2026 JULY 19–22 VANCOUVER, BC
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Determining the Thickness of a Second-Generation Electron Skin Collimator

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ABSTRACT

Purpose: To determine the optimal thickness of an electron skin collimator that minimizes the surface dose inhomogeneity ("hot" spots), which reached up to 23% for previous prototypes, while maintaining the prior penumbral advantages.

Methods: We investigated different collimator thicknesses and shapes using stackable copper plates. Varying the copper thicknesses allowed us to determine whether energy-specific collimators would be beneficial for reducing inhomogeneities for 6, 9, 12, and 15 MeV electron beams. A fixed MU was delivered to radiochromic film with a 10x10 cm field. Copper pieces of varying thickness (0.64 cm and 1.27 cm), including intentionally thicker-than-necessary plates, were positioned at the field edge based on expected electron ranges. Dose inhomogeneity was defined as the percentage increase in dose relative to the central field dose.

Results: Using 1.27 cm copper, dose inhomogeneity was measured at 102.9%, 104.1%, 104.6%, and 103.7% for 6, 9, 12, and 15 MeV electrons, respectively. The 0.64 cm copper was insufficient for 12 and 15 MeV but produced dose inhomogeneities of 106.4% and 109.5% for 6 and 9 MeV electrons. Although 1.27 cm copper provides a larger scattering surface, it achieved lower inhomogeneities for these energies and maintained penumbra performance of the previous prototypes.

Conclusion: Copper thicknesses greater than the minimum required for attenuation do not worsen scatter-induced dose inhomogeneity. These results suggest that future skin collimator designs should prioritize selecting a thickness capable of effectively attenuating the highest-energy electrons, without concern that the additional material will degrade performance at lower energies.

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INTRODUCTION

Cerrobend collimation is currently the standard for electron radiotherapy. These **applicators leave non-negligible airgaps to the patient that increase beam penumbra**. Skin lead collimation is one technique to improve this, but these devices are crafted specifically for each patient. To address these concerns, we previously developed a prototype "cable collimator" made from stainless steel, which reduced the lateral penumbra compared to a traditional applicator by up to 93%. However, **this cable collimator also significantly increased undesirable surface dose inhomogeneities**. In our development of a second- generation electron collimation system, we investigate the optimal thickness for our collimation device. We use copper plates **to determine if energy-matched thicknesses are advantageous, or if a single thickness collimator is sufficient** for our purposes despite providing a larger scattering surface.

The CSDA ranges of electrons in copper is an important factor to consider in designing an experiment to determine the most efficacious collimating thickness. **Copper thicknesses of 0.64 cm and 1.27 cm were chosen for testing**, with the 1.27 cm copper plate being "thicker-than-necessary" for all energies. The CSDA ranges for 6, 9, 12, and 15 MeV electrons in copper are 0.47 cm, 0.67 cm, 0.82 cm, and 1 cm, respectively.

METHODS AND MATERIALS

In our efforts to reduce the surface dose inhomogeneity seen with the first electron skin collimator, we considered that the next prototype(s) might utilize multiple "energy-matched" thicknesses, That is, one might expect that copper thicknesses barely exceeding the CSDA range of a given electron energy might fully attenuate the beam while providing minimal scattering surface, thus minimizing the hot spot.

A fixed MU was delivered for four energies (6, 9, 12, and 15 MeV) to a strip of EBT 3 radiochromic film. 1.27 cm copper plates were placed on the central axis of a field defined by a 10x10 cm applicator for all four energies. 0.64 cm copper plates were placed in the same position for 6 and 9 MeV beams.

Dose percentage profiles were created for each combination of energy and collimating thickness tested. A surface dose inhomogeneity ("hot" spot) is defined as the increase in dose on the edge of the field defined by the copper collimator. Penumbra is defined as the lateral distance between the 20% and 80% of maximum dose. The resulting hot spot and penumbra created by the copper collimator were compared to those of the cable collimator from a previous study.

Figure 1. The stackable copper plates used in this analysis

RESULTS and DISCUSSION

The **left side of each dose profile in Figures 2-5 represents the edge of the field defined by the copper plate**, while the right is the edge of the 10x10 cm field defined by the applicator. Each profile has been **normalized to the central axis to better indicate the presence of hot spots due to scatter**. This is illustrated by the green dashed lines, which mark the 100% dose (at the central axis) and the global maximum dose of the whole profile. For 6 and 9 MeV electrons, **1.27 cm copper creates less dose inhomogeneity compared to 0.64 cm copper, even though both thicknesses are adequate attenuators of those beams based on CSDA.**

Lateral penumbra was also measured on each profile, indicated by the vertical red lines. The comparative inhomogeneity and penumbra results between the copper plates and the previously studied "cable collimator" are given in Table 1. In all cases, the **1.27 cm copper plates created less surface dose inhomogeneity than the cable collimator while maintaining or improving lateral penumbral width**.

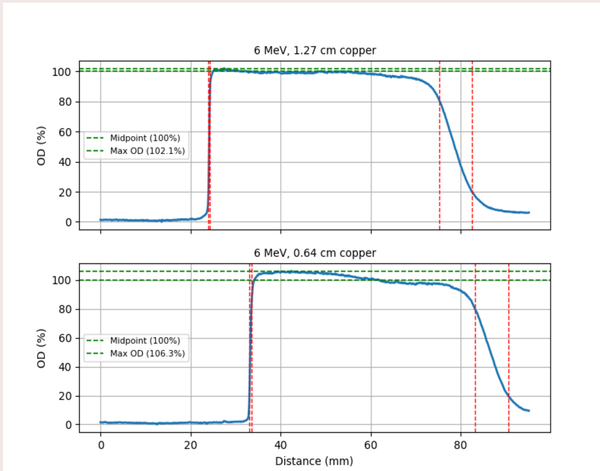

Figure 2. Profiles for 6 MeV electron beams with 1.27 cm (top) and 0.64 cm (bottom) thicknesses of copper.

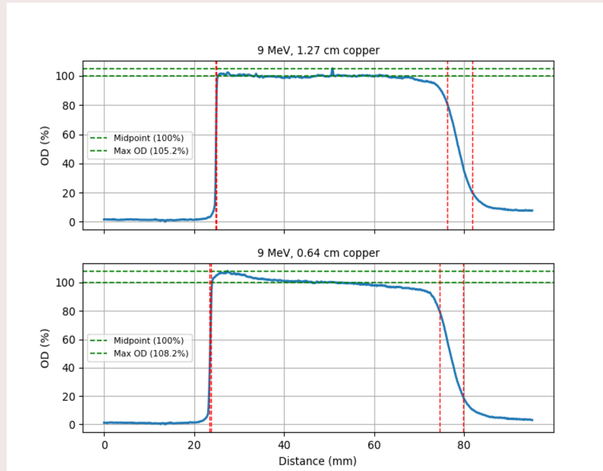

Figure 3. Profiles for 9 MeV electron beams with 1.27 cm (top) and 0.64 cm (bottom) thicknesses of copper.

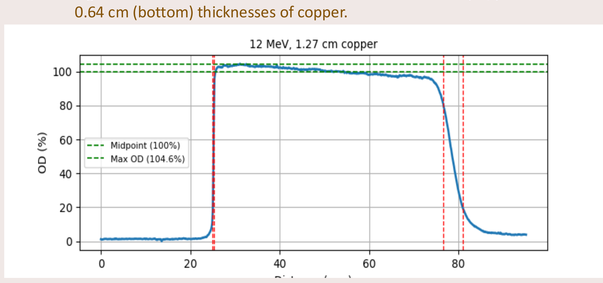

Figure 4. Profile for 12 MeV electron beam with 1.27 cm copper

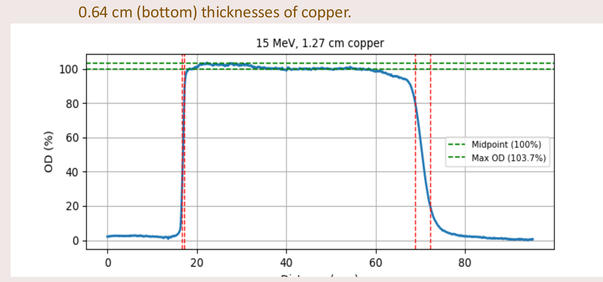

Figure 5. Profile for 15 MeV electron beam with 1.27 cm copper

Energy (MeV)		Dose inhomogeneity	Penumbra (mm)
6	Cable collimator	105%	1.3 mm
	1.27 cm copper	103%	0.3 mm
9	Cable collimator	107%	1.0 mm
	1.27 cm copper	104%	0.3 mm
12	Cable collimator	114%	1.1 mm
	1.27 cm copper	105%	0.3 mm
15	Cable collimator	123%	1.3 mm
	1.27 cm copper	104%	0.5 mm

Table 1. Dose inhomogeneities and penumbral widths from prior analysis of the cable collimator and current evaluation of the copper plates

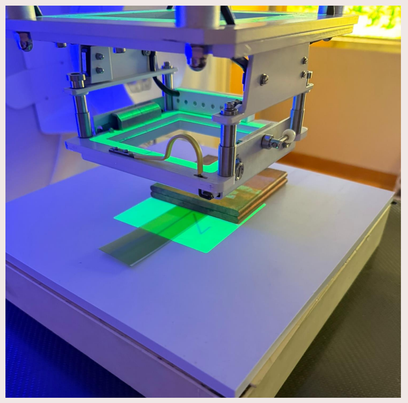

Figure 6. The irradiation setup, with 1.27 cm copper on top of radiochromic film

CONCLUSIONS

Although **1.27 cm is much greater than the CSDA range of 6 and 9 MeV electrons, it did not worsen scatter-induced dose inhomogeneity compared to 0.64 cm copper**. These results suggest that our future designs should prioritize creating a single collimator that is suitably thick to effectively attenuate the highest energy electrons instead of energy-matched thicknesses. The results indicate that **additional material does not degrade performance at lower energies**.

We are also confident that the scatter introduced by this single-thickness copper collimator will not negate the penumbral advantages previously achieved with the cable collimator.

REFERENCES

1. New P, Paschal H, Bassiri N, Rasmussen K, Papanikolaou N, Kirby N. A surface-conforming flexible collimator for improving electron radiotherapy. Phys Med Biol. 2026 Apr 15;71(8). doi: 10.1088/1361-6560/ae59e9. PMID: 41916376.

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