Dose Distribution for Eye Shielding Block in 6 MV Photon Beam Therapy

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The eye lens is known to be radiosensitive organ and catarat can be induced by relatively low dose of radiation. In the treatment of head and neck tumors, shielding blocks are frequently used to minimize dose on sensitive organs. The shielding block, which is made of high atomic number materials (cerrobend), produce significant dose perturbations in megavoltage photon beams. The effects of these perturbations of eye shielding blocks are measured with film and ion chambers for the treatment of head and neck malignancies. Optimum parameters for the treatment are suggested.

Key Words: Eye shielding, Megavoltage beam, Cerrobend

INTRODUCTION

Radiation treatment for head and neck tumors is frequently necessary to irradiate a portion of the eye, but the eye lens is treated as a radiosensitive organ and it should be protected to minimize the complications. Cataract formation is the most common radiation damage in the treatment of head and neck malignancies. Although cataracts can form with a single dose as low as 200 cGy, a fractionated dose greater than 500 cGy should certainly be avoided[1~4].

If there is a possibility of preserving useful vision in head and neck irradiation, the eye lenses should be shielded in each field to minimize the risk of radiation damage without sacrificing the goal of tumor control.

The methods to minimize the dose on eye are the bolus tunnel method, the arc pendulum method and the shielding block method.

The bolus tunnel method has a risk of delivering a higher dose to the eye, due to secondary electrons produced from the tunnel wall. The arc pendulum method is difficult to execute and make many errors[5~7]. The shielding block method is frequently used to attenuate the primary beam to a desired level by hanging a thick block in the beam.

These method is easy and practical to use, however, with renewed interest in the dose perturbations caused by high atomic number material in megavoltage beams, it is important to investigate the dose perturbation parameters to minimize eye dose[8~12]. These treatment may be improved if optimum parameters for the shielding are available.

These study was conducted to evaluate such parameters in the shielding block method for minimizing dose to the superficial structures of the eye and providing an adequate dose to the tumor.

METHODS AND MATERIALS

The eyeball is a sphere of approximately 2.5 cm in diameter. For radiation protection, only three structures, cornea, lens, and retina are considered here. The cornea, a transparent structure, lies less than 1 mm from the surface. The eye lens, the most sensitive structure, is 3~5 mm from the surface. The retina, a delicate nerve bed which forms the inner lining of the eyeball, is approximately 25 mm from the surface[13,14].

The dose at a point under a shielding block is a complex function of various parameters,

$$D=f\ (E,\ A,\ t,\ h,\ d,\ Z)$$

Where D is dose under the block, f stands for a function, E is the energy of the photon beam, A is the radiation field size, t is the thickness of the shielding block. The transmission, T to attenuate the beam to a desired level is given as follow.

$$T=\mathrm{Exp}\ (-\mu t).$$

Where μ is an effective attenuation coefficient, d is the depth of interest in the phantom, h is the distance from the surface to the bottom of the shielding block, and Z is the effective atomic number of the shielding block. Some of these parameters are shown in Fig. 1.

The shielding block to be placed away from the surface is suitable in megavoltage beams and the block attenuates the primary beam to a desired level. However, it also produces secondary elec-

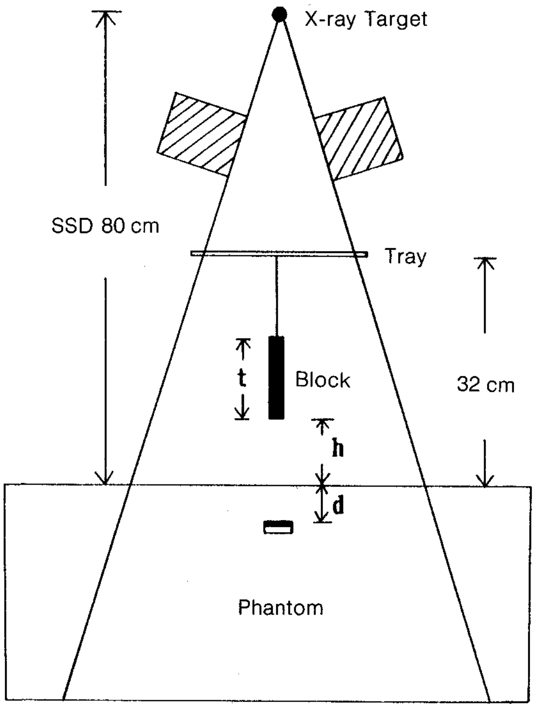

Fig. 1. Schematic diagram of the experimental design.

trons which result in a higher dose at the surface.

The nature of these secondary electrons is dependent on the atomic number of the block. How far they can travel is governed by their energy and the scattering power of the material of the block.

Dose under the block at the surface arises from electron contamination from the collimating system, head assembly, tray assembly, and air, as well as forward scattered secondary electrons from the shielding block.

At depths between surface and depth of maximum dose (d_{max}), the dose is due to the combination of transmitted primary photons, scatter dose from the phantom and head assembly, and secondary electrons produced from the block. Dose beyond the depth d_{max} is dominated by scatter.

This investigation was designed to study the various contributors to the eye dose and to optimize the parameters for shielding to minimize dose to the eye.

Radiation dose under the eye block was measured with a thin window parallel plate ionization chamber (PTW-033) and TLD (LiF) in the polystyrene phantom. The dose distribution was profiled with film dosimetry (Kodak X-Omat TL enveloped film).

The photon beam studied was 6 MV X-ray from NEC-1006X which is suitable to treat for head and neck tumor. The eye shielding blocks were made with 7.5 cm thickness of cerrobend which is an alloy with Bismuth (50%), Lead (26.7%), Tin (13.3%), and Cadmium (10%).

The divergent eye block had a diameter of 1 cm at the distal end which covers the ion chamber and eye lens adequately. To keep the eye block vertical so that its full length was in beam, a hanging block method was used.

The measured transmission, T, through the eye block and supporting tray at a depth of maximum build up, d_{max} was approximately 3.2% for 6 MV X-ray. In most cases the ratio of charge collected was treated as the ratio of doses. Since most data in this study are relative, the perturbations caused by the ion chamber in the medium was neglected.

The measurement was normalized at the isocenter of open field which was set at the depth of 1.5 cm, for field sizes of 6×6, 10×10 and 15×15 cm^2. To compare the results, the measured doses were calculated as normalized dose which is the ratio of dose for interesting points with block to dose of open field at maximum build up region. Measurements of dose at a depth under the shielding block were performed at 1 mm, 5 mm, 25 mm, and 50 mm distance below the surface to represent cornea, lens, retina, and tumor, respectively.

The eye shielding block was used a perpendicular beam due to most anterior fields. However, device can be made to protecrt the eye in any possible angle and can be adjust distance near the eye. The dose distribution under the block at a distance d_{min} which produced the minimum dose was measured with film dosimetry and dose profiles were plotted using a film densitometric scanning system (Sakura PDM-5, micro-densitometer).

Exposures were made in a dose region where the dose was linearly proportional to the optical density. The measurement errors were within +2% except at $d=0$ where variations up to 20% were observed. This was attributed to the improper positioning of the block on the ion chamber.

RESULTS

The eye blocks of different thickness were used to measure the effect of the cerrobend block thickness on dose under block. Fig. 2 shows the normalized dose at three depths versus thickness of cerrobend, measured for the 6 MV X-ray beam. It seems there is very little gain as block thickness is increased above 7 cm. This suggests that most of the dose contribution is from scatter and not from the primary transmission. Hence only a 7.5 cm thick cerrobend block was used for further study and the dose at d_{max} is increased as 18% to open fields (10 ×10 cm^2) instead of 3.2% (5 HVL's). Fig. 3 note the normalized dose versus distance for cornea, lens and retina respectively. Results of measurements at a depth of 1 mm representing dose to the cornea are plotted against distance, h, between surface and block. Note that there is a minimal dose under the block, when the block is at the surface, the dose is higher. The major dose contribution was from the electrons produced in high Z medium near the surface. As h increases, dose decreases, and a minimum point h_{min} is reached, at which the dose is approximately equal to that expected from the primary transmission. At larger distances the dose increases. This may be caused by the predominance of head scatter reaching the point of measurement. A distances beyond 15 cm, the dose falls off linearly, which is probably due to the greater area of the block covering the phantom (ratio of blocked to open field increases as h increases). The distance with minimum dose, h_{min}, for 6 MV photon is about 10 mm from surface, it is approximately equal to 0.5 of the depth of dose maximum for the photon energies. The shift in h_{min} is probably caused by the energy of the secondary electrons and their lateral distribution, which is governed by the scattering power of the medium of the block. There is no prominent dose minimum at these depths for lens and retina. The doses are nearly constant but have a downward trend which is caused by the projection of the block covering a greater area. When h is zero, the lens dose is slightly greater compared with the large values of h, but for the retina this effect is not seen. This suggests that there is a significant contribution at

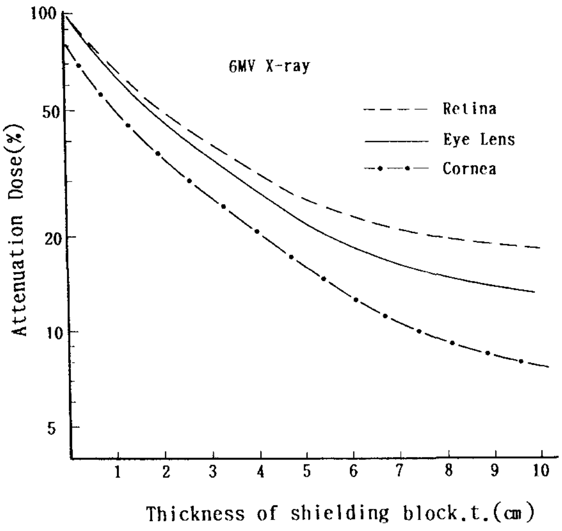

Fig. 2. Attenuated dose is plotted against thickness of eye shielding cerrobend block for 6 MV beam.

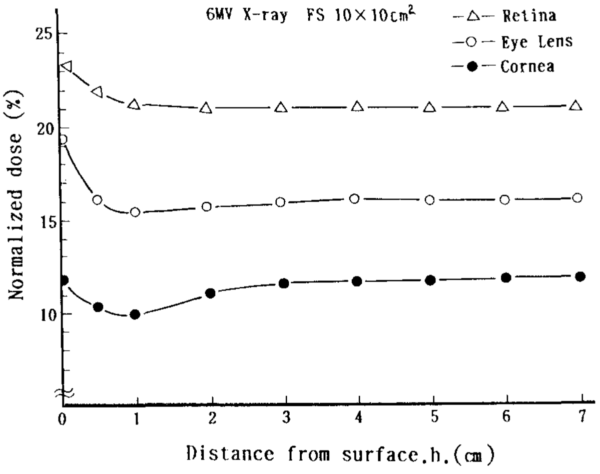

Fig. 3. Normalized dose versus distance between block and surface measured at depth 1 mm (cornea), 5 mm (eye lens), 25 mm (retina) in 6 MV X-ray.

superficial depths from the secondary electrons generated in the shielding block. At larger depths, these electrons are diffused and absorbed and all the dose is contributed by scattered photons. The normalized dose of cornea, eye lens, retina are 10%, 15.2%, 21.5% of open field (10×10 cm^2) at h_{min}, respectivly.

Fig. 4 is shown the dose of eye lens for field sizes at the varing block to surface distance, h, in 6 MV X-ray. As the field size increases, the dose of lens increases, and the dose difference was increased at large distance. The doses of eye lens at h_{min} are 10.8%, 15.2%, 18.9% for 6×6, 10×10, 15×15 cm^2 fields, respectively.

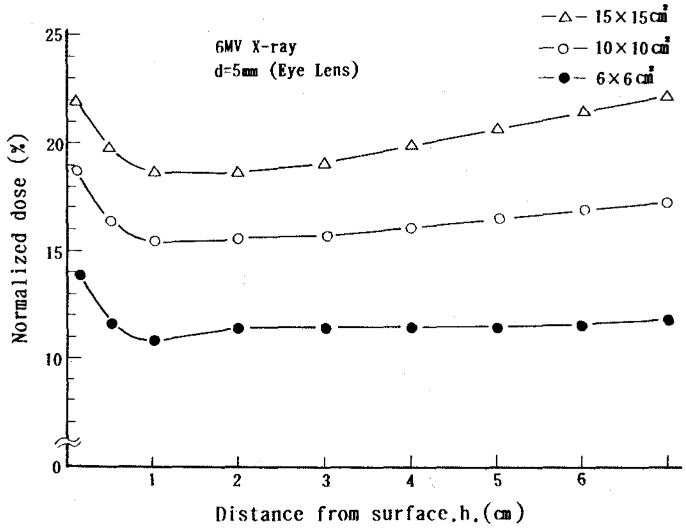

Fig. 4. Normalized dose for field sizes versus distance between block and surface measured at 5 mm depth (eye lens) in 6 MV X-ray.

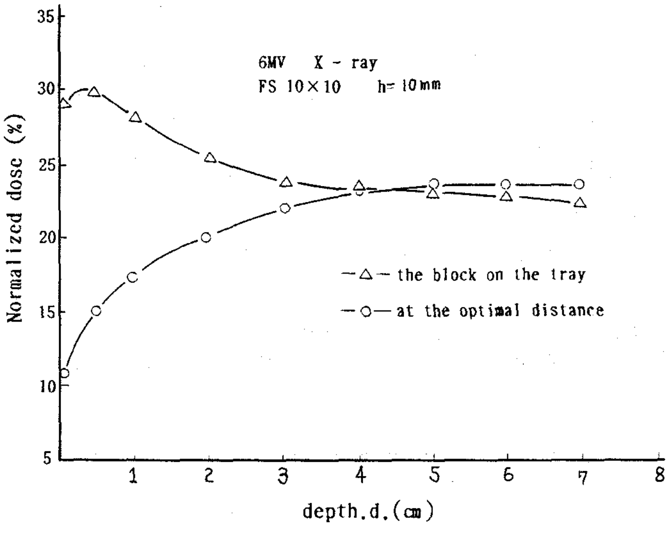

Fig. 5. The comparison of nomalized dose along the central axis in phantom for the block on the tray and the optimal distance in 6 MV X-ray.

Fig. 5 shows the comparison of eye shielding effects by placing the blocks on the conventional regular block tray and at the optimal distance, h_{min}, versus depth, d, in the phantom. There was striking difference in the dose of the surface and the dose to lens between the block at the regular tray and the block at the optimal distance. The surface dose is maximum at block on tray but the lowest dose is a surface when the block is placed at a distance h_{min}. These data show an increase of dose with depth that is characteristic of a depth dose distribution that is dominated by scatter contributions.

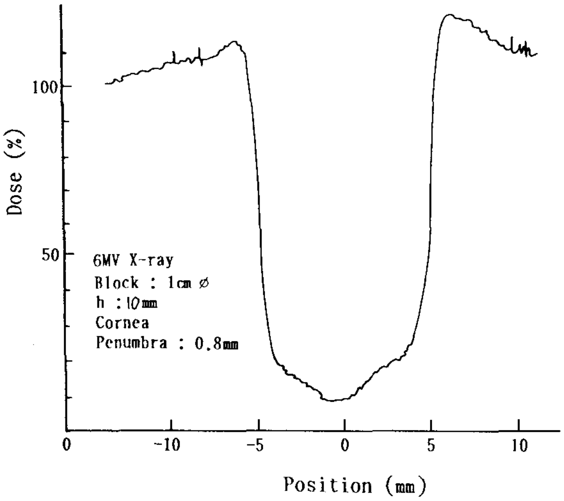

Fig. 6. Dose profile taken with shielding block at 1 mm depth (cornea).

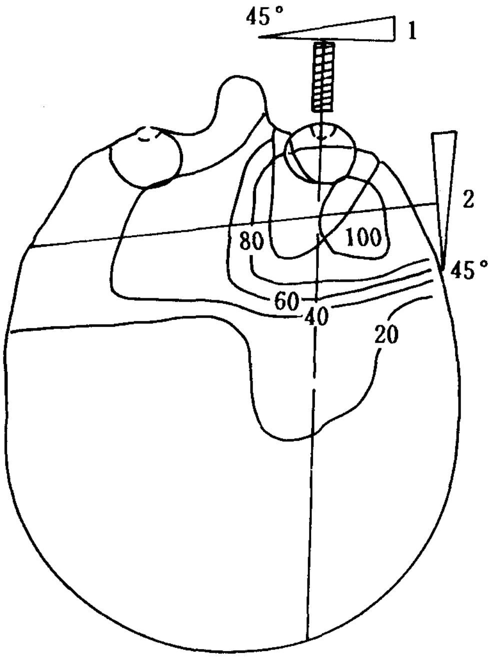

Fig. 7. Isodose plan combined two wedges and eye shielding block at optimal distance for treatment on left side lymphoma with 6 MV X-ray.

To see the effect of this scatter contribution on the dose profile under the block, Fig. 6 was plotted from the film data for a 6-MV beam. The edges are sharp and there is no significant rounding off of the profiles caused by the phantom scatter and secondary electron diffusion but the dose distribution outside of shielding block was increased with scattered ray.

Fig. 7 is shown the isodose planning sheet for treatment of orbital lymphoma with 6 MV X-ray, two wedge fields (AP, Lat.) combined lens shielding block.

DISCUSSION

When treating the eye with a shielding block, the minimum achievable dose to the cornea in an anterior field is limited by the primary transmission, in the range of 3~6%. At the lens, dose is approximately 15% of the unblocked dose maximum for all beams, which may be a high enough dose for cataract formation. Depending upon the tumor site, one can tailor the dose distribution by the combination of brachytherapy[15], electron beam[16], and photon beams[17~19] to provide adequate coverage and spare the lens.

Beyond about 5 HVL, the thickness of a shielding block is not a critical parameter. A minimum dose is achieved at a superficial depth when distance, d, is approximately half the depth of dose maximum of the photon energy. There is no dose minimum at greater depths, hence, for the lens and retina the position of the block does not alter the dose. Dose profiles at the block edge at depth are sharp for 6 MV X-ray beam from linear accelerator. Provided $h > h_{min}$, the choice of atomic number for a shielding block was found to be not critical, since the dose at depth is not from the secondary electrons originating from the block but rather from the phantom scatter. However, the effective atomic number and h_{min} are inversely related, which is due to the scattering power of the material of the shielding block.

From the data presented here, the minimum superficial dose is limited by the primary transmission, but at depths, dose is much higher because of scatter filling in under the block. When radiation therapy is used for the treatment of malignant tumors of the head and neck, the possible complication of a cataract might be accepted as a normal risk if there is a possibility of preserving useful vision.

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국문초록 =

6 MV 광자선치료에서 안구차폐기구의 제작과 선량분포 측정

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이 경 자

눈의 수정체는 방사선에 매우 예민한 장기이며 비교적 적은 선량에서도 백내장의 원인이 될 수 있다. 그러므로 두경부암의 방사선치료에서 수정체를 최대한 차폐하면서 병소에 집중 조사하는 방법이 개발되어야 한다.

저자는 안구의 표면에서 0.5 cm 깊이에 위치하며 폭 1 cm인 눈의 수정체를 최대한 차폐하면서 주위 병소를 치료하기 위하여 원자번호가 높은 차폐물질을 이용하였으며 최적조사조건은 측정실험을 통하여 결정하였고 이를 임상치료에 응용하였다.

수정체의 차폐기구는 제작하기 쉽고 차폐효과가 큰 혼합금속(Cerrobend)이 적당하였으며 두께 7.5 cm와 직경 1 cm의 원뿔기둥모양이 가장 이상적이었다.

차폐기둥의 밑면과 표면과의 거리가 10 cm일 때 수정체에 가장 적은 선량이 부여되며 병소에는 비교적 많은 선량이 부여된다. 이때 각막(Cornea, 1 mm), 수정체(Eye Lens, 5 mm), 망막(Retina, 25 mm) 및 병소(Tumor, 50 mm 이상)의 선량은 차폐물이 없을 때와 비교하여 각각 10.0%, 15.2%, 21.5% 및 23.2%로 측정되었다.