linear accelerator treatment head was simulated for a 5 MeV nominal energy electron beam. After validating the simulation results, the changes in dose distributions in water phantom in presence of spoilers were investigated.

MC modelling of electron beam

In this study, BEAMnrc code, an EGSnrc

user code, was used to simulate the linear accelerator and particle transport. Structures of treatment head were modelled as component modules (CMs) using manufacture provided information. For this purpose, the structural modules SLAB, CONETAK, CONETAK, CHAMBER, JAWS, MLC and APPLICAT were used to model the exit window, primary scattering foil, secondary scattering foil, ionization chamber, secondary collimator, multileaf collimator and applicator, respectively (Figure 1). In this model, a circular electron beam with a radius of 0.1 cm (ISOURC=0) was used. Lower cutoff energy for charged particle and photon transporting were 0.7 MeV and 0.01 MeV, respectively. Two field sizes 10 × 10 cm^2 and 20 × 20 cm^2 were modelled. The dimensions of radiation fields at the isocenter, located at Z=100 cm from the source (Z=0), were modelled. Information of particles transition were recorded in scoring plane located at the end of last scraper of electron applicator (Z=95.141 cm). These phase space data were used as a source for dose calculation using DOSXYZnrc code.

Dose calculations

For the second step using the scored phase space data, PDD along central axis and in plane profiles at R_{95} were calculated by DOSXYZnrc for 10 × 10 cm^2 field size and at SSD=100 cm in a 30 × 30 × 40 cm^3 water phantom. PDD and profiles were calculated using 1 cm × 1 cm × 0.2 cm and 1 cm × 1 cm × 0.5 cm voxel sizes, respectively. Calculated dose values were used to plot PDD and dose profile curves using statdose, an EGSnrc subroutine.

Dose measurements

PDD curves along central axis and in plane profiles were measured using similar beam configurations in an automatic MP3-M water

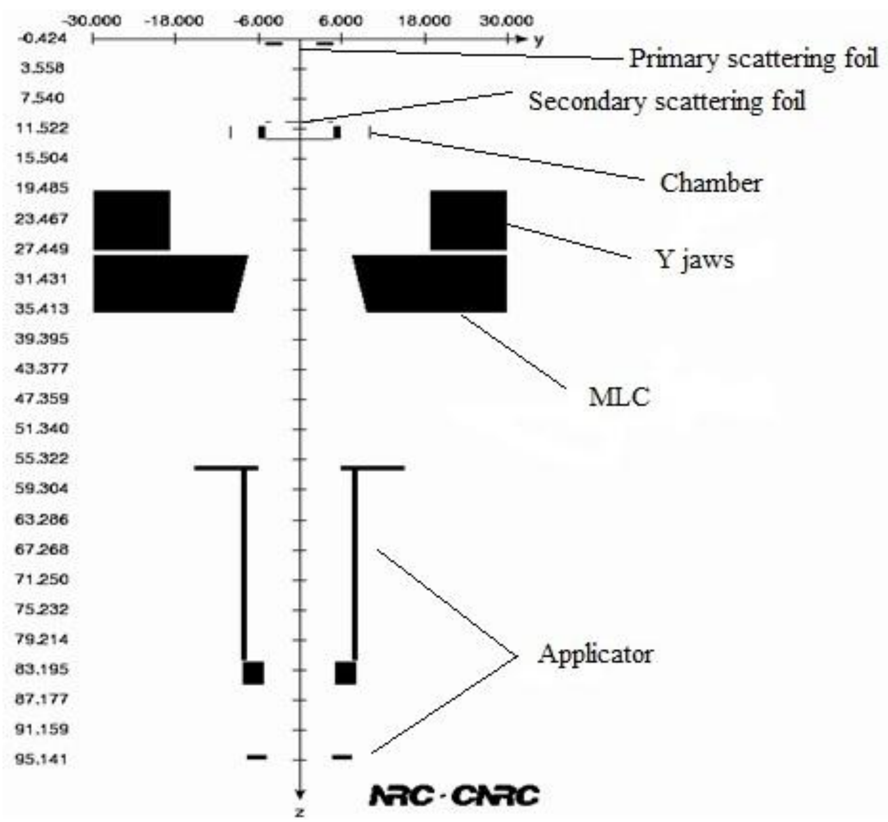

Figure 1: Diagram of Siemens Primus electron treatment head as simulated by BEAMnrc user code

tank using Roos parallel plate (acrylic coated entrance window of 1.1 mm thickness and sensitive volume of 0.35 cm^3) chamber and Semi flex 31010 (volume of 0.125 cm^3) chamber (all from PTW, Freiburg, Germany), respectively.

MC model validation

MC model commissioning was performed by comparing the calculated and measured PDD and profiles. The following formula was used to calculate the percent differences [16].

$$\text{Percentage difference} = \frac{\text{Calculation} - \text{Measurement}}{\text{Measurement}} \times 100$$

The criterion for accepting a simulated beam model is less than %2 and %3 difference for PDD in the buildup and fallout regions, respectively, and for profiles, less than %1 and %2 around the central axis and edges of the field regions, respectively [17].

In order to tune the energy of developed beam model, we initially chose nominal energy of 6 MeV, as incident electron energy for the phase-space calculation. Then, this value was altered (using 0.1 MeV steps) until the calculated PDD best fit the measured. Electron beam width was tuned by calculating the beam profile at R_{95} depth. In order to obtain agreement between calculated and measured profiles, factors such as scattering foil geometry and FWHM of electron beam intensity distribution were modified.

Dose calculations with spoiler

An acrylic spoiler, positioned at the end of electron applicator (cone), was simulated using the SLAB CM. Dose distributions in water phantom were calculated for 10 × 10 cm^2 and 20 × 20 cm^2 field sizes and 1.1, 1.3, 1.5, 1.7, 1.9 and 2.2 cm spoiler thicknesses. The xy cross-section of spoiler for each applicator was equal to field size multiplied by the ratio of source-to-end of applicator distance to SSD, i.e. 0.95 m. Surface dose, therapeutic range (R_{90}), R_{50}, output factors and penumbra widths were compared to open field without spoiler. According to the AAPM instruction, dose profile curves were obtained in R_{95} depth [18]. R_{50}, the depth in water whose dose is equal to half of dose at d_{max}, serves as a beam quality specifier [19].

For each spoiler thickness, output factor was calculated as the ratio of dose at dmax in the presence of spoiler to the dose at d_{max} for the open beam. Penumbra widths was calculated using the beam profiles as the difference in lateral distances of two points having %80 and %20 of dose values from central axis of the beam [20].

Results

Model validation was performed by comparing the calculated dose distributions for different beam energies to measured values for the 5 MeV electron beam. The comparison for a 5.9 MeV calculated beam showed the best agreement as shown in Figures 2 and 3. Calculated PDD curves with different thicknesses of acrylic spoiler and without spoiler are displayed in Figures 4 and 5 for field sizes of 10 × 10 cm^2 and 20 × 20 cm^2, respectively. Figures 6 and 7 show the dose profile curves

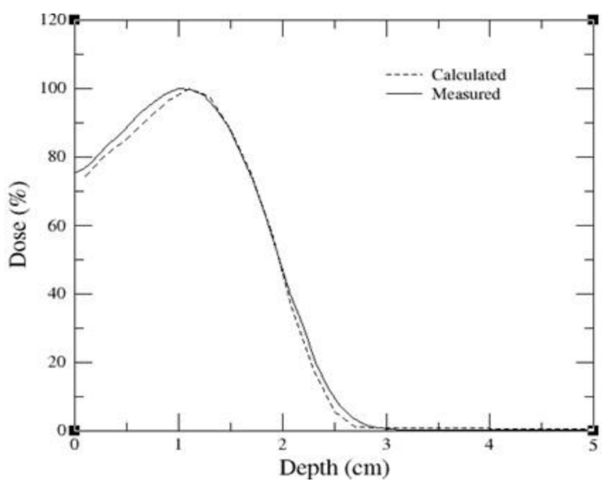

Figure 2: Comparison of measured 5 MeV and calculated 5.9 MeV PDD curves for 10 × 10 cm² field size and 100 SSD.

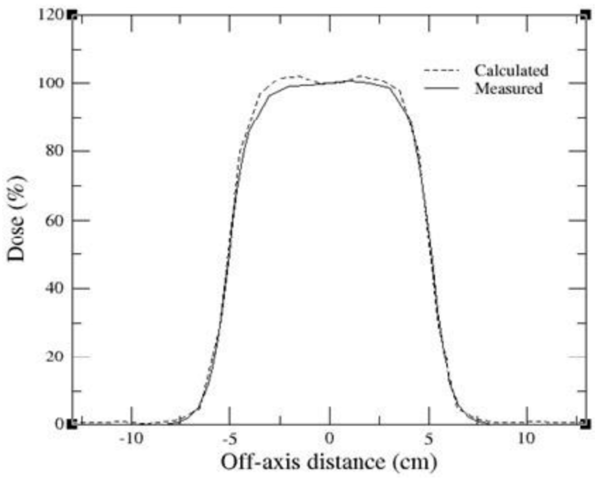

Figure 3: Comparison of measured 5 MeV and calculated 5.9 MeV dose profile curves for 10 × 10 cm² field size and SSD=100 cm.

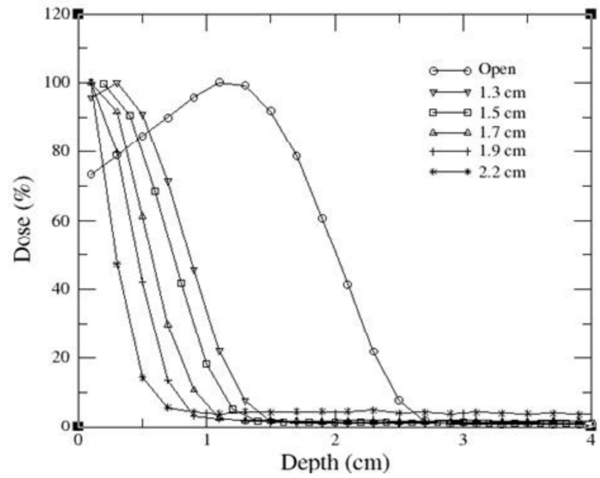

Figure 4: PDD curves for 5 MeV electron beam for 10 × 10 cm², open field and different thicknesses of spoiler.

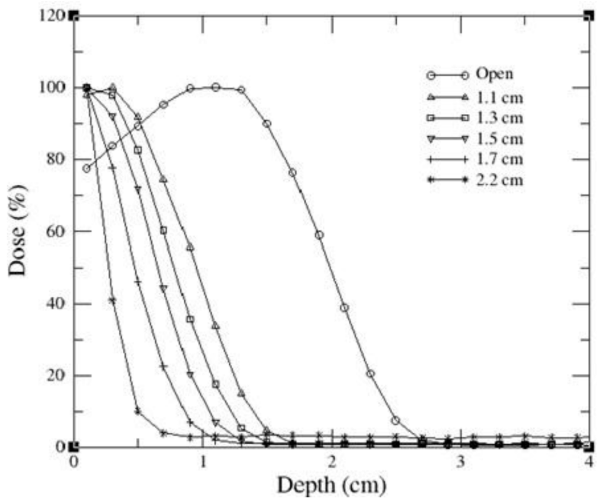

Figure 5: PDD curves for 5 MeV electron beam for 20 × 20 cm², open field and different thicknesses of spoiler.

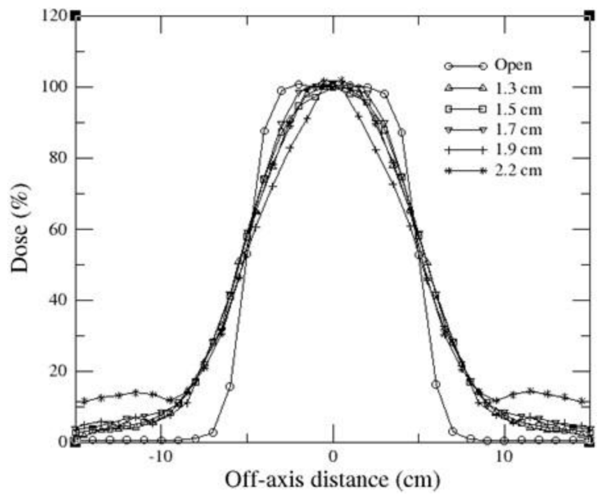

Figure 6: Dose profile of 5 MeV electron beam for 10 × 10 cm², open field and with different thicknesses of spoiler.

with different thicknesses of acrylic spoiler. Figure 8 shows the change in R_{90} as a function of spoiler thickness for both fields. A summary of surface dose percentage, R_{90}, R_{50}, output correction factor and penumbra width created with different thicknesses of spoiler is shown in Table 1.

Discussion

The aim of this study was to evaluate the therapeutic properties of a 5 MeV electron beam when using a spoiler for the local treatment of MF tumors by MC simulation method. Benchmarking of the developed 5.9 MeV electron beam model demonstrated a maxi-

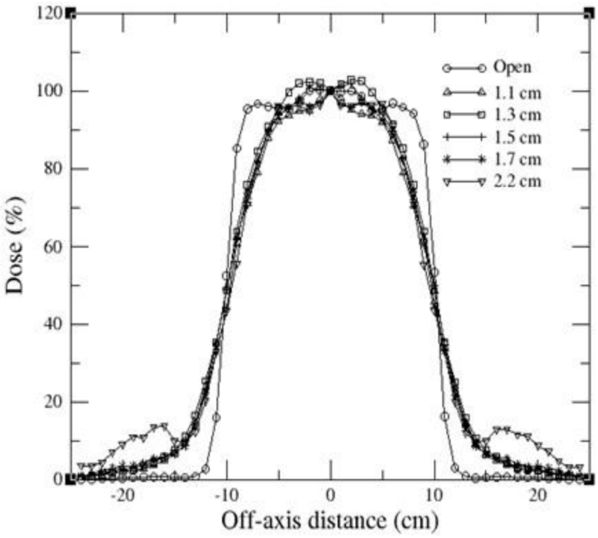

Figure 7: Dose profile of 5 MeV electron beam for 20 × 20 cm^2, open field and with different thicknesses of spoiler.

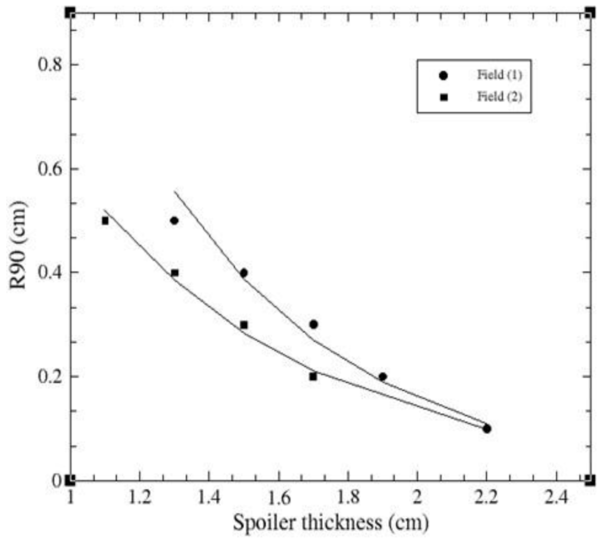

Figure 8: Therapeutic range, R_{90}, as a function of spoiler thickness for two fields 10 × 10 cm^2 (Field 1) and 20 × 20 cm^2 (Field 2), 5 MeV electron beam.

Table 1: Percent surface dose, R_{90}, R_{50}, output correction factor and penumbra of two fields 10 × 10 cm^2 and 20 × 20 cm^2, 5 MeV electron beam as a function of spoiler thicknesses.

Field size (cm^2)	Spoiler Thickness (cm)	Surface dose (%)	R_{90} (cm)	R_{50} (cm)	Output factor correction	Penumbra %80 - %20 (cm)
10×10	0.0	73.20	1.5	2.00	1.000	1.6
	1.3	95.60	0.5	0.87	0.625	4.4
	1.5	99.60	0.4	0.76	0.504	4.2
	1.7	100.0	0.3	0.59	0.376	4.1
	1.9	100.0	0.2	0.47	0.350	4.2
	2.2	100.0	0.1	0.29	0.097	4.3
20×20	0.0	77.30	1.5	2.00	1.000	1.7
	1.1	97.90	0.5	0.96	0.951	5.5
	1.3	100.0	0.4	0.78	0.827	5.1
	1.5	100.0	0.3	0.65	0.737	5.1
	1.7	100.0	0.2	0.49	0.652	5.0
	2.2	100.0	0.1	0.28	0.220	4.9

mum difference of %2 between calculated and measured PDD curves in the build-up region. In other areas, the differences were smaller and not more than %2. To verify the simulation of the scattering foil and collimation system, measured and calculated lateral dose profiles were compared. The comparison revealed less than %1 difference in the vicinity of central axis, and less than %2 at the edges of the field. Different thicknesses of acrylic spoiler were used to reduce the treatment depth (R_{90}) of an open 5 MeV electron beam from 1.5 cm to at least 0.1 cm while boosting the surface dose to more than %90 with respect to dose at d_{max}. For each spoiler thickness, investigated dosimetry specifications including PDD curves, lateral dose profiles and output factors for 10 × 10 cm^2 and 20 × 20 cm^2 field sizes. Results indicated that in the presence of a 1.3 cm spoiler, R_{90} changed from 1.5 cm (open field) to 0.5 cm and 0.4 cm for 10 × 10 cm^2 and 20 × 20 cm^2 field sizes, respectively. Figure 8 shows an exponential relationship between increase in spoiler thickness and change in R_{90}. In this research, the general trend of increases in surface dose and shift of d_{max} to the surface were as reported by others. Unwanted effects of spoiler reported in the literature include bremsstrahlung photon contamination, increased width of penumbra and increased out-of-field dose [12]. In this study, the increase in bremsstrahlung contamination was noticeable only for 2.2 cm spoiler, about %2 in both field sizes. Maximum increase in penumbra width was 2.8 cm and 3.8 cm for 10 × 10 cm^2 and 20 × 20 cm^2 field sizes, respectively. Although without spoiler, the penumbra difference between the two field sizes was only 1 mm; in the presence of spoilers, the difference was as large as 1 cm. Similar increase in penumbra, 1.9 to 3.6 cm, was reported by Hernández et al. for aluminum foil spoilers in 6 MeV electron beam [12]. Increase in penumbra is due to scattering of low-energy electrons when passing through spoiler which results in rise in percent surface dose as well as out of field dose [12]. When using beam spoilers, the problem of broaden penumbra can be solved by placing lead penumbra trimmers at the outer field edge. Beam output factor (OF) for different spoiler thicknesses was measured. For the 1.3 cm spoiler, OF reduction was 0.375 and 0.173 for 10 × 10 cm^2 and 20 × 20 cm^2 field sizes, respectively. In the aluminum spoiler study, much larger reduction in output was reported, i.e. OF= 0.270 for 10 × 10 cm^2 field size [12]. The higher reduction in output is a function of electron scattering angle which is larger for higher density materials and for smaller field sizes.

Conclusion

The application of water equivalent spoilers for treatment of Mycosis Fungoides using local electron fields was studied. In general, R_{90} decreased exponentially with increase in spoiler thickness. The effect of field size on penumbra was much larger for spoiled beam compared to the open beam. For a larger field size, a smaller thickness of spoiler provided a higher surface dose and output factor and a lower beam penetration. The results of this research can be applied to optimize the radiation treatment of MF patients in our hospital.

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Conflict of Interest

None

References

1. Hogstrom KR, Almond PR. Review of electron beam therapy physics. *Phys Med Biol*. 2006;**51**:R455-89. doi: 10.1088/0031-9155/51/13/R25. PubMed PMID: 16790918.
2. Khaledi N, Arbabi A, Sardari D, Mohammadi M, Ameri A. Simultaneous production of mixed electron--photon beam in a medical LINAC: A feasibility study. *Phys Med*. 2015;**31**:391-7. doi: 10.1016/j.ejmp.2015.02.014. PubMed PMID: 25773884.
3. Rosenberg I. Radiation oncology physics: a handbook for teachers and students. *British journal of cancer*. 2008;**98**:1020. doi: 10.1038/sj.bjc.6604224. PubMed PMCID: 2266863.
4. Khan FM, Gibbons JP. Khan's the physics of radiation therapy: Lippincott Williams & Wilkins; 2014.
5. Criscione VD, Weinstock MA. Incidence of cutaneous T-cell lymphoma in the United States, 1973-2002. *Arch Dermatol*. 2007;**143**:854-9. doi: 10.1001/archderm.143.7.854. PubMed PMID: 17638728.
6. Kazmierska J. Clinical results of the total skin electron irradiation of the mycosis fungoides in adults.

Conventional fractionation and low dose schemes. *Rep Pract Oncol Radiother*. 2014;**19**:99-103. doi: 10.1016/j.rpor.2013.08.008. PubMed PMID: 24936327. PubMed PMCID: 4054994.

7. Parida DK, Rath GK. Advantages and implications of high dose rate (HDR) total skin electron irradiation (TSEI) for the management of Mycosis Fungoides. Indian experience. *Rep Pract Oncol Radiother*. 2014;**19**:104-8. do: 10.1016/j.rpor.2013.07.001. PubMed PMID: 24936328. PubMed PMCID: 4054997.
8. Yahalom J, Illidge T, Specht L, Hoppe RT, Li YX, Tsang R, et al. Modern radiation therapy for extranodal lymphomas: field and dose guidelines from the International Lymphoma Radiation Oncology Group. *Int J Radiat Oncol Biol Phys*. 2015;**92**:11-31. doi: 10.1016/j.ijrobp.2015.01.009. PubMed PMID: 25863750.
9. Kassaee A, Bloch P, Yorke E, Altschuler MD, Rosenthal DI. Beam spoilers versus bolus for 6 MV photon treatment of head and neck cancers. *Med Dosim*. 2000;**25**:127-31. doi: 10.1016/S0958-3947(00)00038-8. PubMed PMID: 11025258.
10. Kang SK, Cho BC, Park SH, Park HC, Bae H, Kim JO, et al. Monte Carlo-based treatment planning for a spoiler system with experimental validation using plane-parallel ionization chambers. *Phys Med Biol*. 2004;**49**:5145-55. doi: 10.1088/0031-9155/49/22/009. PubMed PMID: 15609564.
11. McKenzie AL. A simple method for matching electron beams in radiotherapy. *Phys Med Biol*. 1998;**43**:3465-78. doi: 10.1088/0031-9155/43/12/006. PubMed PMID: 9869025.
12. Hernandez V, Sanchez-Reyes A, Badal A, Vila A, Mur E, Pedro A, et al. Use of an electron spoiler for radiation treatment of surface skin diseases. *Clin Transl Oncol*. 2010;**12**:374-80. doi: 10.1007/s12094-010-0519-3. PubMed PMID: 20466622.
13. Park SY, Ahn BS, Park JM, Ye SJ, Kim IH, Kim JI. Dosimetric comparison of 4 MeV and 6 MeV electron beams for total skin irradiation. *Radiat Oncol*. 2014;**9**:197. doi: 10.1186/1748-717X-9-197. PubMed PMID: 25194217. PubMed PMCID: 4261910.
14. Das IJ, Kase KR, Copeland JF, Fitzgerald TJ. Electron beam modifications for the treatment of superficial malignancies. *Int J Radiat Oncol Biol Phys*. 1991;**21**:1627-34. doi: 10.1016/0360-3016(91)90342-2. PubMed PMID: 1938573.
15. Nygaard K, Odland OH, Kvinnsland Y, Nygaard B, Heggdal J, Muren LP. Measurements and treatment planning calculations of electron dose distributions below bolus edges. *Radiother Oncol*. 2005;**74**:217-20. doi: 10.1016/j.radonc.2004.12.014. PubMed PMID: 15734210.
16. Wieslander E. Verification of dose calculation algorithms in treatment planning systems for external radiation therapy: a Monte Carlo approach: Medical Radiation Physics, Lund University; 2006.
17. Jabbari N, Hashemi-Malayeri B. Monte Carlo modeling of electron beams from a NEPTUN 10PC medical linear accelerator. *Nukleonika*. 2009;**54**:233-8.
18. Khan FM, Doppke KP, Hogstrom KR, Kutcher GJ, Nath R, Prasad SC, et al. Clinical electron-beam dosimetry: report of AAPM Radiation Therapy Committee Task Group No. 25. *Med Phys*. 1991;**18**:73-109. doi: 10.1118/1.596695. PubMed PMID: 1901132.
19. Burns DT, Ding GX, Rogers DW. R50 as a beam quality specifier for selecting stopping-power ratios and reference depths for electron dosimetry. *Med Phys*. 1996;**23**:383-8. doi: 10.1118/1.597893. PubMed PMID: 8815381.
20. Healy BJ, Padmanabhan P, Nitschke KN. Tin foil as bolus material for therapeutic electron beams from the Varian Clinac 2100C/D. *Australas Phys Eng Sci Med*. 2005;**28**:8-13. doi: 10.1007/BF03178858. PubMed PMID: 15920984.