Biological bases for the revision of dose limits to the eye lens

The International Commission on Radiological Protection (ICRP) Committee-I reviewed the information related to radiogenic cataracts just before issuing the general recommendations ICRP 103 (2007)[1] and realized the fact that the eye lens is more sensitive than previously assumed. This was based on the studies of children treated for hemangioma and review of the atomic-bomb (A-bomb) survivor data.[2,3] During the last decade, innumerable epidemiological studies on many different human populations exposed to low and high-level radiations have further confirmed the sensitivity of the eye lens. Recently, the ICRP[4,5] issued revised recommendations reducing the equivalent dose limits to the eye lens. The Atomic Energy Regulatory Board of India has initiated a series of measures to develop protection devices for reducing exposure to the eye lens, for radiation monitoring, to sensitize the critical groups involved in cine fluoroscopy-guided procedures, and evolve specialized training programs for those who have the potential to receive significant lens doses. Some of the information relevant to this decision is outlined below.

Cataract is an eye disease characterized by the opacity of the lens which under normal conditions focuses the image on the retina to enable perception of the visual information. Such opacity may lead to just reduction in the vision, partial impairment of vision, or total blindness. Cataract is the single-most important cause of blindness in human beings. Depending on the nature and location, cataracts are classified as posterior subcapsular (PSC), cortical, and nuclear. Precataractous lens changes are polychromatic sheen to the posterior capsule, vacuoles in PSC region, and a number of opaque dots/opaque flecks.[6]

Radiation is one of the agents that are known to induce cataracts. Radiation cataract was considered in the past as a deterministic effect with a threshold dose >1–2 Gy for acute exposures and 5–8 Gy for chronic exposures.[7] Following acute exposure to large doses >2 Gy, cataract is likely to occur with a latent period of 2–3 years. Neutrons are several folds more efficient than photons in inducing cataracts. At present, it is clear that a number of factors such as age, sex, hereditary factors, duration of exposure, blood sugar level (diabetes), blood pressure and cardiovascular diseases, alcohol consumption, smoking, exposure to sunlight, ultraviolet-B and infrared radiations, and use of corticosteroids may influence the formation of cataracts.

A number of factors[8,9] related to the mode of exposure such as dose rate, radiation quality, scoring systems used, variable latent periods, lack of clarity pertaining to the mechanism of induction, and the aforesaid confounders have created considerable uncertainty in the assessment of threshold dose for the induction of cataract.

The mechanism of formation of radiation-induced cataracts remains unclear. Radiation may disturb a number of physiological processes such as the formation of transparent lens fibers by differentiation of epithelial cells, reduction in the repair enzymes, hampering of the mechanism of replacement of damaged fibers, and damage to the lens cell membrane. Radiation can also inflict oxidative damage to lens fiber proteins by the radiation-induced free radicals and cause DNA damage resulting in opacity at a later stage.[10]

In the past, A-bomb[7] survivor data were among the primary source information on cataract induction following acute exposures to large doses. Since then a considerable amount of data has accrued for acute as well as protracted exposures. Epidemiological studies for acute exposures include revised A-bomb survivor data[3,11,12] and Chernobyl liquidators.[13] For protracted exposures, the risk assessment is based on occupationally exposed, medically exposed, and accidentally exposed individuals.[14]

Information on radiogenic cataracts is also derived from studies on the birds exposed in Chernobyl. The epidemiological studies include prospective cohort studies, retrospective case–control studies, and cross-sectional studies. However, many uncertainties in the studies fail to provide a clear indication of a threshold dose.

Exposure at low doses and lower dose rates may have long latent periods of several decades.[9] This has led to an overestimation of the threshold dose for induction of cataract. Most of the studies use different systems. In general, polychromatic sheen to the posterior capsule, vacuoles in PSC region, and ten or more opaque dots/opaque flecks are considered as precataractous lens changes. These may subsequently progress to vision-impairing cataracts. The Lens Opacity Classification System[15] uses reference slides classification based on nuclear color and opalescence, posterior and subcapsular cataracts into 5–6 grades. Many other systems used in different studies are Merriam-Focht System,[16] Oxford Clinical Cataract Screening System,[17] Wisconsin System,[18] and World Health Organization Cataract Grading Group System.[19] Differences in these systems in grading the cataract have also resulted in some degree of confusion, making intercomparison of the reports difficult. Semi-quantitative technique developed by Merriam-Focht specific for scoring radiation cataracts has the following stages:[13,16]

- Stage 1: Discrete PSC opacity (>0.25 mm); aggregates of dots >10 numbers; vacuoles >5 numbers
- Stage 2: More extensive PSC/cortical changes covering 25% of the posterior area of the lens
- Stage 3: Advanced dense posterior opacity preventing the split beam reaching the vitreous
- Stage 4: Premature cataract, near total opacification
- Stage 5: Mature cataract - total lens opacification manifests as a pearly white lens.

This system appears appropriate for scoring radiation cataract.

Reanalysis of the A-bomb survivors related to the risk of cataracts by a number of researchers[3,11,12,20,21] suggests a relative risk of 1.1 up to a dose of 0.92 Sv, whereas the odds ratio increases to 1.39 when the doses up to 4 Sv are considered. The Ukrainian/American Chernobyl Ocular Study involves 8607 Chernobyl liquidators who were subjected to ophthalmological examinations done after 12 years and again after 14 years after the exposure by slit-lamp examination. Group dosimetry, dose calculation techniques, thermoluminescent, and electron spin resonance dosimetry techniques based on tooth enamel were used for assessment of individual doses. Lens doses ranged from 0 to 1000+ mGy, but most of the study cohorts received doses in the range of 50–250 mGy. Based on the Merriam-Focht scoring system, the study suggests a threshold dose in the range of 0.35–0.5 Gy irrespective of the stage of cataractogenesis. Even though precataractogenic lesions were seen in nearly 20% of the cohorts, only 15 (0.2%) showed advanced cataracts.[13]

Low-dose cohorts include radium dial painters, astronauts/cosmonauts, air force pilots, flight personnel, radiological technicians, medical workers, interventional cardiologists, children living around Chernobyl, and residents of contaminated buildings in Taiwan.[2,14,15,22-24] The main conclusions based on most of the studies related to low doses and low dose-rate exposures suggest an elevated risk of PSC as well as cortical cataracts. Even though there is a possibility of a threshold of 500 mSv, it cannot be confirmed due to uncertainty in the mechanisms involved in induction. Lower doses and protracted exposures are associated with longer latent periods, thus resulting in the overestimation of a threshold dose. Those engaged in cine-fluoroscopy-guided interventional procedures such as hepatic chemoembolization, catheterization, endoscopic retrograde cholangiopancreatography, and gastroenterologists receive doses ranging from 0.01 to 0.05 mSv per procedure. Astronauts, airline pilots, residents in contaminated buildings, and radium dial painters also showed elevated risk.

ICRP has examined the entire epidemiological data. In its April 2011[4] statement on tissue reactions for eye lens, it suggested a threshold dose of 0.5 Sv based on the data drawn from low dose-rate exposure cohorts. For occupationally exposed in planned exposure situations, ICRP has recommended equivalent dose limits of 20 mSv/year for the eye lens, averaged over a period of 5 years and not exceeding 50 mSv in any single year. For occupational exposure of apprentices and students in the age range of 16–18 years, ICRP has recommended the equivalent dose limit of 20 mSv/year. As for the public, the dose limits remain unchanged.

This drastic reduction in the dose limits warrants a series of radiation protection measures to comply with the new regulations. In fact, it has stimulated the radiation protection fraternity and the national regulatory bodies to undertake brainstorming activity to comply with the ICRP recommendations. The new epidemiological data are quite convincing, compelling on the necessity to comply with the ICRP recommendations.

Many of the radiation protection aspects such as dosimetry of eye lens and designing and testing of protective equipment have been elaborately discussed elsewhere.[25-27] As for the monitoring of radiation workers, the first and foremost is to develop the Hp (3) tissue-equivalent dose meters. The next step is the testing and validation of these dosimeters and optimization of the position in which the dose meter should be worn (neck, side of the eyes depending on the diagnostic procedure). The second step is the development of personal protective equipment - protective lead glasses (e.g., sports style wrap-around). One of the challenging problems is to ensure that the workers fully and correctly make use of the protective equipment. The third step is to identify groups of radiation workers to be monitored, for example, those engaged in interventional procedures and workers who are likely to receive doses of 15 mSv/year. Regulatory bodies must initiate training programs for high-risk medical professionals about the need and correct use of protective equipment. The new recommendations have also stimulated research activity related to the lens doses received by interventional radiologists in different procedures. The generation of this data can help in optimization of the procedures and to restrict the number of procedures performed per day, if need be, to comply with the dose limits. These preliminary preparatory works may take a year or two to comply with the recommendations of the ICRP.

Srinivasa Badanidiyoor Rao

Department of Biophysics, Adjunct Professor of Biophysics,
University of Mumbai, Mumbai, Maharashtra, India

Address for correspondence:
Dr. Srinivasa Badanidiyoor Rao,
University of Mumbai, Vidyanagari, Santacruz (East),
Mumbai - 400 098, Maharashtra, India.
E-mail: bsrao2005@rediffmail.com

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