Dosimetric characteristics of Thermo-Shield material for orthovoltage photon beams

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Conventionally, lead has been used for field shaping in orthovoltage radiation therapy. Recently, a compensator material named Thermo-Shield was presented for field shaping in electron beams. Thermo-Shield is composed of nontoxic, high atomic weight metal particles dispersed in a thermoplastic matrix. It is manually moldable and conforms to human anatomy or any shape at temperatures of 108–132 °F. It is reusable and can be continuously reshaped to better fit the treatment field. Dosimetric characteristics of thermoplastic material were studied for Philips RT250 orthovoltage photon beams ranging from 75 to 250 kVp. It was found that Thermo-Shield should be four to five times thicker than lead to achieve the same transmission (less than 5%). However, it did not cause significant degradation in penumbra. Clinical procedures for use are discussed. © *2003 American Association of Physicists in Medicine.* [DOI: 10.1118/1.1572431]

Key words: radiation therapy, dosimetry, orthovoltage beam, transmission, Thermo-Shield

I. INTRODUCTION

Radiotherapy has traditionally played an important role in the treatment of a wide range of benign and malignant skin tumors. One of the major concerns of radiotherapy is sparing healthy tissue while irradiating target tissue. To minimize dose and to shield sensitive organs in radiation therapy, a shielding block is frequently used to protect surrounding tissues during treatment of skin or oral lesions with therapeutic photon beams. The blocks are made of high atomic number materials and are custom designed for each patient, based on the size and the shape of the area to be shielded or protected. In orthovoltage x-ray treatment, beam shaping and shielding are accomplished by thin sheets of lead shields.[1–3] The sheets can be contoured to the patient's anatomy and holes can be cut into the sheets, creating a field and allowing the radiation to pass through. These blocks outline the field and protect normal tissues. Commonly, the transmission factors for the blocking material are less than 5%. However, lead sheets suffer from issues such as nonuniformity of thickness, difficulties in accurate cutting and alignment, high melting point, and toxicity. Recently, a material called Matrix Thermo-Shield (Med-Tec, Inc., Chapel Hill, NC) has been introduced as a replacement for lead. Currently, dosimetric studies on the Thermo-Shield are rare. A study by Paliwal *et al.*[4] explored the attenuation characteristics of this material for clinical beams. While this study was limited to high photon and electron energy beams from a linear accelerator, Thermo-Shield material is, in practice, more suitable for orthovoltage than high energy beams when photon beams are considered.

In this study, we investigated the dosimetric characteristics of Thermo-Shield for orthovoltage photon beams.

II. MATERIALS AND METHODS

A. Transmission characteristics

Photon attenuation characteristics of lead and Thermo-Shield for orthovoltage beams were measured using 5×5 and $10\times10\ \mathrm{cm}^2$ field sizes in broad beam geometry. A Markus chamber was placed in the solid water at 1 mm depth with 12 cm of solid water below for adequate backscatter. Measurement at shallow depth eliminates very low energy electrons produced in the air. The amount of charge collected by the ionization chamber was measured with a CNMC K 607 electrometer, using a bias potential of -300 V across the chamber. The polarity effect was checked and found not to exceed 1%. Measurements were made with 0, 1.4, 1.5, 2,6, 4.8, 6.3, 7.4, 8.9, and 10.4 mm of Thermo-Shield placed above the solid water for all orthovoltage photon energies (75 kVp-2 mm Al filter, 100 kVp-0.2 mm Cu filter, 150 kVp-0.35 mm Cu filter, 250 kVp-0.5 mm Cu filter, and 250 kVp-0.4 mm Th filter) produced by the Philips RT 250 machine. Nominal half-value layers for beams are 2.8 mm Al, 5.5 mm Al, 0.59 mm Cu, 1.3 mm Cu, and 2.3 mm Cu, respectively. To compare the Thermo-Shield attenuation properties with lead attenuation properties, another set of measurements were done using lead slabs of thickness of 0, 0.4, 0.9, 1.3, 1.7, 2.5, and 3.0 cm for all orthovoltage photon energies except 75 kVp, for its low penetration. To fabricate uniform thickness of the Thermo-Shield slab, material was stuffed between two solid plastic slabs after enough time of immersing in 125 °F water. Waxed papers were placed between the plastic and the Thermo-Shield so they would not stick together. Thermo-Shield was then pressed with uniform force between the two plastic slabs until its desirable thickness was achieved. Thickness variation was about ±0.1 mm.

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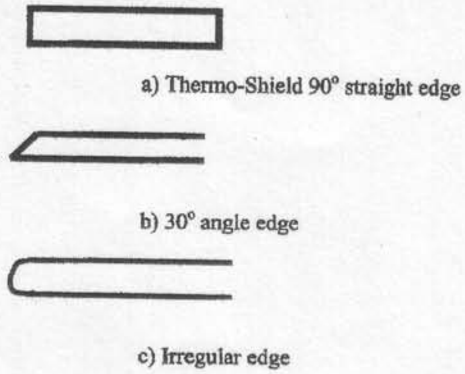

FIG. 1. Thermo-Shield slabs used in measurements.

It was then cut into a 15×15 cm^2 slab by a sawmill. Because of physical nature of the Thermo-Shield, it was not easy to make each slab without any thickness variations. Thickness variation was about ± 0.1 mm among four sides. Each slab was placed at the same position for each measurement to minimize uncertainty due to thickness variation within a slab. For each energy, the readings were normalized to a 0 cm reading. The relative logarithm of the normalized readings of each energy was plotted against the Thermo-Shield and the lead slab thickness. From the plots, the thickness of 5% transmission was determined for each energy by fitting the data to an exponential function given by $I/I_0 = \exp^{-\mu(1-at)t}$, where I/I_0 is the relative transmission reading, μ is the linear attenuation coefficient, a is the build up coefficient, and t is the thickness of the slab.[4]

B. Penumbra

The penumbra is defined as the region characterized by a rapid decrease in dose as one moves outward from the center where only a portion of the source is contributing primary radiation. To evaluate the penumbra, beam profiles normalized to a dose of 100% on the central axis were measured with films. The penumbra width is usually expressed as the lateral distance between 80% and 20% dose lines.[1] Penumbra measurements were performed with Kodak X–Omat V films at 1 mm depth for 75 kVp-2 mm Al and 250 kVp-0.4 mm Th. Three different edge shapes of Thermo-Shield slabs were considered (Fig. 1): a 90° straight edge, a 30° gradient edge to represent an extreme case, and a realistic edge made by hand. A mold machine was used to create a 30° gradient edge of the Thermo-Shield slab. The thickness of the Thermo-Shield slab was 10 mm and was found to be thick enough to provide more than 95% of attenuation capability in attenuation measurements. Field size was 10×10 cm^2 at 50 cm source-to-surface distance. During exposure, the slab was placed to shield half of the field; the other side was aligned with the center line of the field to minimize divergence effect on penumbra. Exposed films were developed using an automatic controlled processing machine (Kodak RP X–Omat processor) in stable condition. A scanning densitometer (WP 102, Wellhofer) was used to scan the films.

TABLE I. Attenuation characteristics of Thermo-Shield in fitted equation for field sizes of 5×5 and 10×10 cm^2.

Beam energy (kVp)	Filter	5×5 field size[a] $-\ln(I/I_0)$	10×10 field size[a] $-\ln(I/I_0)$
75	2.0 mm Al	$-0.1604x^2+2.126x$	$-0.2003x^2+2.0917x$
100	0.2 mm Cu	$-0.0891x^2+1.3287x$	$-0.0905x^2+1.2305x$
150	0.35 mm Cu	$-0.0001x^2+0.7476x$	$-0.0009x^2+0.7049x$
250	0.5 mm Cu	$-0.0147x^2+0.5403x$	$-0.0145x^2+0.5294x$
250	0.4 mm Th	$-0.0074x^2+0.4358x$	$-0.0077x^2+0.4273x$

[a] x = thickness in millimeters.

Obtained optical densities were converted to one-dimensional dose distribution by using the calibrated optical density-to-dose curve.

III. RESULTS

Fitted equations in linear to log scale for attenuation characteristics of Thermo-Shield with field sizes of 5×5 and 10×10 cm^2 for five orthovoltage photon beams are summarized in Table I. A plot of the fitted equation for 250 kVp-0.4 mm Th filter beam is shown in Fig. 2 because it is the most used energy in general. As can be seen, field size dependency is more significant in lower energy beams. Table II addresses the minimum thickness needed to assure less than 5% transmission. Values for lead are also shown for comparison purpose. The 5% transmission thickness for Thermo-Shield material ranges from 2 to 8.5 mm, whereas for lead it ranges from 0.7 to 2 mm. The thickness required for Thermo-Shield to achieve the same transmission (5%) is approximately four times thicker than that for lead.

Measurements of beam penumbra width at depth of 1 mm for 10×10 cm^2 field size are listed in Table III. Figures 3 and 4 show the measured profiles with three Thermo-Shield slabs at a depth of 1 mm for 75 kVp-2 mm Al filter and 250 kVp-0.4 mm Th filter beams, respectively. The three profiles exhibit a very similar shape regardless of the angle of

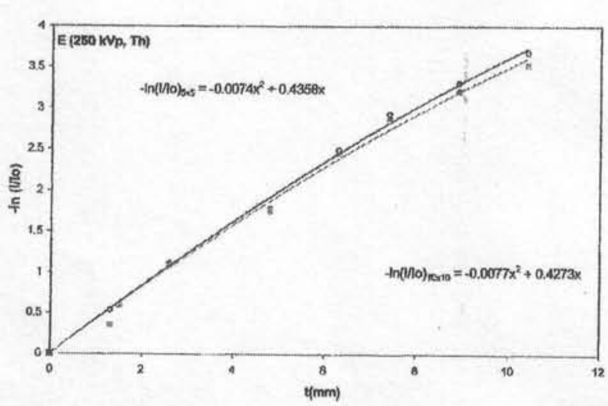

FIG. 2. Plots of $-\ln(I/I_0)$ vs Thermo-Shield slab thickness for 5×5 and 10×10 cm^2 field sizes at 250 kVp-0.4 mm Th filter beam.

TABLE II. Minimum thickness of Thermo-Shield and lead to ensure less than 5% transmission.

Beam energy (kVp)	Filter	5×5 field size <5% transmission thickness (mm)	10×10 field size <5% transmission thickness (mm)
Thermo-Shield			
75	2.0 mm Al	2.0	2.0
100	0.2 mm Cu	3.0	3.5
150	0.35 mm Cu	4.0	4.5
250	0.5 mm Cu	7.0	7.0
250	0.4 mm Th	8.0	8.5
Lead			
75	2.0 mm Al	NA[a]	NA[a]
100	0.2 mm Cu	0.7	0.75
150	0.35 mm Cu	0.9	0.95
250	0.5 mm Cu	1.6	1.7
250	0.4 mm Th	2.0	1.0

[a]NA = not applicable.

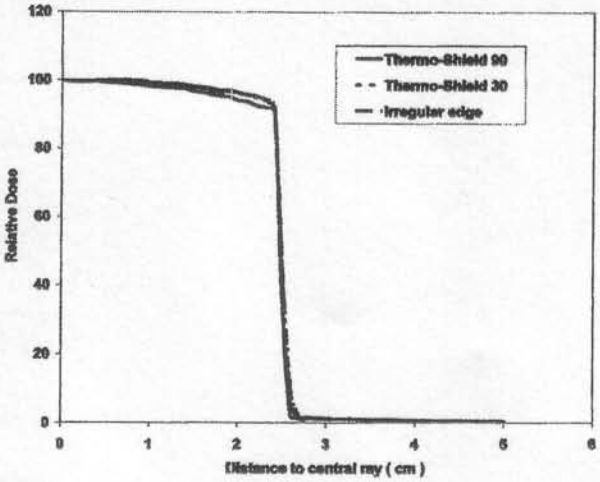

FIG. 3. Dose profile at 1 mm depth for 75 kVp–2 mm Al filter beam.

Thermo-Shield edge for 75 kVp-2 mm Al filter beam (1.33–1.37 mm). For 250 kVp-0.4 mm Th filter beam, 30° edge caused a significant length of partial transmission, resulting in a higher penumbra of 2.43 mm as compared to the straight edge (1.67 mm) and the irregular edge (1.83 mm).

IV. DISCUSSION

It is important to set-up a proper and efficient way to handle Thermo-Shield material in clinic. For facial treatments in our hospital, we fabricated shields on face impressions rather than working on the patients directly. We found, however, that shields often did not fit well even when they were rigidly made on impressions. At first, we suspected Thermo-Shield material might vary in its shape in regular room temperature after being molded. Careful observations were made on the behavior of Thermo-Shield material in regular room temperature. Several shields were made on a patient's face impression and were placed on a flat floor for 24 h at room temperature. Afterwards, the shields were put back on the impression to check whether they would fit. Through qualitative experiments, we found the variation of shape in Thermo-Shield shields to be insignificant. Our conclusion is that the impression does not resemble the patient's face exactly, resulting in a variation between the real face surface and the impression surface. One way to overcome this is to work directly on the patient's face. However, this method requires intensive care not to burn the patient. We recommend applying Vaseline to the face. We also recommend fabrication of a thin slab of Thermo-Shield to minimize heat transfer and working time, then adding more layers to create the full thickness of the shield.

TABLE III. Penumbra (P_{80-20}) at a 1 mm depth with Thermo-Shield.

Edge shape	75 kVp–2 mm Al filter	250 kVp–0.4 mm Th filter
90° straight edge	1.3	1.7
30° angle edge	1.4	2.4
Irregular edge	1.4	1.8

V. CONCLUSION

Thermo-Shield material has unique physical characteristics and radiation-shielding properties that make it feasible for field shaping in orthovoltage clinics. For the highest level of protection, the use of 10 mm thickness cutout is recommended. Thermo-Shield with a 30° edge results in a high penumbra for the 250 kVp energy. On the other hand, for the 75 kVp, the shape of the edge has no effect whatsoever on the penumbra. Thermo-Shield material is feasible to be used as a replacement for the current widely used lead shield in orthovoltage treatment clinics, following the provided recommended clinical procedure.

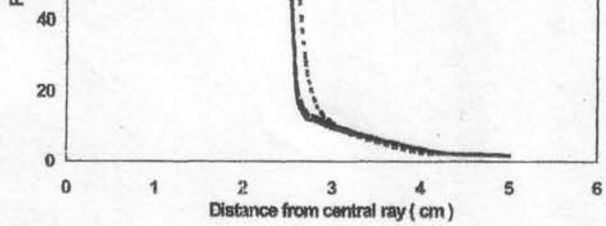

FIG. 4. Dose profile at 1 mm depth for 250 kVp–0.4 mm Th filter beam.

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[1]E. C. Mccollough, "Selection of techniques for orthovoltage radiation therapy," Int. J. Radiat. Oncol., Biol., Phys. **18**, 1237–1238 (1990).

[2]F. M. Khan, *The Physics of Radiation Therapy* (Williams & Wilkins, Philadelphia, 1994).

[3]I. J. Das, "Broad beam attenuation of kilovoltage photon beams: Effect of ion chambers," Br. J. Radiol. **71**, 68–73 (1998).

[4]B. R. Paliwal, S. Rommelfanger, and R. K. Das, "Attenuation characteristics of a new compensator material: Thermo-Shield for high energy electron and photon beams," Med. Phys. **25**, 484–487 (1998).