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● *Physics Contribution*

EVALUATION OF EYE SHIELDS MADE OF TUNGSTEN AND ALUMINUM IN HIGH-ENERGY ELECTRON BEAMS

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Purpose: To protect the lens and cornea of the eye when treating the eyelid with electrons, we designed a tungsten and aluminum eye shield that protected both the lens and cornea, and also limited the amount of backscatter to the overlying eyelid when using electron beam therapy.
Methods and Materials: Custom curved tungsten eye shields, 2 mm and 3 mm thick, were placed on Kodak XV film on 8 cm polystyrene and irradiated to evaluate the transmission through the shields. To simulate the thickness of the eyelid and to hold the micro-TLDs, an aquaplast mold was made to match the curvature of the eye shields. Backscatter was measured by placing the micro-TLDs on the beam entrance side to check the dose to the underside of the eyelid. Measurements were done with no aluminum, 0.5, and 1.0 mm of aluminum on top of the tungsten eye shields. The measurements were repeated with 2- and 3-mm flat pieces of lead to determine both the transmission and the backscatter dose for this material.
Results: Tungsten proved to be superior to lead for shielding the underlying structures and for reducing backscatter. At 6 MeV, a 3-mm flat slab of tungsten plus 0.5 mm of aluminum, resulted in .042 Gy under the shield when 1.00 Gy is delivered to d_{max}. At 6 MeV for a 3-mm lead plus 0.5-mm aluminum, .046 Gy was measured beneath the shield, a 9.5% decrease with the tungsten. Backscatter was also decreased from 1.17 to 1.13 Gy, a 4% decrease, when using tungsten plus 0.5 mm of aluminum vs. the same thickness of lead. Measurements using 9 MeV were performed in the same manner. With 3 mm tungsten and 0.5 mm of aluminum, at 3 mm depth the dose was .048 Gy compared to .079 Gy with lead and aluminum (39% decrease). Additionally, the backscatter dose was 3% less using tungsten. Simulating the lens dose 3 mm beyond the shield for the 2-mm and 3-mm custom curved tungsten eye shields plus 0.5 mm of aluminum was .030 and .024 Gy, respectively, using 6 MeV (20% decrease). Using 9-MeV electrons, the dose 3 mm beyond the shield was .048 Gy for the 2-mm shield and .029 Gy for the 3-mm shield (40% decrease). Backscatter was not further decreased using thicker tungsten. With a 6-MeV beam, using the 2-mm or 3-mm custom tungsten eye shields plus 0.5 mm of aluminum, the backscattered doses were 1.03 and 1.02 Gy, respectively. The backscatter dose with 9 MeV was 1.06 Gy using the 2-mm custom shield plus 0.5 mm aluminum and 1.05 Gy with a 3-mm custom shield plus 0.5 mm aluminum. There was very little difference in backscatter dosage under the eyelid using 0.5 vs. 1.0 mm of aluminum. Therefore, for patient comfort, we recommend using 0.5 mm of aluminum.
Conclusions: Tungsten is superior to lead as a material for eye shields due to its higher density and lower atomic number (Z). Using 6- and 9-MeV electrons, tungsten provides the necessary protection for the lens and cornea of the eye and decreases the amount of backscatter to the eyelid above the shield. © 1998 Elsevier Science Inc.

Tungsten, Lead, Transmission, Eye Shielding, Electron beams, Backscattered electrons.

INTRODUCTION

Tumors that involve the eyelid, such as basal or squamous cell carcinoma, and total skin electron beam therapy for mycosis fungoides, require treatment of the eyelid using high energy electrons. The goal in these instances is to provide a homogenous dose to the eyelid, spare the lens and cornea, and limit the dose to the inner surface of the eyelid. For a shield to fit under the patient's eyelid, it needs to be as thin as possible, with a maximum thickness not exceeding about 4 mm. To accomplish these goals, rigorously designed eye shields are needed to protect the eye, but also to limit the amount of backscatter to the under surface of the eyelid (1, 2). As a result, eye shields need to be made from a combination of high-density material for attenuation of the radiation beam plus a low atomic number (Z) material to reduce the backscatter dose to the eyelid (3–5). Most commercially available shields are made of lead. The density of lead is 11.34 g/cm^3, making it a good material for beam attenuation. Tungsten has a higher density (19.3 g/cm^3), which enables the use of a thinner eye shield to provide the

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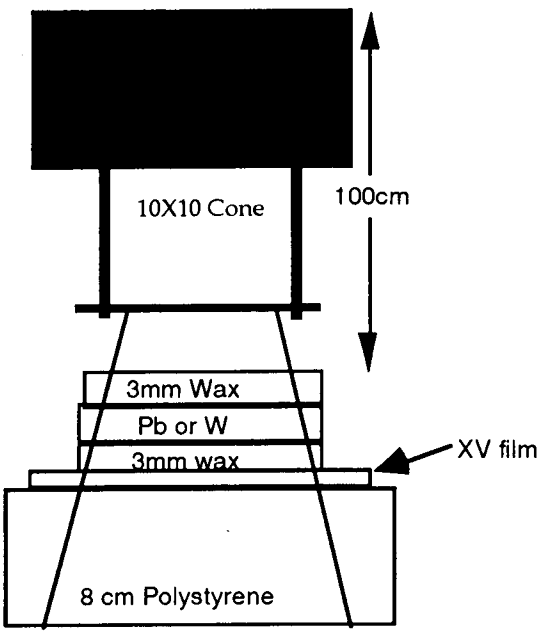

Fig. 1. Setup of transmission measurements of flat pieces of lead and tungsten.

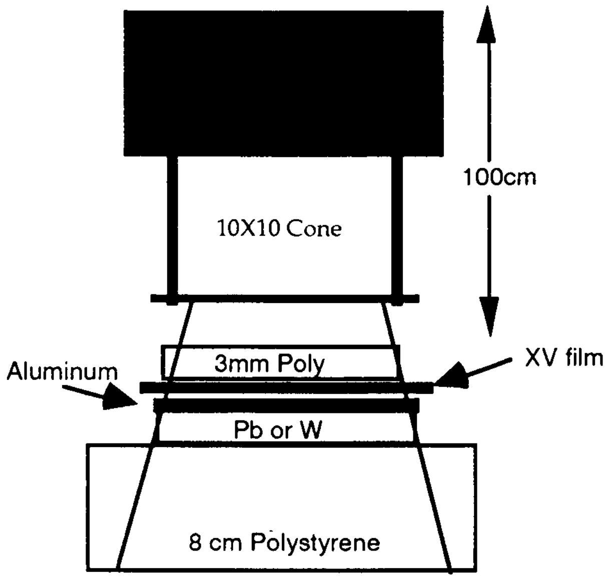

Fig. 2. Backscatter diagram of flat pieces of lead and tungsten.

same protective value as lead, yet be more comfortable for the patient.

Another advantage of tungsten is its low toxicity compared to lead. In evaluating the airborne exposure limits of lead (0.15 mg/m^3) and tungsten (5 mg/m^3), lead is approximately 30 times more toxic than tungsten (6). Even though most eye shields are coated in some fashion, this coating can become chipped or worn during normal use. This is of concern because the ocular route has been shown to be a portal of entry for systemic absorption (7, 8). Previous studies have shown that tungsten provides adequate protection of the eye and underlying structures while allowing for the construction of thinner eye shields (5).

An additional, although minor, factor to keep in mind when designing eye shields is that the electron-beam depth dose characteristics, specifically from the surface to d_{max}, of different accelerators can vary. The thickness of the eyelid that must be treated ranges from 0 to 3 mm. This presents a problem because the central axis percentage depth dose-curves of modern electron beams change considerably in the buildup region, especially those having dual scattering foils. For our Varian 2100C, the surface dose for 6 and 9 MeV is 72 and 77%, respectively, increasing to 100% at a depth of 1.5 cm for 6 MeV and 2.2 cm for 9 MeV.

In this study, we investigated eye shields made of tungsten and aluminum to limit the backscatter dose to the under surface of the eyelid and to optimally protect the lens and cornea. Our intent was to optimize the thickness of these two materials for total skin electron irradiation and for routine 6- and 9-MeV electron treatments.

METHODS AND MATERIALS

Our current procedure for shielding the eye consists of placing a nonprescription soft contact lens in the eye, over which is placed a curved eye shield made from 3.3 mm of lead covered by 1.4 mm aluminum. To determine the optimum thicknesses of a tungsten and aluminum eye shield, we measured the transmission and backscatter for 2 and 3 mm thicknesses of lead or tungsten plus various thicknesses of aluminum placed above the high-Z material.

The first part of this study consisted of measuring transmission through flat pieces of lead and tungsten. This was done by placing Kodak XV-2 ready-pack film on 8 cm of polystyrene. On top of the film was 3 mm of wax, to simulate the depth to the anterior aspect of the lens, a flat piece of either 3.0 mm thick lead or 3 mm tungsten, then 3 mm of wax on top, to simulate the thickness of the eyelid (Fig. 1). SSD, 100 cm, was set to the top of the wax. This arrangement was then given 1.00 Gy to d_{max} with 6- and 9-MeV electron beams generated by a Varian Clinac 2100C linear accelerator[1] using 10 × 10 electron cone. Normalization films were done with a 10 × 10 electron cone delivering 1.00 Gy to the films for 6 and 9 MeV. All films were developed at the same time, along with an unexposed film. A sensitometric curve was generated to accurately convert optical density to dose (9).

Next, the amount of backscatter from lead was investigated. The dose at the tissue-lead interface can be increased as much as 30 to 70% over what the dose would be without the higher Z material (4, 10–12). We placed the 3-mm thick

[1] Clinac 2100C, Varian Assoc., Palo Alto, CA.

Table 1. Dose in Gy at 3mm depth (location of the lens) through flat lead and tungsten, with various combinations of aluminum

	3 mm Lead	3 mm Pb + 0.5 mm Al	3 mm Pb + 1.0 mm Al	3 mm Tungsten	3 mm W + 0.5 mm Al	3 mm W + 1.0 mm Al	2 mm Tungsten	2 mm W + 0.5 mm Al	2 mm W + 1.0 mm Al
6 MeV	.042	.046	.052	.035	.042	.047	.043	.047	.052
9 MeV	.079	.079	.074	.038	.048	.051	.090	.085	.079

Doses were measured with XV film when 1.00 Gy delivered to d_{max}.

Table 2. Dose in Gy on the under surface of the eyelid when using flat lead or tungsten

	3 mm Lead	3 mm Pb + 0.5 mm Al	3 mm Pb + 1.0 mm Al	3 mm Tungsten	3 mm W + 0.5 mm Al	3 mm W + 1.0 mm Al	2 mm Tungsten	2 mm W + 0.5 mm Al	2 mm W + 1.0 mm Al
6 MeV	1.20	1.17	1.13	1.17	1.13	1.10	1.16	1.14	1.11
9 MeV	1.15	1.15	1.12	1.12	1.12	1.09	1.11	1.12	1.09

Doses were measured using XV film when 1.00 Gy delivered to d_{max}. This data illustrates the amount of dose due to backscatter from the high-Z shield.

lead on top of 8 cm of polystyrene, over which was placed various thicknesses of aluminum. An XV ready-pack film was placed on top of the aluminum with 3.02 mm of polystyrene above the film to simulate the thickness of the eyelid (Fig. 2). The films were then exposed as described above with 6- and 9-MeV electrons. The experiment was repeated with no aluminum, 0.5-, and 1.0-mm thicknesses of aluminum on top of the lead. These same backscatter measurements were repeated with tungsten and the same corresponding thicknesses of added aluminum. The results are shown in Tables 1 and 2.

The second part of the study measured the transmission and backscatter of commercially available curved tungsten eye shields, which have a density of 17.2 g/cm^3 [2] (Fig. 3). Transmission measurements were done using film following the same setup procedure used for the flat pieces of tungsten. The setup consisted of placing 3 mm of dental wax on the outer and inner surface of the shield. The outer wax simulated the thickness of the eyelid and the wax on the underside of the shield simulated the depth to the anterior surface of the lens. The shield was then placed on XV film on top of 8 cm of polystyrene. Transmission measurements were done with combinations of no aluminum, 0.5, or 1 mm of aluminum on the outside surface of the eye shields.

Backscatter measurements were obtained with micro-TLD cubes[3] that measured 1 mm × 1 mm × 1 mm, each having their own calibration factor. A 3-mm thick aquaplast® mold was made to fit the curvature of the outer surface of the eye shield, which simulated the eyelid. Small indurations were drilled on the under surface of the aquaplast to hold the micro-TLD cubes so that measurements of the backscattered dose on the inner eyelid surface could be obtained. Wax was also placed on the under surface of the eye shield to represent the patient's eye. Measurements were then done with no aluminum, 0.5-, and 1.0-mm thickness of aluminum on top of the tungsten eye shields.

RESULTS AND DISCUSSION

The objectives of this study were to optimize eye shielding for patient treatments that would protect the lens and cornea of the eye and deliver a homogeneous dose to the eyelid. In meeting these objectives, tungsten provided more attenuation than the same thickness of lead, as well as less backscattered dose to the inner surface of the eyelid. In our investigation, we found that the dose to the anterior surface of the lens when 1.00 Gy was given to d_{max} with a 6-MeV electron beam was .030 Gy with a 2-mm tungsten custom shield plus 0.5 mm aluminum, and .024 Gy with a 3-mm custom tungsten shield plus a 0.5-mm aluminum cap (Table 3). With 9 MeV, the dose to the anterior aspect of the lens was .048 Gy with a 2-mm tungsten custom shield plus 0.5 mm aluminum, and .029 Gy using a 3-mm tungsten custom shield with a 0.5-mm aluminum cap, as shown in Table 4.

The optimum amount of aluminum needed above the tungsten to absorb backscattered electrons was found to be dependent on the percent depth dose characteristics of the clinical electron beam. For our Varian Clinac 2100C, the dose at the phantom surface with a 10 × 10 cone when 1.00 Gy is delivered to d_{max} is 0.72 Gy and 0.77 Gy for 6- and 9-MeV electrons, respectively. Because the average surface dose is approximately 0.75 Gy, backscatter from the eye shield can partially compensate for this dose deficit. At a depth of 3 mm on our machine, we have 0.78 Gy for 6 MeV and 0.81 Gy with 9 MeV. By using an eye shield with a thin piece of aluminum on the outer surface of the tungsten, there is an enhancement of dose at the under surface of the eyelid. For example, without the eye shield in place, the surface dose is 0.72 Gy with 0.79 Gy at a depth of 3 mm using 6 MeV. With an eye shield consisting of 3 mm of tungsten and 0.5 mm of aluminum, 0.80 Gy is measured at the surface and 1.02 Gy at a depth of 3 mm (Table 3). Aluminum thickness above the tungsten can also be opti-

[2] Radiation Products Design, Albertville, MN.

[3] TLD-100 cubes, Bicron, Solon, OH.

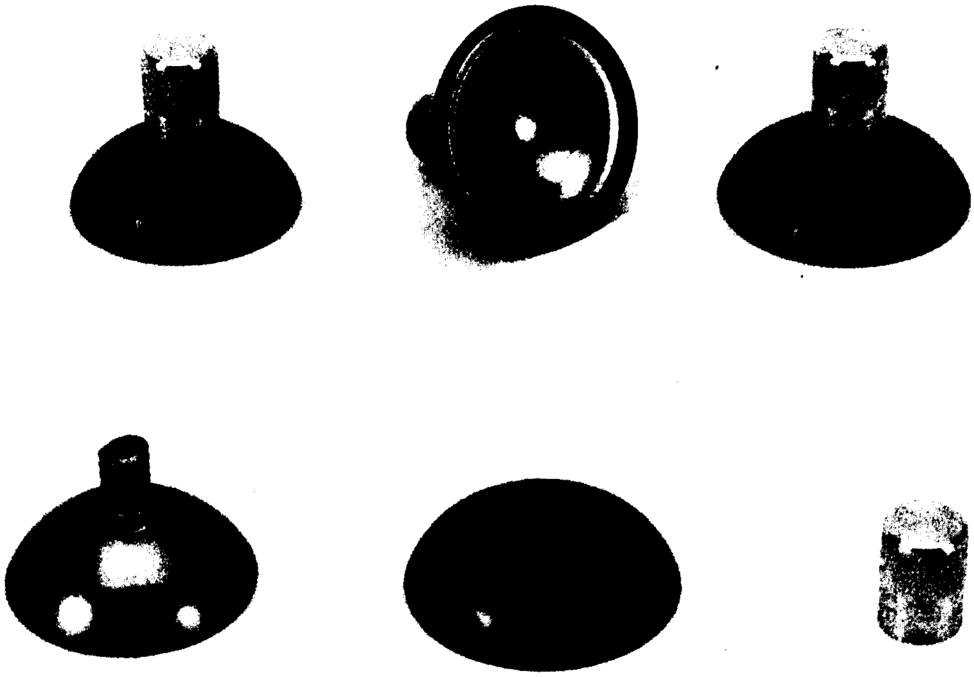

Fig. 3. Commercially available curved tungsten eye shields.

mized for a beam with a higher surface dose. For our Varian 2500 linear accelerator, the surface dose averages 0.86 Gy for both 6 and 9 MeV, and 0.93 Gy at a depth of 3 mm. Because this accelerator has a higher surface dose than our Clinac 2100, less backscatter dose is needed above the eye shield to compensate for dose build-up requiring thicker aluminum above the tungsten eye shields. In evaluating the possible combinations of tungsten and aluminum, we found that 0.5 mm of aluminum in combination with 3 mm of tungsten provides acceptable protection for the eye, as well as a reasonable amount of backscatter dose for conventional 6- and 9-MeV treatments on both linear accelerators used in our department.

For radiation treatments to the eyelid using 6 MeV, a shield composed of 2 mm of tungsten and 0.5 mm aluminum provided acceptable dose homogeneity through the eyelid and protection to the underlying eye with enhanced comfort for the patient.

CONCLUSION

The main objective of this study was to determine the optimum thickness of the tungsten and aluminum to attenuate the beam to an acceptable amount and provide a homogeneous dose to the eyelid. The results obtained verify that tungsten is clearly a better material to use in the construction of eye shields due to its higher density and lower Z vs. lead. Measurements taken show that there is little difference in backscatter above the eye shield in using no aluminum, 0.5, or 1.0 mm of aluminum. Therefore, for patient comfort we recommend the use of 0.5 mm of aluminum.

These commercially available shields are convenient to use and allow different amounts of aluminum to be attached to the top. A clever screw-down feature allows the aluminum portion to be individually varied for each patient and situation. Shields can be easily gas sterilized and the aluminum, having an anodized coating, is mechanically and chemically durable. It is also of impor-

Table 3. 6 MeV; dose in Gy when 1.00 Gy is delivered to d_{max}

Custom shield	Surface	d = 3 mm* (under eyelid)	Lens (3 mm)†
No shield	0.72	0.79	0.85
2 mm W (No Al)		1.08	.034
2 mm W (0.5 mm Al)		1.03	.030
2 mm W (1.0 mm Al)		0.95	.030
3 mm W (No Al)		1.12	.025
3 mm W (0.5 mm Al)		1.02	.024
3 mm W (1.0 mm Al)		0.97	.025

* Measurement done using Micro-TLD cubes.
† Measurements done using XV-2 film.

Table 4. 9 MeV; Dose in Gy when 1.00 Gy is delivered to d_{max}

Custom shield	Surface	d = 3 mm* (under eyelid)	Lens (3 mm)†
No shield	0.77	0.81	0.85
2 mm W (No Al)		1.11	.056
2 mm W (0.5 mm Al)		1.06	.048
2 mm W (1.0 mm Al)		1.02	.044
3 mm W (No Al)		1.13	.033
3 mm W (0.5 mm Al)		1.05	.029
3 mm W (1.0 mm Al)		1.06	.028

* Measurements done using Micro-TLD cubes.
† Measurements done using XV-2 film.

tance to consider the surface dose characteristics of electrons for the accelerator in which the eye shields are being used. Due to differences in depth dose distributions for various beams, the thickness of the aluminum placed above the tungsten will need to be optimized for each patient.

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