Custom electron bolus treatment planning with skin collimation using the pencil-beam redefinition algorithm

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Purpose/Objective

The aims of this study are to demonstrate (1) the improvement in the patient dose distribution from using skin collimation when treating with bolus electron conformal therapy (ECT) and (2) the utility of the pencil beam redefinition algorithm (PBRA) for calculating dose in the presence of bolus and skin collimation.

Introduction

ECT is defined as the use of one or more electron beams for the following purpose: (1) containing the planning target volume (PTV) in the 90% (of given dose) dose surface: (2) achieving as homogenous a dose as possible (e.g., 90% to 100%) or a prescribed heterogeneous dose distribution to the PTV; and (3) delivering a minimal dose to underlying critical structures and normal tissue [1]. ECT can be achieved through energy modulation of the incident electron beam by using a custom wax bolus that has been fabricated using a milling machine to fit the patient surface and provide variable energy degradation across the field (Fig. 1a) [2-5]. For bolus ECT, the bolus is designed for the 90% dose surface to encompass the PTV and to conform to its distal surface. This requires a beam energy sufficiently high to reach the deepest regions of the PTV and results in thicker bolus over shallower portions of the PTV, leading to a large penumbra width and an increased dose to structures adjacent to the PTV. Tertiary skin collimation between the patient and bolus sharpens the penumbra and can reduce this effect (Fig. 1b).

Standard computer treatment planning using a standard pencil beam algorithm or Monte Carlo methods is more complex when lead skin collimation is present and has yet to be demonstrated. Treatment planning using the PBRA [6] is advantageous in that beam data is easily commissioned and the accuracy of PBRA dose calculations [7,8] is comparable to Monte Carlo-type dose algorithms such as BEAM/DOSXYZ [9,10] (Fig. 2). It is also possible to model beam modifiers such as custom bolus and skin collimaton as was done in this study.

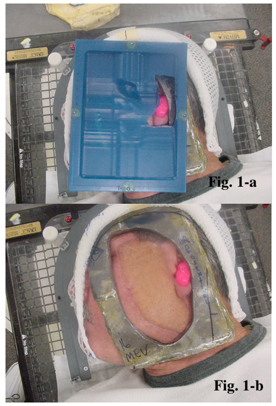

Fig. 1 Patient setup for ECT using a custom electron bolus (a) and skin collimation (b).

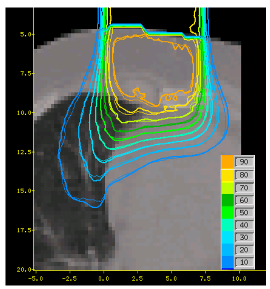

Fig. 2. Comparison of isodose lines computed for an internal mammary chain breast field using a Monte Carlo-type dose algorithm (thick lines) and the PBRA (thin lines).

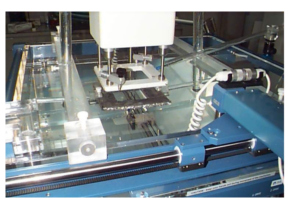

Fig. 3. Experiment setup for measuring dose profiles in water beneath lead skin collimation.

Methods

Skin collimation has been incorporated into the PBRA on our in-house treatment planning system COPPERPlan [11-13]. The PBRA was modified such that the electron fluence of pencil beams exiting the skin collimation was set to zero.

PBRA accuracy of dose beneath skin collimation was evaluated by comparing calculated with measured dose profiles. Dose profiles were measured at 10 and 15 MeV in a 100-cm SSD water phantom for a 10x10-cm² applicator insert. Skin collimation was simulated by positioning a 1-cm thick lead plate with an 8x8-cm² opening on the water surface (Fig. 3). Measurements were also made with 1 or 2 cm of water above the bottom surface of the lead to simulate the bolus.

The utility of skin collimation was studied using a CT model of a patient that presented with basal cell carcinoma of the left parotid. Two bolus ECT plans were created, one without and one with skin collimation. In the first plan, the field size was sufficiently wide and bolus designed so that the 90% dose contour conformed to the distal surface of the PTV. In the second plan, skin collimation was added to sharpen the penumbra. Dose-volume histograms (DVHs) for the PTV, lens, and ocular orbit were evaluated.

Results

Results show that the PBRA-calculated dose in the presence of skin collimation is sufficiently accurate for treatment planning. Figure 4 shows a comparison of the PBRA-calculated and measured dose profiles at the 3-cm depth with and without skin collimation present at the 2-cm depth. PBRA-calculated doses agree within 2% in the high dose region (D > 90%, D_{max}=100%), and distances to agreement are within 1 mm in high-dose gradient regions of the penumbra. Differences in the low dose region (D < 10%) are as large as 4% and are attributed to the PBRA not modeling large-angle scattering.

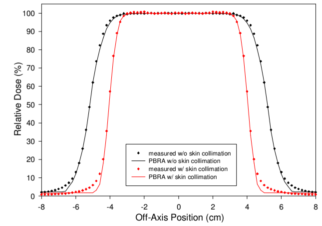

Fig. 4. Comparison of 3-cm depth dose profiles measured and calculated in water for a 15-MeV electron beam at the with and without lead collimation present at the 2-cm depth.

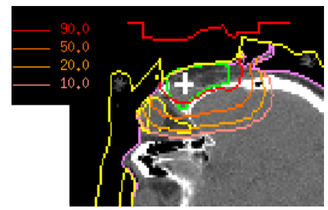

Fig. 5. PBRA-calculated dose distribution for custom electron bolus (red line floating above CT image of patient head) treatment plan without skin collimation present. The 90% isodose line (red) conforms to the distal end of PTV (green line).

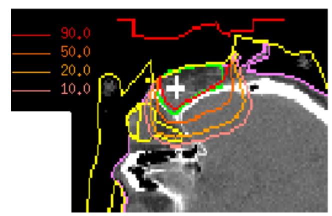

Fig. 6 PBRA-calculated dose distribution for custom electron bolus (red line floating above CT image of skull) treatment plan with skin collimation present. Again the 90% isodose line (red) conforms to the distal end of PTV (green line) but less dose is delivered to the orbit (yellow contour inside CT image of patient head)

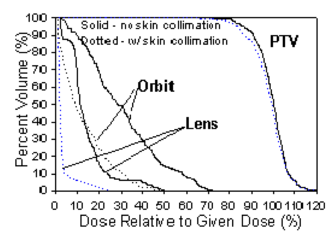

Fig. 7 Comparison of DVHs for custom electron bolus treatment plans with and without skin collimation present (given dose = 53 Gy).

Results cont.

The superior aspect of the patient plan using bolus ECT without skin collimation is illustrated in Figure 5. Due to the width of the beam penumbra and the proximity of the PTV to the eye, the lens and ocular orbit receive considerable dose compared to the plan with skin collimation in Figure 6. DVHs in Figure 7 show insignificant changes in the DVH of the PTV, but significant changes in the DVHs of the critical structures. For the lens, dose to the 10% volume is reduced from 24% (13 Gy) to 5% (3 Gy). For the ocular orbit, dose is reduced from 58% (31 Gy) to 30% (16 Gy).

Conclusions

1) Some patient treatment plans with bolus ECT will benefit from the utility of skin collimation for sharpening the penumbra, particularly when the PTV lies near critical structures.

2) The PBRA can be used for calculating electron dose within 4% in the presence of skin collimation, particularly in the case of bolus ECT.

References

1) KR Hogstrom et al. "Modulated Electron Therapy." In: *Intensity-Modulated Radiation Therapy: The State of the Art*. JR Palta and TR Mackie (eds.) AAPM Medical Physics Monograph No. 29. Proceeding of the AAPM 2003 Summer School. Madison, WI: Medical Physics Publishing, pp 749-786, 2003.

2) DA Low et al. "Electron bolus design for radiotherapy treatment planning: bolus design algorithms," *Med. Phys*. 19:115-124, 1992.

3) DA Low et al. "Computer-aided design and fabrication of an electron bolus for treatment of the paraspinal muscles," *Int. J. Radiat. Oncol. Biol. Phys*. 33:1127-1138, 1995.

4) GH Perkins et al. "A custom three-dimensional electron bolus technique for optimization of postmastectomy irradiation." *Int. J. Radiat. Oncol. Biol. Phys*. 51:1142-1151, 2001.

5) R Kudchadker et al. "Conformal Head and Neck Radiotherapy Using Custom Electron Bolus," *Med. Phys*. 29:1337, 2002.

6) AS Shiu and KR Hogstrom, "Pencil-beam Redefinition algorithm for electron dose distributions," *Med. Phys.* 18:7-18, 1991.

7) RA Boyd et al. "Electron pencil-beam redefinition algorithm dose calculations in the presence of heterogeneities," *Med. Phys*. 28:2096-2104, 2001.

8) RA Boyd, Pencil-Beam Redefinition Algorithm Dose Calculations for Electron Therapy Treatment Planning. Ph.D. Dissertation, Graduate School of Biomedical Sciences, The University of Texas Health Sciece Center-Houston, 2001.

9) DWO Rogers et al. "BEAM: A Monte Carlo code to simulate radiotherapy treatment units," *Med. Phys*. 22:503-524, 1995.

10) C-M Ma et al. "DOSXYZ User's Manual," Report No. PIRS-0509b, National Research Council of Canada, 1995.

11) G Starkschall et al. "A full three-dimensional radiotherapy treatment planning system," *Med. Phys*. 18:647, 1991.

12) G Starkschall et al. "Electron-beam bolus for 3-D conformal radiation therapy." In: *3D Radiation Treatment Planning and Conformal Therapy Symposium*. JA Purdy and B Emami (eds.) St. Louis, MO: Medical Physics Publishing, Madison, WI. 1995: 265-282, 1993.

13) G Starkschall et al. "Tools for 3-D electron-beam treatment planning." In: *XIth International Conference on the Use of Computers in Radiation Therapy*. AR Hounsell, JM Wilkinson, and PC Williams (eds.) Manchester, UK: Christie Hospital NHS Trust, pp 126-127, 1994