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Electron dose distributions caused by the contact-type metallic eye shield: Studies using Monte Carlo and pencil beam algorithms

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A metallic contact eye shield has sometimes been used for eyelid treatment, but dose distribution has never been reported for a patient case. This study aimed to show the shield-incorporated CT-based dose distribution using the Pinnacle system and Monte Carlo (MC) calculation for 3 patient cases. For the artifact-free CT scan, an acrylic shield machined as the same size as that of the tungsten shield was used. For the MC calculation, BEAMnrc and DOSXYZnrc were used for the 6-MeV electron beam of the Varian 21EX, in which information for the tungsten, stainless steel, and aluminum material for the eye shield was used. The same plan was generated on the Pinnacle system and both were compared. The use of the acrylic shield produced clear CT images, enabling delineation of the regions of interest, and yielded CT-based dose calculation for the metallic shield. Both the MC and the Pinnacle systems showed a similar dose distribution downstream of the eye shield, reflecting the blocking effect of the metallic eye shield. The major difference between the MC and the Pinnacle results was the target eyelid dose upstream of the shield such that the Pinnacle system underestimated the dose by 19 to 28% and 11 to 18% for the maximum and the mean doses, respectively. The pattern of dose difference between the MC and the Pinnacle systems was similar to that in the previous phantom study. In conclusion, the metallic eye shield was successfully incorporated into the CT-based planning, and the accurate dose calculation requires MC simulation.

Introduction

Radiation treatment for eyelid conjunctival mucosa-associated lymphoid tissue (MALT) lymphoma is sometimes performed using an electron beam of 6 MeV from a linear accelerator. The MALToma is very susceptible to radiation, so a dose of approximately 20 to 25 Gy for a 2-Gy fractionation has been recommended for treatment.[1–3] A contact-type metallic eye shield can be used for the electron treatment to protect not only mainly the lens from later cataract formation but also the cornea and the retina. However, no plan has introduced metallic shields in the CT-based treatment planning. The obvious reason is that metal artifacts in the CT image hinder the proper identification of the organs and thereby affect the correct dose calculation.

Recently, inspired by the use of the CT-compatible dummy applicator in the brachytherapy plan, the use of an acrylic dummy shield was suggested for artifact-free CT-based treatment planning for treatment near the orbital space.[4] In that study, an acrylic shield of the same size as the metallic shield was machined and used for the CT scan on a solid phantom.[5] In the Monte Carlo (MC) simulation, the material information was incorporated, and the calculation agreed within 5% with the measurements.

To our knowledge, the dose distribution for a patient adopting the metallic eye shield has never been reported, except a poster presentation in which they prepared the dummy shield as the same size of the tungsten shield by using thermoplastic pellets and briefly compared the lens dose distributions on the Pinnacle system with and without density correction of the shield, showing the usefulness of the dummy shield for CT simulation and treatment planning.[6] Here, a retrospective dose calculation study using a contact-type metallic eye shield for patients with eyelid cancer is presented. The CT-based MC calculation was compared with the

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Pinnacle results (Version 8.0 m, Philips Medical Systems, Netherlands).

Materials and Methods

As previously suggested, an acrylic dummy eye shield machined to have the same 2-mm thickness as the metallic one was used while performing the CT scan of the patient (Fig. 1). The original tungsten shield (Radiation Products Design, Inc., MN, USA) consisted of a curved tungsten body (W, density = 17.0 g/cm^3), a stainless steel knob (SUS, presumed density = 7.9 g/cm^3), and a 0.5-mm thick aluminum cover (Al, density: 2.718 g/cm^3) to reduce backscattered radiation.

For the 3 patient cases, the planning CT was obtained with a slice thickness of 1.25 mm, with the acrylic shield placed on the patient's eye. After transferring the images onto the Pinnacle system, the shield body, the shield knob, and the cover were delineated as shown in Fig. 2. In addition, for dose evaluation, along with the lens, the retina was delineated, occupying the posterior spherical half of the globe with a 1-mm thickness, and the target was selected on the eyelid covering the shield. The densities of these regions of interest (ROIs) were assigned to each density value on the planning system. This retrospective study was designed to focus on the dose distribution near the metallic shield; therefore, field shaping was made as a simple single electron field of 6 MeV, 6 × 6 cm^2, with no electron block. The isocenter was placed on the top center of the shield knob and 100 monitor units (MU) were prescribed, in which the output of the linear accelerator was calibrated at the depth of the maximum (d_{max}) dose with a field size of 10 × 10 cm^2 and a source-to-surface distance of 100 cm (SSD). As the height of the shield was 2 cm and the measured relative output of the linac was 0.956 under reference conditions for 102-cm SSD, the 100 MU was equivalent to 95.6 cGy at d_{max}. Dose calculation was fulfilled with the dose grid resolution of 1.0 × 1.0 × 1.25 mm^3.

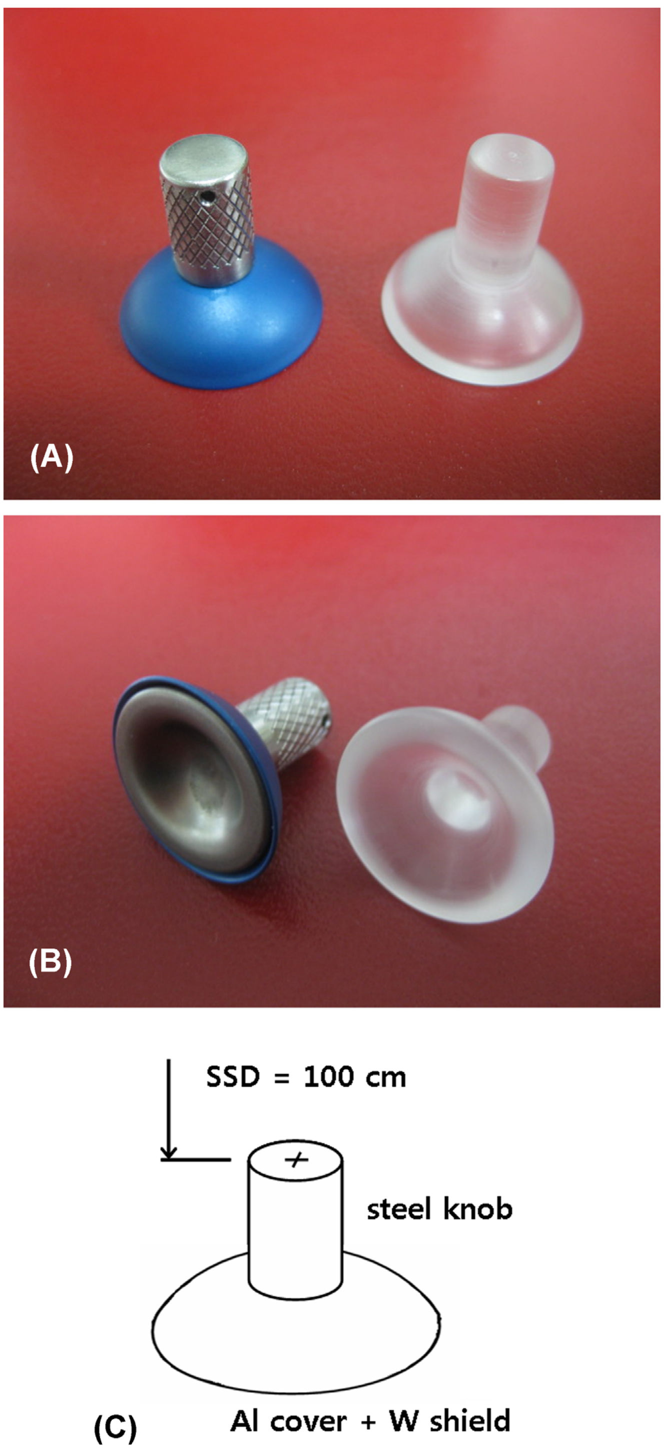

Fig. 1. Tungsten and CT-compatible acrylic dummy shields with a schematic view.

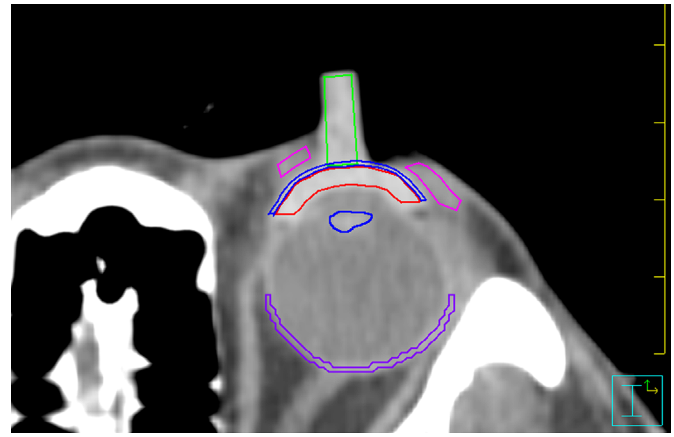

Fig. 2. Delineated ROIs for the tungsten shield (shield body, shield knob, and aluminum cover). The lens, retina, and target eyelid were also contoured for dose evaluation.

For the MC-based calculation, the Monte Carlo codes BEAMnrc and DOSXYZnrc were used.[4,7,8] First, the BEAMnrc was commissioned for a 6-MeV electron beam from a Varian 21EX (Varian Medical Systems, Palo Alto, CA, USA), where all the components from the primary collimator to the electron applicator were included. We considered 2 square fields of 10 × 10 cm^2 and 6 × 6 cm^2 for the reference and the irradiation fields, respectively. Through trial and error, the primary input energy of the electrons was chosen to be 6.72 MeV. Fig. 3 shows the comparison of the measured percentage depth doses (PDD) and lateral profiles for the MC simulation and measurement, where the calculated R_{50} and the electron practical range R_p of the calculated PDD were in agreement to within 1 mm with the measurement.[9,10]

For the CT-based dose calculation using the DOSXYZnrc, the CT images have to be converted through the provided package "ctcreate," in which the material information is incorporated based on the Hounsfield units. Because the CT numbers of the acrylic dummy shield were in a range that was not too different from those of the tissues, they had to be modified for definite distinction. The coordinate information for the delineated ROIs on the Pinnacle system was used. The CT numbers inside both ROIs for the W body and the SUS knob were changed arbitrarily into 17,000 and 7,900, respectively, using a small script. To ensure the modification of the CT numbers for an aluminum cover of 0.5-mm thickness, a single line of pixels along the outside of the shield body was changed to 2,700.

During conversion of the modified CT image, information on the 5 materials of air, water, W, SUS, and Al was used. The dose calculation resolution was the same as those of the Pinnacle calculation. Cutoff energies of 0.1 MeV for electrons and 0.01 MeV for photons were used in all simulations. The same irradiation setup as that of the Pinnacle system was simulated. The absolute dose calculation result with an applicator of 6 × 6 cm^2 was obtained using the reference condition, and then transferred onto the Pinnacle system for comparison.

Results and Discussion

A commercial tungsten eye shield was incorporated into the CT-based eyelid carcinoma planning using the acrylic shield. Because the shield used in the CT scan was made of acrylic material, it did not produce metallic artifacts in the CT images, resulting in the clear identification of the nearby organs. Fig. 4 shows an example of the axial dose distributions from the Pinnacle system (Fig. 4a and b) and the MC calculation (Fig. 4c). When the