Experimental lens-sparing optimization in therapeutic orbital irradiation with electron beams

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Received March 4, 2004

There has been a number of approaches in the literature for therapeutic malignant and benign orbital irradiation. All techniques intend to deliver a homogenous dose to the orbital and retroorbital target volume while sparing the lens of excessive dose. In this experimental lens-sparing study, 4 MeV and 12 MeV anterior electron irradiation has been used with cerrobend shielding circular blocks of varying diameter and thickness placed on a thin Mylar at the distal tip of the electron applicator to spare the lens. The first phase of the study in water phantom has been designed to determine the shield thickness and diameter constant for 4 MeV and 12 MeV electron beams. After optimizing the lens dose by water phantom, the second phase of our study has been designed to measure doses at lens and other specific localizations in randophantom under same conditions with 4 MeV and 12 MeV electron beams. By this technique lens accumulated 18.56% of prescribed dose and lateral aspects of the lens received 44.59% of the prescribed dose in 4 MeV electron irradiation, whereas this was 13.86% and 44.80%, respectively in 12 MeV electron irradiation. The technique used is found to be an extremely simple and effective technique allowing an easier setup with excellent dose distribution characteristics with lens sparing applicable to orbital irradiation practice.

Key words: orbital irradiation, cataract, lens

Radiation therapy is an effective modality for treatment of both malignant and benign diseases of the orbit [4, 7, 13, 16, 17, 21]. Many radiotherapy techniques for orbital and retroorbital treatment have been described in the literature [2, 4, 6, 7, 12, 13, 15–17, 19–22]. Radiotherapy techniques can be divided into two groups; non-lens-sparing and lens-sparing. Non-lens-sparing treatments are mostly done in Bone Marrow Transplantation conditioning with TBI (Total Body Irradiation) for leukemias, where structures around the lens need to be irradiated to avoid leukemic relapses. With non-lens sparing techniques, it is relatively easy to deliver the prescribed dose to the entire retina, but the lens will receive similar dose, and a potentially dense cataract is almost inevitable.

Radiation-associated cataract occurs as a result of posterior lens epithelial germinative zone's being exposed to radiation [5]. Retrospective and molecular studies revealed cataractogenesis and a study showed 57% lens opacification in 8 years with 15 Gy lens dose [9, 14]. Lens has an equatorial diameter of 9–10 mm and is 5 mm below corneal surface [8, 14]. Germinative zone containing mitotic-active cells constitutes a 3–4 mm ring around the lens center [14]. Different studies suggest different techniques to avoid cataractogenesis [5, 9].

On the other hand, lens-sparing technique is very difficult. The lens dose is often well above accepted threshold values. Most of the published techniques use photons, which penetrate deeper than electrons into the target volume. Electron beams can be arranged so as to keep the dose very localized and superficial.

Multiple issues need to be considered when treating a lesion of the eye or orbit. The first issue is obviously the optimal delivery of dose to the tumor and areas deemed to be at risk. Consideration of dose to normal structures is the next priority. This includes minimizing the risk of injury to the retina, lens, lacrimal gland and contralateral eye.

In some situations the opposite eye is included in the treatment, but often it is not and dose to the remaining normal eye will be vital to the long-term vision of the patient. The lens is the most dose-sensitive structure of the eye, but cataract development is also readily treated. Dose fractionation, dose rate and total dose both play a part in the development of cataract [5].

In this study, an irradiation technique for lens-sparing is presented with 4 MeV and 12 MeV orbital anterior electron irradiation.

Material and methods

The first phase of the study in water phantom has been designed in this study to determine the shield thickness and diameter constant for 4 MeV and 12 MeV electron beams to optimize a lens-sparing technique for orbital region anterior electron irradiation with a hanging lens block placed on a thin Mylar at the distal tip of the electron applicator. After optimizing the lens dose by water phantom, the second phase of our study has been designed to measure doses at lens and other specific localizations in randophantom under same conditions with 4 MeV and 12 MeV electron beams. 4 MeV and 12 MeV electron beams were selected for probable orbital and retroorbital tumor localizations. Circular cerrobend blocks consisting of 50% Bi, 26.7% Pb, 13.3% Sn, 10% Cd alloy with different diameters and thicknesses were used for shielding and bottoms of the blocks were covered with vax bolus to avoid the adverse effects of scattered electron beams.

In the first phase, shield blocks of differing diameters as 7 mm, 10 mm, 12 mm, and 14 mm with predetermined optimal constant thicknesses of 5 mm and 7.5 mm have been used respectively for 4 MeV and 12 MeV electron irradiation in a water phantom at different depths (0 cm, 0.5 cm and 1 cm for 4 MeV, 0 cm, 0.5 cm and 3 cm for 12 MeV) obtaining dose profiles for each shield diameters. A water phantom system (Nucletron, Holland) and 0.12 cc cylindrical ion chamber (RK 83-05 Scanditronix, Uppsala, Sweden) were used for dosimetric measurements. After dose profiles of different diameters were obtained, we experimented to verify the effect of the shield thicknesses of 2.5 mm, 5 mm, 7.5 mm, 10 mm and 12.5 mm with 12 mm diameter for 4 MeV and 12 MeV electron irradiation, where 12 mm constant diameter has been chosen due to its compatibility.

After optimizing the lens dose by water phantom, the optimized dose attained has been used in the randophantom orbital irradiation. An artificial adult patient phantom was used along with a linear accelerator (Philips SL-25, UK), Thermoluminescent Dosimeter (TLD_{100}) and TLD reader (Victoreen 2800) to measure the effect of dose distribution using 12 mm diameter and 2.5 mm thickness for 4 MeV and 12 mm diameter and 5 mm thickness for 12 MeV found in water phantom measurements. Electron applicator field size was 6X6 cm. Six holes were drilled consistent with computerized tomography film into the left orbital region of the phantom in the tumoral target zone, surrounding bone, optic nerve, central lens location, and on both edges of the lens sites corresponding to the shielding projection, whereas 6 TLD_{100}s were placed in these holes. Randophantom-measured and water-phantom calculated doses were compared for six different predescribed points. We repeated the experiment three times delivering 2 Gy electron irradiation with 4 and 12 MeV energies each time separately to allow us evaluate whether or not effective lens sparing optimization could have been achieved by our electron irradiation technique.

Results

The profiles obtained with 12 MeV electron irradiation at the same measurement depth (z=0.5 cm) is shown in Figure 1, where it can be seen that as block diameter increases the dose under the shielding block decreases. The curves in Figure 1 represent dose profiles corresponding to differing

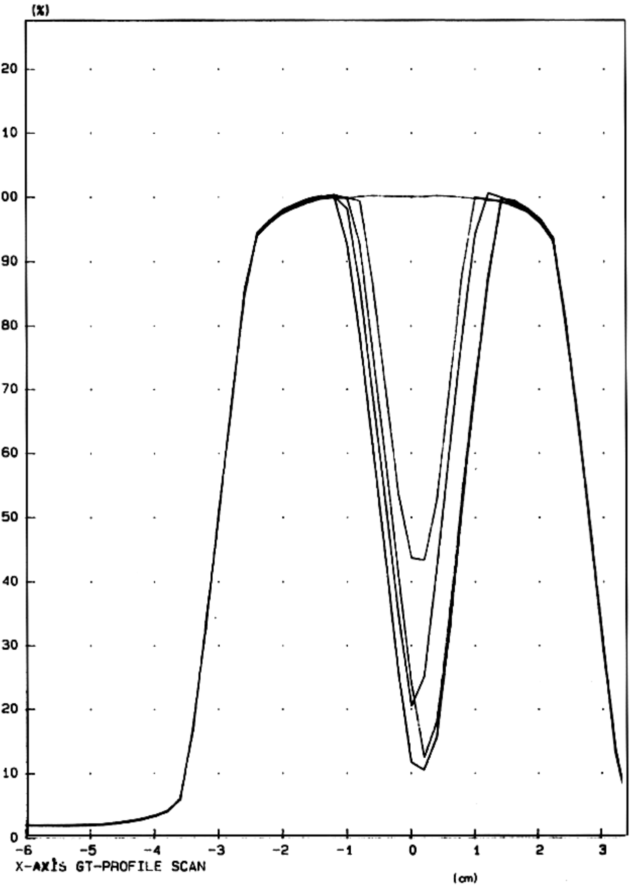

Figure 1. Effect of shield block diameter on dose distribution for 12 MeV electron. Curves respond to block diameters of 7 mm, 10 mm, 12 mm, 14 mm from top to bottom curves, respectively.

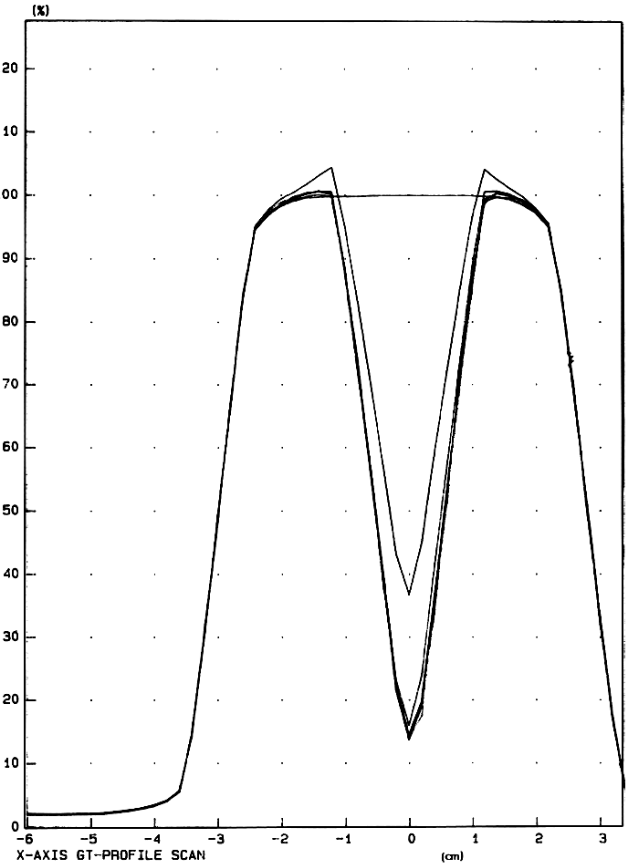

Figure 2. Effect of shield block diameter on dose distribution for 12 MeV electron. Curves respond to block thickness of 2.5 mm, 5 mm, 7.5 mm, 10 mm, 12.5 mm from top to bottom curves, respectively.

block diameters of 7 mm, 10 mm, 12 mm and 14 mm from top to bottom and show that block diameter exceeding 12 mm has not significantly changed the relative dose profile. The same observation has also been determined for 4 MeV electron irradiation.

The effect of thickness variation on dose distribution in 12 MeV corresponding to the shielding block at 0.5 cm depth is shown in Figure 2, where it can be seen that as block thickness increases the dose, under the shielding block decreases. The curves in Figure 2 represent dose profiles corresponding to differing block thicknesses of 2.5 mm, 5 mm, 7.5 mm, 10 mm and 12.5 mm from top to bottom and show that block thickness exceeding 5 mm has not significantly changed the relative dose profile. The curves for 4 MeV showed that block thickness exceeding 2.5 mm has not significantly changed the relative dose profile.

When we analyze the dose profiles of 4 MeV irradiation-induced absorbed dose at surface (Z=0 cm) for lens localization; 44.43% dose has been obtained in the lens edges (equatorial lens diameter was accepted as 9 mm), and 19.15% dose has been obtained in the lens center (center of the field), whilst dose for cornea localization (which is 3 to 5 mm above the lens) is 97.46% shown in Figure 3.

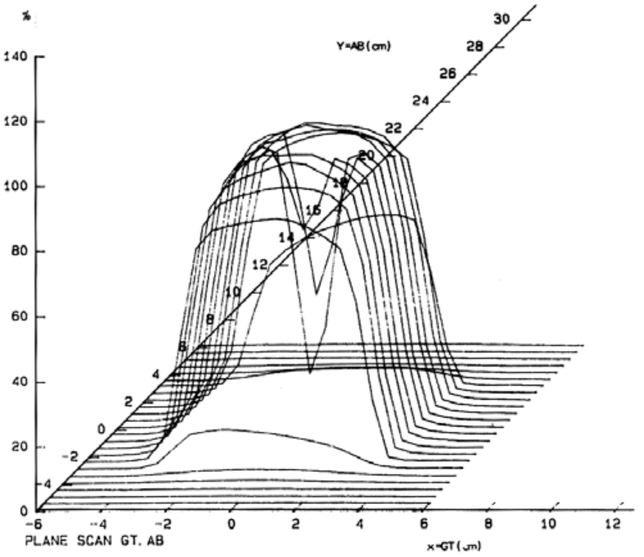

Figure 3. Dose profiles at Z=0 cm for 4 MeV electron.

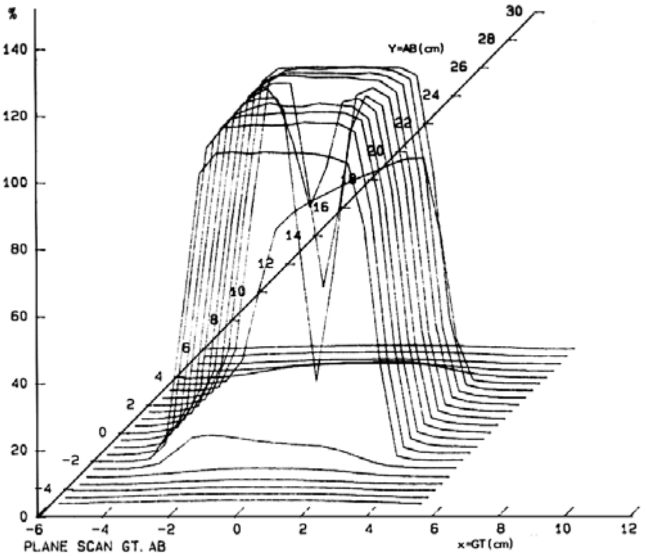

Figure 4. Dose profiles at Z=0.5 cm for 12 MeV electron.

Figure 4 shows that the dose profiles at Z=0.5 cm central shielding block projection which refers to central lens localization is 15.03%, and block edge projection received 45.75% of the given dose with 12 MeV electrons. Figure 5 shows that the dose profiles at Z=3 cm central shielding block projection is 73.98% and block edge projection received 86% of the given dose with 12 MeV electron irradiation.

After determining the shield block diameter and thickness, we have done randophantom measurements using 12 mm diameter and 5 mm thickness for 12 MeV and 12 mm

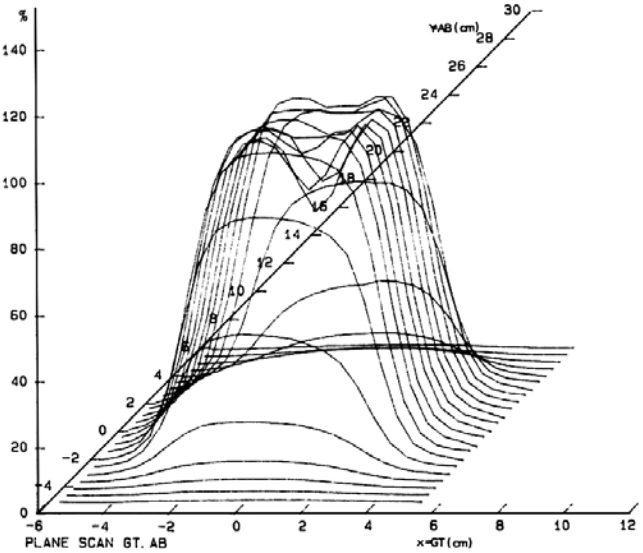

Figure 5. Dose profiles at Z=3 cm for 12 MeV electron.

Table 1. 4 MeV electron beam with 2 Gy irradiation

TLD_{100} site	Calculated water phantom (cGy)	Measured Rando Phantom (cGy)	Difference (%)
Tumoral target zone	200	194	–3.0
Surrounding bone	76	78	2.6
Optic nerve	40	36	–10.0
Central lens site	39	36	–7.7
Left edge of lens	88	84	–4.5
Right edge of lens	88	89	1.1

Table 2. 12 MeV electron beam with 2 Gy irradiation

TLD_{100} site	Calculated water phantom (cGy)	Measured Rando Phantom (cGy)	Difference (%)
Tumoral target zone	200	202	1
Surrounding bone	90	84	–6.7
Optic nerve	30	28	–6.7
Central lens site	30	28	–6.7
Left edge of lens	91	92	1.1
Right edge of lens	91	89	–2.2

diameter and 2.5 mm thickness for 4 MeV found in water phantom measurements. Dosimetric result of 4 MeV 2 Gy electron beam irradiation regarding 6 TLD sites placed in the tumoral target zone, surrounding bone, optic nerve, central lens location, and on both edges of the lens corresponding to the shielding projection are shown in Table 1 and for 12 MeV irradiation are shown in Table 2.

Discussion

Therapeutic aim in cancer radiotherapy in orbital region is covering the entire clinical target volume with minimal dose to the lens. Orbital irradiation has been a field for teletherapy technique developments in lens sparing. Many teletherapy techniques have been developed and the benefits of convenience and lack of dose deep to the orbit are offset to some extent by high cataract risk. Although modern surgical techniques and the insertion of an artificial lens make this an easily remedied complication, it is better to avoid complications whenever possible and feasible.

Direct electron beam irradiation is a good way of delivering therapy to the orbital region however cataractogenesis risk still exists. By the randophantom irradiation technique we used with an anterior electron irradiation with a hanging lens block placed on a thin Mylar at the distal tip of the electron applicator, lens accumulated 18.56% of prescribed dose and lateral aspects of the lens (mean of the left and right lens edges) received 44.59% of the prescribed dose in 4 MeV electron irradiation, whereas this was 13.86% and 44.80%, respectively in 12 MeV electron irradiation that we can consider within reasonable limits.

Figure 4 shows that the dose absorbed at Z=0.5 cm central shielding block projection which refers to central lens localization is 15.03% and block edge projection received 45.75% of the given dose with 12 MeV electrons. Figure 5 shows that the dose absorbed at Z=3 cm central shielding block projection is 73.98% and block edge projection received 86% of the given dose with 12 MeV electron irradiation where Z=3 cm level corresponds to sites requiring irradiation and Z=0.5 cm level is around lens localization not requiring to be irradiated. Thus, with our technique there is no need for an additional lateral portal as used in various other techniques resulting in clear reduction of setup-induced errors causing morbidity and time consuming.

ARTHUR et al [1] using an electron/photon matched field technique have found a posterior lens dose accumulation of less than 40% but for the lateral aspects of the lens less than 30% and, comparing to our results with our technique less dose in the lateral aspects but slightly more in the lens dose has been obtained. BORGER et al have used an anterior appositional electron beam with a hanging lens block have found a lens dose below 20% comparable to our results [6]. HENK et al have used lead cylinder shielding and have obtained 36–50% lens dose with Co-60 beam therapy and 11–18% lens dose with 5 MeV X-rays in their clinical setting [14].

The sensitivity of the lens to radiation is well-defined with a threshold of as low as 2 Gy for cataract formation, but we are trying to establish a better sparing technique that will at least help spare the surrounding structures of excessive dose for a less impaired vision. This technique seems to be a simple technique allowing an easier set-up with excellent dose distribution with lens sparing characteristics applicable to orbital irradiation practice.

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