Advances in Radiation Oncology (2023) 8, 101289

advances in radiation oncology

www.advancesradonc.org

Research Letter

Development and Dosimetric Characterization of a Customizable Shield for Subtotal Skin Electron Beam Therapy

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Received 3 March 2023; accepted 8 June 2023

Purpose: Purpose: Subtotal skin electron beam therapy may be an option for patients with cutaneous lymphoma receiving radiation therapy to treat large areas of their skin but may benefit from sparing specific areas that may have had previous radiation therapy, are of specific cosmetic concern, and/or show no evidence of disease. We report here on the design, implementation, and dosimetric characteristics of a reusable and transparent customizable shield for use with the large fields used to deliver total skin electron beam therapy at extended distance with a conventional linear accelerator.

Methods and Materials: A shield was designed and manufactured consisting of acrylic blocks that can be mounted on a steel frame to allow patient-specific shielding. The dosimetry of the device was measured using radiochromic film.

Results: The shield is easy to use and well-tolerated for patient treatment, providing minimal electron transmission through the shield with a sharp penumbra at the field edge, with no increase in x-ray dose. We report on the dosimetry of a commercial device that has been used to treat more than 30 patients to date.

Conclusions: The customizable shield is well suited to providing patient-specific shielding for subtotal skin electron beam therapy.

Introduction

Skin-directed radiation therapy is an effective palliative option for patients with cutaneous lymphomas, ranging from local treatment of specific areas to total skin electron (TSE) beam therapy.[1-3] TSE treatment with low-energy beams (≤9 MeV) can offer uniform dose distributions across the patient's total skin with low toxicity,[3,4] particularly with boosts to regions at

Sources of support: This work had no specific funding.

Research data are stored in an institutional repository and will be shared upon request to the corresponding author.

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https://doi.org/10.1016/j.adro.2023.101289

risk of underdosing because of self-shielding and surface obliquity. TSE is typically delivered using large electron fields with the patient set up at an extended distance from the linear accelerator (usually several meters), with the patient either assuming multiple poses[5] or standing on a rotating platform.[6] Because the disease is typically limited to the skin, it is common to shield areas such as the eyes or the fingernails and toenails to minimize the risk of toxicity to these organs.[1,7]

Additional patient-specific shielding may also be considered based on the extent of disease, previous radiation therapy history, and patient preference for avoiding alopecia or other cosmesis concerns. Subtotal skin electron (STSE) beam therapy (also known as "partial skin electron beam therapy") can be achieved using a variety of shielding approaches.[8-15] Most importantly, the device must have negligible electron transmission through the shield, a sharp penumbra at the field edge, limited effect on the delivered dose in the treatment areas away from the field edge, and no measurable increase in x-ray contamination dose. Ideally, the shielding should be reusable, simple to customize for a specific patient, and allow for reproducible setup. Other desirable characteristics are visual transparency (for verification of patient positioning and patient comfort) and that it not come in direct contact with the patient (for patient comfort, safety, and sanitary concerns). No commercially available solution met all of these requirements, so our team worked with a commercial vendor (Radiation Products Design, Albertville, MN) to manufacture a customizable shielding system based on our design and specifications. The intent was to provide shielding for treating large areas of skin that extends circumferentially around the patient, which can be well-defined in terms of a location (or 2) along the patient's craniocaudal axis. We report key design features and dosimetric characterization of the system for clinical delivery of STSE.

Methods and Materials

At our institution, TSE beam therapy is delivered using a modified Stanford technique,[5] with the patient set up 2.5-m lateral to isocenter.[16] For each of the 6 poses, a 6 MeV high dose rate TSE beam is used to deliver 2 fields, offset from the horizontal by 19°. For treatment, the patient is positioned on a wooden treatment platform, and the patient's height is adjusted by placing large Styrofoam blocks under their feet to ensure that their umbilicus is at the level of the beam's central axis when the gantry is positioned at the horizontal (equivalently, this is the center of the line connecting the central axis of the dual field).

A TSE-specific beam spoiler is affixed to wooden posts at the corners of the treatment platform and is used to reduce the energy of the incident electrons and to provide secondary scattering. This beam spoiler is made from a 0.6-cm thick slab of clear, scratch-resistant, extruded acrylic (density 1.2 g/cm^3). The patient is set up so that they are 10 cm behind the spoiler.

The STSE shielding system is composed of 16 acrylic slabs (10.5 cm in height) that can be adjustably mounted on a wheeled steel frame (Figs. 1 and 2) and positioned directly in front of the beam spoiler for treatment (and quickly moved between the storage area and the treatment room). Clear cast acrylic was an ideal choice for transparent shielding material because of its low effective atomic number (minimizing bremsstrahlung radiation), with flame polishing on the edges to improve durability. A slab thickness of 2.5 cm of the cast acrylic (density 1.2 g/cm^3) was determined to be sufficient to fully shield 6 MeV electron beams when used in conjunction with the beam spoiler. This provided a total water equivalent thickness of 3.7 cm, which is longer than the previously measured practical range for the electrons in this beam. Ship-lapping was used to minimize transmission between adjacent

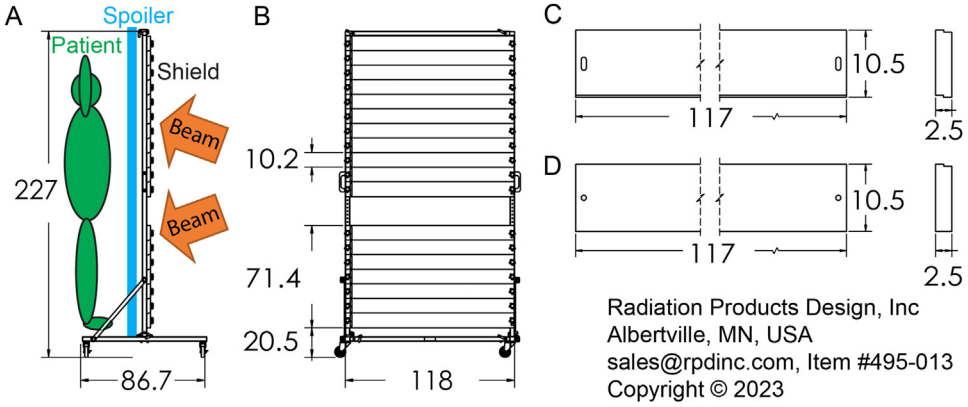

Figure 1 (A) Front and (B) side elevation schematic diagrams of subtotal skin shield and individual (C) middle block and end blocks. The front elevation shows the positioning of the spoiler and patient, as well as the incident beam directions. Dimensions are given in centimeters. Reproduced with permission (Radiation Products Design, Inc).

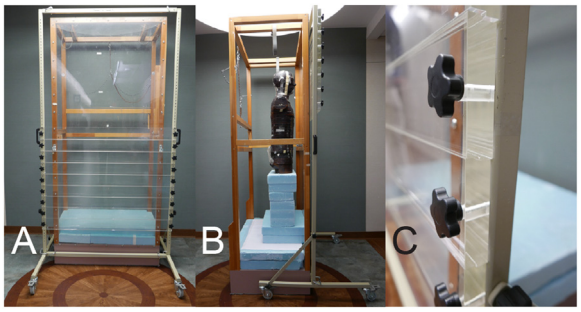

Figure 2 The customizable acrylic shield is shown set up in front of the treatment stand to shield the lower extremities for upper hemi-body treatment with the (A) front and (B) side view. (C) Side-view of the blocks showing the ship-lapped edges and mounting screws.

blocks, with a flat surface on the blocks used at the transmission edge of the shielding. The blocks are secured to the steel frame with screws, and to reduce the time to screw in the blocks a custom set of adapters was 3-dimensionally printed for use with electric drills.

Dosimetric measurements were performed under treatment conditions using the clinical TSE technique, with the treatment stand placed so that the front edge of the beam degrader was 242-cm lateral to the treatment isocenter. All beams were delivered using a dual-field technique (beams ±19° from horizontal) with a high dose rate 6 MeV beam. To assess the shielding factor, transmission measurements were made with the treatment area entirely shielded. Measurements were made for 4 clinical shielding scenarios, treating the (1) lower hemi-body, (2) upper hemi-body, (3) head and neck region, and (4) mid-torso (Figs. 2 and 3). Vertical distance from the junction of the dual-field to the shield's edge for each shielding arrangement is given in Table 1. Percent depth dose and surface-dose profiles (both vertical and horizontal) were measured using radiochromic film (Gafchromic EBT3; Ashland Advanced Materials, Bridgewater, NJ). A solid water phantom was set up at the standard patient treatment position of 10-cm behind the beam spoiler (shown in Fig. 3B). For each shielding arrangement, the dose at a depth of 5 cm in the phantom was taken to be the x-ray contamination dose.

Surface dose was also assessed using films placed on either an anthropomorphic phantom (for upper hemi-body, head and neck, and midtorso shielding arrangements as shown in Fig. 3A) or a cylindrical phantom (for lower hemi-body), which was then rotated successively by 60° through all 6 positions, representing a patient treatment. Surface dose was compared with the dose expected at the given location for patient TSE treatment to determine whether a calibration factor correction was necessary for the given shielding arrangement. Film was analyzed according to institutional protocol.[17]

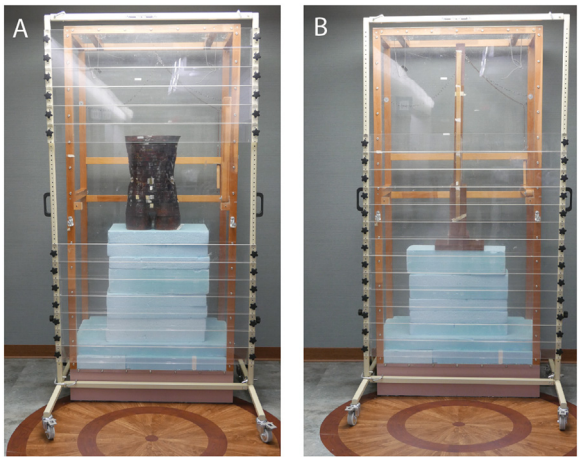

Figure 3 Subtotal skin shield arranged for (A) midtorso treatment (with anthropomorphic phantom for 6-field output measurements) and (B) head and neck only treatment with phantom arranged for vertical profile measurement with radiochromic film placed on meterstick for alignment.

Results

The purchased STSE shielding device met our specifications for physical dimensions, transparency, structural integrity, and patient safety. When fully shielded, the transmission was less than 1% for most of the treatment area, increasing to 2% at 80-cm superior to the field junction (Fig. 4). There was no evidence of interblock transmission through the ship-lapping. For the shielding arrangements, comparison of the percent depth doses with the TSE baseline indicated no meaningful differences: D90 and D80 measurements agreed to within 0.3 mm, and x-ray

Table 1 Key dosimetric parameters for different shielding arrangements

Beam arrangement	Lower hemi-body	Upper hemi-body	Head and neck	Mid-torso
Distance to shield edge* (cm)	16	16	33	−27, +33
Distance to 90% dose (cm)	+6	+7	+7	+2.5
Distance to 10% dose (cm)	−5	−6	−4	−9
Output correction factor	1	1	1	1.015

+/− indicates distance into the unshielded/shielded regions of the field.
* Distance measured from junction of dual-field.

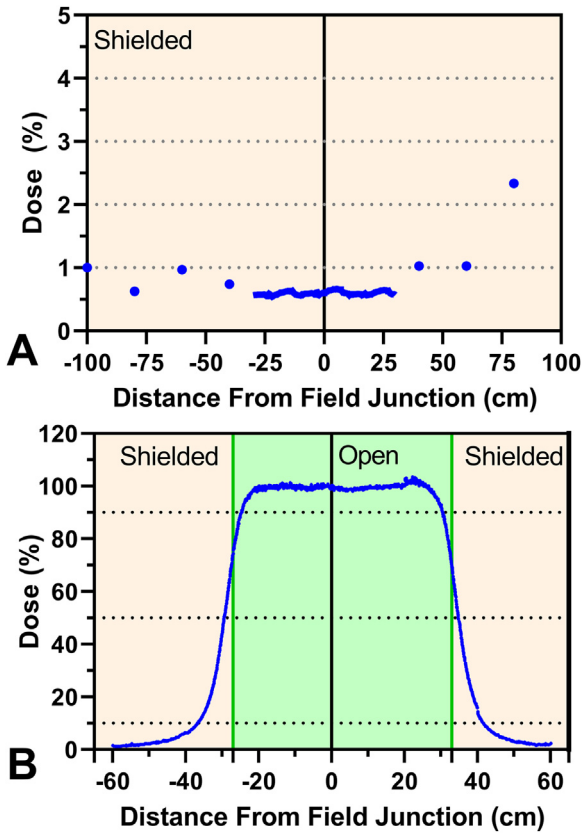

Figure 4 Vertical profile along midbody of (A) transmission dose with the patient entirely blocked by the shield and (B) shield arranged for lower hemi-body treatment (green vertical line represents the physical edge of shield), as percent of prescribed dose.

contamination remained less than 1%. Vertical profiles (the superior-inferior direction along midline) for representative shielding arrangements are shown in Fig. 4, with the penumbra values given in Table 1. Based on the 6-field surface dose measurements of the 4 tested shielding arrangements, only the midtorso shielding arrangement would require an output factor correction for monitor unit calculation (that is, an increase of 1.5%).

Discussion

The reusable and transparent shield provides the intended shielding without increasing x-ray dose. Most importantly, the penumbra for the shielding is sharp (the distance between 90% and 10% dose is less than 13 cm) even with the shield placed 11-cm upstream from the patient's surface (that is, in front of the beam degrader). This position for the shielding was as close to the patient as we could position without requiring modification of patient poses and positioning (and ultimately safety) to accommodate it. We felt that the decrease in dose homogeneity resulting from these modifications outweighed the minor potential gains in penumbra sharpness. In addition, placing the shield in front of the degrader has some key advantages: the shield does not make direct contact with the patient during treatment and does not impede patient positioning, pose any risk, or require the additional cleaning and disinfecting required for equipment that contacts the skin of STSE patients (streamlining the pre- and posttreatment workflows). Phantom measurements for 4 common shielding scenarios indicated that minimal or no output correction factors were needed, because the delivered dose to exposed regions was consistently within 2% of the output without the STSE system. A priori, we had concerns that the use of a metal frame could increase secondary photon production, leading to an increased x-ray contamination dose, but there was no measured difference in x-ray dose to the phantoms.

This device is intended to treat large areas of affected skin extending circumferentially around the patient. It is intended to treat the patient's entire skin above or below a specified location (or between 2 locations) along the patient's caudocranial axis. If more complex or irregular shielding is required, alternative shielding methods should be used. However, many of these approaches are compatible with the STSE shield reported here. For fields smaller than 60 cm in height, there may be a reduction in output: it may be necessary to adjust the planned monitor units based on patient-specific phantom measurements before the first fraction and as indicated by in vivo dosimetry. Treatment areas smaller than 30×30 cm^2 may be better suited to conventional electron therapy or orthovoltage therapy. Discussion between the physician and the covering physicist's team and therapy team is needed to determine whether this device is the appropriate shielding method for a given patient.

In addition, patient set-up can contribute to variations in the delivered dose: in vivo dosimetry is recommended for assurance of dose delivery accuracy, particularly in areas of special concern to the patient or physician. For instance, if the distance from the degrader to the patient is changed, it can have a significant effect on the dose distribution and measured output, particularly for the head and neck shielding scenario. Furthermore, patient curvature can have an increased effect on the dose homogeneity because of the shield blocking 1 of the 2 dual fields. This should be taken into account when determining the positioning of the edge of the customizable shielding, and the specific trade-offs should be discussed with the physician. In vivo dosimetry should be used throughout treatment in those regions and may inform adjustments to the shielding and patient positioning fields for future fractions (and even identify areas to boost).

Conclusion

The customizable shield provides a safe, effective, and efficient way to deliver STSE. It combines ease of use with

excellent dosimetric properties in a commercial product. The shield has been used to treat more than 30 patients so far.

Disclosures

William Breen reports being on the scientific advisory board for GE Healthcare, with all payments made to his institution. John Lucido reports receiving an honorarium paid to his institution for work as grant referee for Global Bridges Oncology and consulting fees paid to his institution by Varian Medical Systems. Aaron Mangold reports currently receiving research grants paid to his institution by Regeneron, Corbus, Incyte, Pfizer, Eli Lilly, Argenyx, Palvella, Abbview, Priovant, and Merck and previous research grants in the past 36 months for Kyowa Kirin, Miragen, Sun Pharma, Elorac, Janssen, and Novartis. He also is currently receiving consulting fees paid to him from Janssen and Boehringer Ingelheim and paid to his institution from Argenyx, Incyte, Regeneron, Clarivate, and Pfizer, previously received consulting fees paid to him from Kyowa Kirin, Clarivate, Soligenix, Phlecs, Incyte, Eli Lilly, Momenta, UCB, and Bristol Myers Squibb, and is currently receiving payment for manuscript writing (for a separate manuscript) from Janssen. He holds a patent for "Topical Ruxolitinib for Treating Lichen Planus" (PCT/US2021/053149; 63/086,898) and has filed for a patent for "Methods and Materials for Assessing and Treating Cutaneous Squamous Cell Carcinoma" (63/423,254). Aaron Mangold is also currently on the Advisory Board for Bristol Myers Squibb currently the President of Pacific Dermatology Society, the Chair of the Community Outreach Committee for the American Academy of Dermatology, on the Board of Directors for the US Cutaneous Lymphoma Consortium, was previously the President of the Arizona Dermatology and Dermatological Society and a Board Member for the Arizona Medical Association (all unpaid), has personal stock ownership of Intellia Therapeutics and Editas, and is receiving medical writing support from Pfizer and Janssen. Chris Deufel reports being a board member of the American Brachytherapy Society.

Acknowledgments

The authors thank Radiation Products Design, Inc for permission to reproduce the image shown in Fig. 1.

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