Effectiveness of Lead Lenses in Reducing Radiation Exposure[1]

Alan H. Richman, M.D.,[2] Bun Chan, M.D., and Monique Katz, M.D.

Optically ground prescription lenses of glass, leaded glass, and plastic were exposed to radiations that simulated routine angiography. Radiations transmitted through the lenses were measured. Plastic provided no protection, regular glass provided moderate protection, and high lead content glass reduced radiation transmission by approximately 70%. A brief review of the literature concerning the biological effects of radiations to the eye is included.

INDEX TERMS: Cataracts • (Eyeball, effect of radiation on, 2[24].470) • Diagnostic radiology, radiation dose • Radiations, protective and therapeutic agents and devices • Radiology and radiologists

Radiology 121:357–359, November 1976

RELATIVELY HIGH DOSES of radiation can damage the conjunctiva, iris, sclera, and blood vessels of the retina. The lens of the eye, however, is the critical site, for it may sustain irreversible damage from a relatively low dose of radiation. Low doses will produce only a temporary reaction in the other ocular structures (1).

The sensitivity of the lens to radiation is felt to be due to the failure of normal cell replacement (2). The lens is surrounded by a capsule. On the anterior surface beneath this capsule is a layer of flattened or cuboid cells which comprise the epithelium of the lens and allow for normal metabolism of the lens. At the peripheral border or equator of the lens these cells become progressively elongated and are transformed into the structure of the lens proper. Von Sallman demonstrated that cytologic damage from radiation to the lens consists of a temporary cessation of mitosis, cell death, and occasional abnormal mitosis producing bizarre cells (3, 4). Because of the enveloping capsule of the lens, these damaged or bizarre cells cannot be sloughed but instead are pushed or migrate to the posterior pole of the lens where early radiation-induced cataract is first clinically manifest (5). Subsequent changes may also be observed in the anterior pole, with progressive opacification of the cortex eventually forming a mature and nonspecific cataract (6).

Until now the only protective devices have been heavy cumbersome lead goggles. These are generally not used because of the inconvenience and discomfort. Commercially available prescription lenses for ordinary glasses are made of either plastic or glass. There are two basic types of glass lenses, and these differ significantly in lead content. Ordinary glass lenses called "crown glass" are used by most people. A less commonly used glass known to opticians as "hi-lite", happens to have a relatively high lead content which allows for a thinner lens than would otherwise be required. It is normally used as a substitute for extremely thick lenses. This experiment was designed to determine if significant protection from radiation is provided by wearing the high lead content glass instead of ordinary glass or plastic lenses.

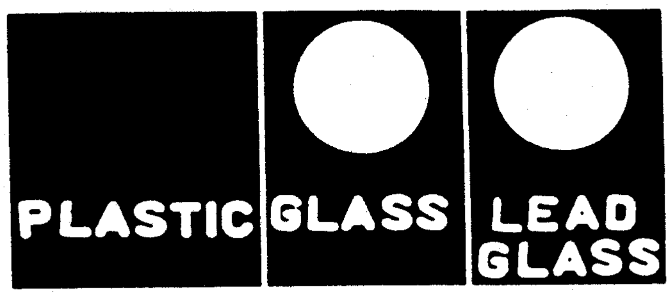

Fig. 1. This radiograph shows the lucency of plastic, the lucent center of the glass lens, and the opacity of lead content glass.

MATERIALS AND METHODS

Lenses of plastic (CR39), glass (crown glass) and high lead content glass (hi-lite) each with a diameter of 4.5 cm and power of −4.00 diopters were used. A radiograph was made of the three lenses (Fig. 1). A thermoluminescence dosimeter and a small ionization chamber were used to measure the transmission of radiations through these three lenses. The dosimeter was a LiF(TLD-700), 1.27-cm diameter disk. TLDs were exposed and read out in a Teledyne TLD-7300C. The ionization chamber was a Physikalisch Technische Werkstatten (PTW) precision chamber connected to a Keithlev-602 electrometer.

To obtain accurate dose measurements with the use of a TLD or ionization chamber at the low scatter dose rate of our special procedure table, flouroscopy time would

[1] From the Department of Radiology, New York Medical College, New York, N. Y. Presented at the Sixty-first Scientific Assembly and Annual Meeting of the Radiological Society of North America, Chicago, Ill., Nov. 30–Dec. 5, 1975.

[2] Current address: Nassau County Medical Center, Department of Radiology, 2201 Hempstead Turnpike, East Meadow, N.Y. 11554. elk

PSO 3

Table I: Summary of LiF:TLD (rads) and Ionization Chamber (Coulombs) Transmission Measurements

Trial	Control	Plastic	Glass	Lead Glass
1	7,130	7,141	4,346	2,376
2	6,489	6,635	4,102	2,278
3	6,394	6,191	3,628	2,161
Average Lif: TLD	6,671 (100%)	6,656 (99%)	4,025 (60%)	2,271 (34%)
Average Ion Chamber	1.86×10^{-12} (100%)	1.86×10^{-12} (100%)	1.03×10^{-12} (55%)	0.46×10^{-12} (25%)

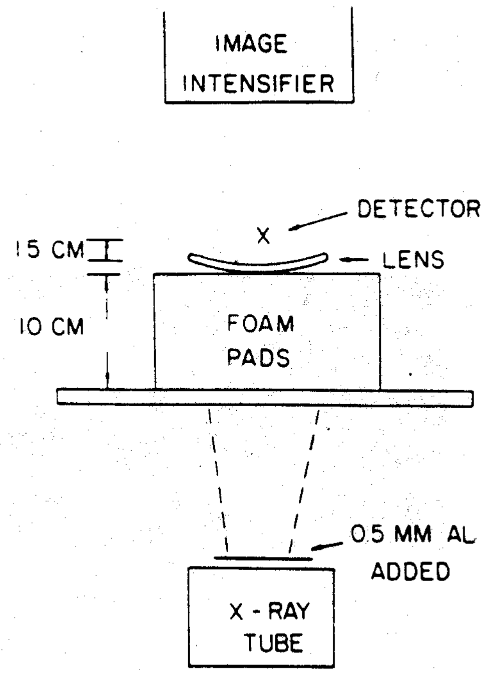

Fig. 2. Experimental setup showing the arrangement of x-ray tube, detector, and image intensifier.

have to be excessively long. To avoid this, measurements were made with the primary beam rather than with the scattered beam. Since the scattered beam generally has a slightly greater h.v.l. than the primary beam (7), an appropriate filter (0.5 mm Al) was added.

The experimental setup is shown in Figure 2. Each lens was placed on a sponge pad 10 cm above the table top to avoid secondary scatter from the table. A LiF:TLD disk was then positioned 1.5 cm from the lens; this simulated the distance between an eyeglass lens and the cornea. Each lens was exposed to a flouroscopic x-ray beam generated at 100 kVp, 4 mA for 2 minutes. Three determinations were made for each lens and for three controls with no lens in place. We corrected for the 38% oversensitivity of the LiF disk at the effective energy of 38 keV of the x-ray beam (8). The same experimental setup was used for measurements made with the ionization chamber connected to an electrometer. Results are summarized in TABLE I.

DISCUSSION

It has been shown that the development of experimental radiation cataracts depends on the animal species (mouse lens 4X more sensitive than rabbit) (9), the fractionation used, and the type of radiation (neutrons more damaging than x rays). Human cataract studies in atom bomb survivors, industrial accidents, and in radiation therapy show that a 1,150-R dose is likely to result in cataracts in 100% of cases (10). Cataracts in mammalian species have been produced with radiation doses as little as 15 R (11) and in humans with as little as 200 R in a single dose (12). With fractionation the threshold dose for cataract production is increased and the time of onset of cataract is delayed (10).

Malsky has shown the average exposure to the eye of an angiographer during a complete cardiac procedure to be approximately 13 mrem with a range of 10–26 mrem (13). Adrian *et al.* have shown the level at the collar to be approximately 3.5 mR, but used less cine time per procedure (14). According to the National Council on Radiation Protection and Measurements (NCRP) the maximum permissible dose to the lens of the eye is 100 mrem per week, 1.3 rem per quarter (13 weeks), or 5 rem per year. Based on the two studies above, an angiographer doing 2–3 examinations per day would approach or exceed the maximum. However, there is, currently no good estimate of the dose required for cataract production in workers exposed to low levels of radiation over an extended period of time. Even in relatively high-dose radiation experiments there is a latency period between exposure and eventual cataract development which may be as long as 20 years with low doses (10).

Prescription lenses available from most optometrists were found to vary greatly in the degree of radiation protection they afforded. Plastic lenses provided no protection, glass lenses moderate protection, and high lead content lenses (hi-lite) reduced radiation transmission by approximately 70%. The thickness of the central portion of the lens will vary depending upon the severity of the myopia; the more severe the myopia, the thinner the central portion of the lens. This in shown by the degree of transmission through the central portion of the glass lens in Figure 1. The lens used in this experiment represents a common prescription for myopic individuals. As the individual becomes less myopic and approaches hyperopia, the thickness of the central portion of the lens will increase and provide an increased level of protection. In actual practice, the orientation of the radiation, the lens, and the eye would vary rather than be perfectly aligned as arranged in our study. A portion of scattered radiation would bypass the lens, and the dose-sparing effect of the leaded lenses would be diminished. This could be partially corrected by wearing two additional lenses along the ear pieces to protect the eye from indirect radiation.

No evidence has been presented to show that there is a significant increase in the incidence of cataracts among angiographers. Nevertheless we feel that the use of high lead content glass instead of plastic or ordinary glass will provide a significant measure of protection without added discomfort or distraction.

Department of Radiology
Nassau County Medical Center
2201 Hempstead Turnpike
East Meadow, N.Y. 11554

REFERENCES

1. Bateman JL: Eye and Irradiation. [In] Pathology of Irradiation, ed by CC Berdjis. Baltimore, Williams & Wilkins, 1971, pp 669-686
2. Ham WT Jr: Radiation cataract. Arch Opthomol 50:618-643, Nov 1953
3. Von Sallman L: Experimental studies on early lens change after roentgen irradiation. I. Morphological and cytochemical changes. Arch Opthamol 45:149-164, Feb 1951
4. Von Sallman L: Experimental studies on early lens changes after roentgen irradiation. III. Effects of X-radiation on mitotic activity and nuclear fragmentation of lens epithelium in normal and cysteine treated rabbits. Arch Ophalmol 47:305-320, Mar 1952
5. Cogan DG, Donaldson DD, Reese AB: Clinical and pathological characteristics of radiation cataract. Arch Opthamol 47:55-70, Jan 1952
6. Evans TC, Richards RD, Riley EF: Histologic studies of neutron- and x-irradiated mouse lenses. Radiat Res 13:737-750, Nov 1960
7. Strickert T, Fosmark H: Some measurements of scattered radiation from an Alderson phantom for x-ray beams from 50-200 kVp. Health Phys 28:209, Mar 1975
8. Almond PR, McCray K, Espejo D, et al: The energy response of LiF, CaF_2, and $Li_2B_4O_7$Mn from 26 keV to 22 meV. Proc 2d Int Conf Luminescence Dosimetry. CONF-680920: 411, 1968
9. Upton AC, Christenberry KW, Melville GS, et al: The relative biological effectiveness of neutrons, x-rays, and gamma rays for the production of lens opacities: Observations on man, rats, guinea-pigs and rabbits. Radiology 67:686-696, Nov 1956
10. Merriam GR Jr, Focht EF: A clinical study of radiation cataracts and the ralationship to dose. J Roentgenol 77:759-785, May 1957
11. Upton AC: [cited in] Bergstrom K, Dahlin H, Gustafsson M, et al: Eye lens doses in carotid angiography. Acta Radiol (Diag) 12: 134-140, 1973
12. Casarett GW: Possible effect of relatively low levels of radiation. Curr Probl Radiol 3:19-23, Mar-Apr 1973
13. Malsky SJ, Roswit B, Reid CB, et al: Radiation exposure to personnel during cardiac catheterization. A preliminary study. Radiology 100:671-674, Sep 1971
14. Adrran GM, Fursdon PS: Radiation exposure to personnel during cardiac catheterization. Radiology 106:517-518, Mar 1973

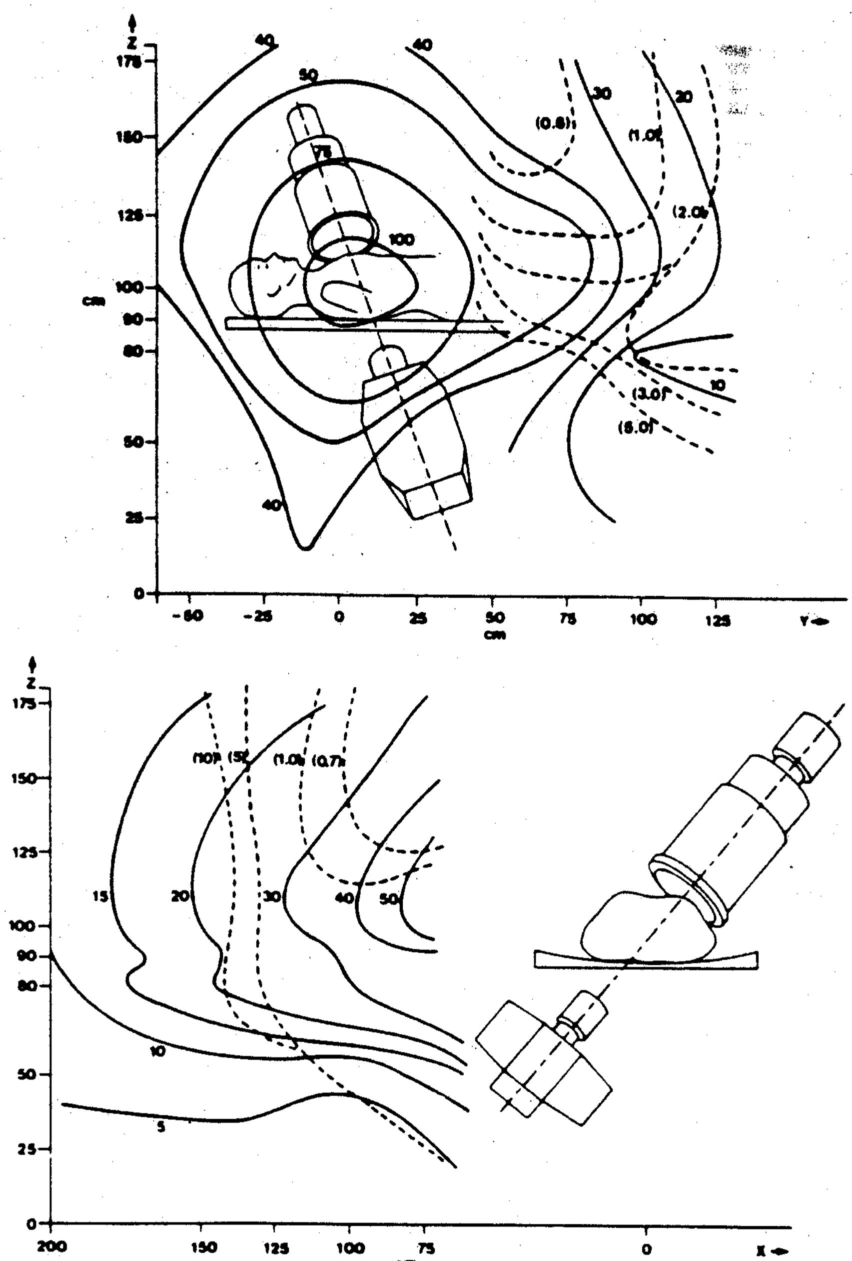

FIGURE 3. Isoexposure curves expressed in milliroentgen/hour for the 50° left anterior oblique 15° cranial angulation in (top) the longitudinal plane with the operator at 75 cm on the Y axis, and (bottom) the horizontal plane with the operator at 75 cm on the X axis. **Solid lines** indicate radiation exposure levels without the protection of the shield; **dashed lines** indicate values with the shield. The vertical center of shield is at 75 cm in both the X and Y planes with the operator behind the shield. Z represents the vertical plane, Y the longitudinal plane, and X the horizontal plane. (Reprinted by permission of publisher from Gertz et al.[28])

should consider the time of the study, placement of personnel, available shielding, location of equipment, adequate monitoring (radiation badge) and a complete quality control program. The aim of an adequate radiation protection program is to reduce the genetic and somatic risks to below the risk for other occupations regarded as safe.[30,31] Risk estimates in the low-dose region involve a great deal of uncertainty and are based in part on incomplete data. The magnitude of the risk to the persons exposed must be kept in perspective if they are to derive a benefit from the medical use of ionizing radiation.

References

1. **Klement AW Jr, Miller CR, Minx RP, Shelen B.** Estimates of ionizing radiation doses in the United States, 1960–2000. Report ORP/CSD 72-1, 1972: Washington DC: U.S. Environmental Protection Agency.
2. **Shelen B, Tucker TT, Johnson DW.** The mean active bone marrow dose to the adult population of the United States from diagnostic radiology. Publ. No. (FDA) 77-8013, 1977; Rockville, MD: U.S. Department of Health, Education, and Welfare, Food and Drug Administration, Bureau of Radiological Health.
3. **Wold GJ, Scheele RV, Agarwal SK.** Evaluation of physician exposure during cardiac catheterization. Radiology 1971;99:188–190.
4. **Wholey MH.** Clinical dosimetry during the angiographic examination. Comments on coronary arteriography. Circulation 1974;50:627–631.
5. **Santen BC, Kan K, Velthuyse HJM, Julius HW.** Exposure of the radiologist to scattered radiation during angiography. Radiology 1975;115:447–450.
6. **Rueter FG.** Physician and patient exposure during cardiac catheterization. Circulation 1978;58:134–139.
7. **Stacey AJ, Davis R, Kerr IH.** Personnel protection during cardiac catheterization with a comparison of the hazards of undercouch and overcouch x-ray tube mountings. Br J Radiol 1974;47:16–23.
8. **Gustafsson M, Lunderquist A.** Personnel exposure to radiation at some angiographic procedures. Radiology 1981;140:807–811.
9. **Martin EC, Olson AP, Steeg CN, Casarella WJ.** Radiation exposure to the pediatric patient during cardiac catheterization and angiography. Emphasis on the thyroid gland. Circulation 1981;64:153–158.
10. **Waldman JD, Rummerfield PS, Gilpin EA, Kirkpatrick SE.** Radiation exposure to the child during cardiac catheterization. Circulation 1981;64:158–163.
11. U.S. Bureau of Radiological Health. Population exposure to x-rays, U.S., 1970. Publ. No. (FDA) 73-8047, 1973; U.S. Department of Health, Education, and Welfare, Food and Drug Administration.
12. National Research Council, Committee on the Biological Effects of Ionizing Radiations. The effects on populations of exposure to low levels of ionizing radiation. Washington DC: Natl Acad Sci 1980.
13. **Upton AC.** Radiobiological effects of low doses. Implications for radiological