Radiation-associated Lens Opacities in Catheterization Personnel: Results of a Survey and Direct Assessments

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ABSTRACT

Purpose: To estimate ocular radiation doses and prevalence of lens opacities in a group of interventional catheterization professionals and offer practical recommendations based on these findings to avoid future lens damage.

Materials and Methods: Subjects included 58 physicians and 69 nurses and technicians attending an interventional cardiology congress and appropriate unexposed age-matched controls. Lens dose estimates were derived from combining experimental measurements in catheterization laboratories with questionnaire responses regarding workload, types of procedures, and use of eye protection. Lens opacities were observed by dilated slit lamp examination using indirect illumination and retroillumination. The frequency and severity of posterior lens changes were compared between the exposed and unexposed groups. The severity of posterior lens changes was correlated with cumulative eye dose.

Results: Posterior subcapsular lens changes characteristic of ionizing radiation exposure were found in 50% of interventional cardiologists and 41% of nurses and technicians compared with findings of similar lens changes in < 10% of controls. Estimated cumulative eye doses ranged from 0.1–18.9 Sv. Most lens injuries result after several years of work without eye protection.

Conclusions: A high prevalence of lens changes likely induced by radiation exposure in the study population suggests an urgent need for improved radiation safety and training, use of eye protection during catheterization procedures, and improved occupational dosimetry.

ABBREVIATIONS

IAEA = International Atomic Energy Agency, ICRP = International Commission on Radiological Protection, RELID = Retrospective Evaluation of Lens Injuries and Dose, SOLACI = Latin American Society of Interventional Cardiology

New findings indicate significant cataract risk at low levels of ionizing radiation exposure (1–4), including occupational exposure by medical professionals involved in interventional cardiology and interventional radiology. Several more recent publications reported occupational eye doses in catheterization laboratories and the prevalence of lens opacities associated with such exposure (5–10). The International Commission on Radiological Protection (ICRP) alerted in 2011 on the epidemiologic evidence that there are some tissue reaction effects, particularly effects with very late manifestations, in situations where threshold doses are, or might be, lower than previously considered. For the lens of the eye, the threshold in absorbed dose was considered to be 0.5 Gy; this is lower by a factor of 10 than deduced in earlier studies and included in previous ICRP documents until 2007 (11). For occupational exposure, the ICRP recommended an equivalent dose limit for the lens of the eye of 20 mSv in a year, averaged over defined periods of 5 years, with no single year exceeding 50 mSv (4).

One of the most striking changes from earlier ICRP recommendations (11) is a reduction in the annual occupational eye dose limit from 150 mSv per year to 20 mSv per year. This recommendation is having an immediate impact on the new International Basic Safety
Standards issued by the International Atomic Energy Agency (IAEA) (12) and the upcoming Directive of the European Commission (13). The 10-fold decrease in the threshold dose for radiation cataract formation, from 5,000 mSv to 500 mSv (4,14,15), is regardless of whether short-term, prolonged, or long-term exposure is involved. This recommendation has significant implications for radiation exposure of interventional radiology and interventional cardiology personnel because a cumulative ocular dose of 500 mSv is well within the range of exposure expected during a working life if proper radiation protection measures using equipment such as ceiling suspended shields or protective eyewear are not routinely employed (7,16,17).

The impact of these new recommendations on the practice of interventional radiology and interventional cardiology is likely to be significant, and it is hoped that a new culture of radiation safety and awareness will be initiated to reduce the high prevalence of lens opacities noted in more recent surveys among individuals working in catheterization laboratories (8–10). Beginning in 2008, an international study, Retrospective Evaluation of Lens Injuries and Dose (RELID) (18), was initiated by the IAEA to measure the prevalence of radiation-associated lens opacities and to evaluate occupational radiation dose to the eyes of cardiology professionals involved in the study. Several surveys have already been completed (8,9). The surveys in Bogota, Montevideo (8), and Buenos Aires were organized with the cooperation and support of the Latin American Society of Interventional Cardiology (SOLACI).

This article presents the results of the retrospective evaluation of radiation doses to the eyes and clinical evaluation of the prevalence of radiation-associated lens changes in a group of cardiology professionals (physicians, nurses, and technicians) evaluated during a major interventional cardiology congress in Latin America (SOLACI 2010, Buenos Aires, Argentina). The article also presents practical recommendations to avoid future occupational lens injury during fluoroscopy-guided procedures.

MATERIALS AND METHODS

As in previous RELID surveys in Bogota and Montevideo (8), the cooperation and support of the SOLACI were enlisted to solicit participants for this new study. The survey was organized by a team of experts selected by the IAEA including a medical physicist, interventional cardiologist, and radiation cataract expert as well as a group of local ophthalmologists trained and coordinated by the IAEA team. All the IAEA experts were involved in previous RELID surveys to ensure that similar methodology and criteria were applied in this survey to enable comparison of results among the different study populations (8,9).

The study participants in Buenos Aires included 127 individuals: 54 interventional cardiologists, 69 nurses and technicians from hemodynamic rooms, and 4 endovascular surgeons. Written informed consent was obtained from all individuals before participation in the study. The control group results were obtained from age-matched volunteer samples of 91 nonmedical professionals who reported no prior relevant exposure to ionizing radiation in the head and neck region. The volunteer samples were comprised of individuals attending earlier SOLACI congresses in Bogota or Montevideo, as described previously (8).

An additional 18 individuals were excluded from the study owing to different factors. There were 13 individuals excluded because they did not undergo a full ophthalmologic examination after completing the survey questionnaire, and 5 excluded because they were not involved in the catheterization laboratory work (2 air crew staff, 2 individuals from the technical exhibition, and 1 clinical cardiologist not working in interventional cardiology). These 18 individuals are not included in the referred sample of 127. If any critical questionnaire data were omitted by a participant (eg, the estimated number of procedures per week or relevant technical details concerning procedures), mean values derived from analysis of the data for the other professionals in the group were used; this occurred in <20% of the individuals examined.

The clinical examination consisted of a comprehensive dilated slit lamp examination to evaluate posterior lens changes in a group of interventional cardiologists, nurses, and technicians (as well as four endovascular surgeons) working in catheterization laboratories. In addition to a dilated slit lamp examination to evaluate posterior radiation–associated lens opacities, a second independent measure of potential visual disability, contrast sensitivity testing, was incorporated into the clinical work-up in some individuals to evaluate the potential future use of this diagnostic test in diagnosing radiation-induced lens changes. The present study is the first to use and evaluate contrast sensitivity testing as an adjunct to conventional dilated slit lamp examinations.

A detailed written questionnaire concerning occupational radiation exposure, workplace practices, and medical history was used, as in previous surveys (8,9), to estimate lens doses and to obtain any significant medical or ocular history (eg, reported history of uveitis, diabetes, or systemic steroid use, all of which are also associated with posterior subcapsular cataract formation and which could confound the analysis of radiation-associated lens opacities). The written survey included approximately 90 questions and was completed by each participant before eye dilation. The questionnaire contained data on professional practices (eg, number of working years in a catheterization laboratory; number of procedures; technical details of procedures such as typical fluoroscopy time, number of cine series, and total number of cine frames or cine time; use of personal protection devices; and personal dosimetry); medical history; medical exposures; and ocular history.
Lens Dose Evaluation

Lens dose estimates were made, as in the previous RELID surveys (8,9), by combining data from experimental values of scattered radiation doses measured in several catheterization laboratories (7,16,19–21) with the subject’s reported yearly occupational workload. For interventional cardiologists, lens doses of 0.5 mSv per procedure were assumed as an initial value if ocular radiation protection was not used. This exposure is estimated to correspond to a typical interventional cardiac procedure (10-minute fluoroscopy time, 800-cine frames) if radiation protection tools are not used (7,16,19–22). Values of 10 μSv/(Gy cm²) have also been published (16), and the typical (simple) cardiology procedure may involve 50 Gy cm² representing a level of scatter dose of 50 × 10 = 500 μSv, the initial value used in the RELID surveys.

Radiation exposure to the eyes is usually measured as dose equivalent using the unit sievert (Sv), but the mean absorbed dose in gray (Gy) is also used. The conversion factor between both quantities and units for x-rays is 1. For nurses and technicians working inside the catheterization suite, a lens exposure of 0.15 mSv per procedure was assumed if ocular protection was not used (8,9). Using questionnaire data supplied by the participants, in particular, the fluoroscopy time, the number of cine series, and cine frames, initial lens radiation doses per procedure were modified further for each individual according to his or her answers to the written survey (7).

Calculations were initially made supposing that individuals have not used radiation protection tools (ceiling suspended screen or protective eyewear or both). The years of work and the number of procedures per week together with the fluoroscopy time and the number of cine series (and number of cine frames, if reported) per procedure were used. In a second step, the reduction in occupational dose secondary to the use of a ceiling suspended screen or protective eyewear was estimated based on the number of years of work and the percentage of use noted by the subjects on the questionnaire.

The use of ceiling leaded suspended screens, leaded eyewear, or radial access was noted. Appropriate correction factors were applied (0.1 for the use of screens and eyewear and 2.0 for radial access) (22). In some centers, equipment technology and working habits have changed over time. Because these changes have an impact on dose levels, this information was documented in the questionnaire and taken into account for lens dose assessment. In these situations, dose was calculated for each period separately, and cumulative dose was estimated as a sum of doses for each time frame (9).

The attributed final occupational dose was calculated by subtracting the eye dose without protection minus the dose absorbed by the shielding. It is assumed that any use of radiation protection devices resulted in a reduction of 90% of the scattered dose during each procedure in which they were used.

Evaluation of Lens Opacities and Decrements in Contrast Sensitivity

Radiation-associated posterior lens changes were evaluated using slit lamp examination and a modified Merriam-Focht scoring system (1,23) that takes into account the frequency of observed posterior and anterior opacities, sutural changes, vacuoles and other lens defects, and the percent opacity as a function of lens anterior and posterior surface area. Photo documentation was included in most cases, using both direct slit lamp biomicroscopy and retroillumination. Eyes were examined after full dilation with 2.5% phenylephrine and 1% cyclopentolate. Each participant was evaluated separately by at least two independent examiners trained in the recognition and evaluation of characteristic radiation-induced lens morphology.

Direct illumination and retroillumination offer complementary approaches for evaluation of posterior lens changes. Direct illumination (axial view) facilitates precise localization of the opacity within the lens. In contrast, retroillumination provides an overall, wide field of view of the opaque regions of the lens and often clearly identifies vacuoles, dots, and spokelike radial projections not visible in oblique direct illumination.

To correlate the severity of posterior lens changes with estimated doses to the lens, a relative scale of severity is used based on the simple addition of Merriam-Focht scores in each eye. A score of 0.5, although indicating an early posterior lens change and likely predictive of further opacification, is nevertheless considered precataractous. In contrast, a score of 1 in either eye is identified as an early-onset opacity. A Merriam-Focht score of ≥1.5 is considered as a cataract in progress.

Contrast sensitivity testing was performed using a Holladay Automated Contrast Sensitivity System (M&S Technologies Inc, Skokie, Illinois). This approach uses rotationally symmetric targets and randomly presented optotypes. Results, presented in graphic format, compare individual values with standardized data.

Statistical Analysis

Statistical analysis to compare findings in cardiologists and nurses and technicians with the control groups was done using Fisher exact test for small samples. P values were adjusted using the Bonferroni correction, which considers each sampling to be independent. Although the two groups (physicians and nurses and technicians) are not statistically independent owing to the fact that they both depend on the same set of data from unexposed controls, similar results were obtained using a permutation test, which accounts for correlation between the tests. Relative risk and 95% confidence intervals for posterior lens opacification were calculated using SISA (Simple Interactive Statistical Analysis, Daan Uitenbroek, Hilversum, Netherlands) software (24).
RESULTS

As stated in the Materials and Methods section, many of the screened participants reported that they did not use personal dosimeters or they did not use them on a regular basis. Results are reported in Tables 1 and 2. The four vascular surgeons (two of them had lens opacities of 0.5 score in the left eye) were not using personal dosimetry. Only two cardiologists used double dosimetry (over and under the protective apron). Among the nurses and technicians (Table 2), only two used double dosimetry. Based on the answers to the questionnaire and the personal interviews, considerably irregular use of personal dosimeters was revealed. Personal occupational dosimetry reports were requested to refine the retrospective dose evaluation, but no report was received.

The global results of the survey for interventional cardiologists (54 individuals with a mean age of 45 years ± 10) and paramedical personnel (69 individuals with a mean age of 39 years ± 11; 55% technicians, 36% nurses, and 9% not specified) are presented in Tables 1 and 2. Based on workload and analysis of the questionnaire results, cumulative lens radiation dose was estimated at 8.3 Gy ± 5.4 for the subgroup with detectable opacities and 3.0 Gy ± 2.9 for the subgroup without lens changes. Details on the declared use of protective screen, protective eyewear, and personal dosimeters are included.

For the 27 cardiologists with lens opacities, 19 had opacities in the right eye, and 22 had opacities in the left. Opacities were bilateral in 14 cardiologists. Among the nurses and technicians, 29 had lens opacities; 20 had opacities in the right eye, and 17 had opacities in the left eye; and opacities were bilateral in 9 individuals.

The correlation between the severity of the posterior lens changes and the estimated cumulative eye dose is presented in Figure 1. Cumulative lens occupational radiation dose was estimated at 2.7 Gy ± 2.0 for the subgroup with opacities and 1.8 Gy ± 1.9 for the subgroup without opacities. One representative example of a typical posterior cataract is shown in Figure 2 observed by slit lamp biomicroscopy using direct illumination; this cataract was noted after 22 years of work in a catheterization laboratory. The stage of the injury in this case is 1.5; Figure 3 shows the same lens observed using retroillumination to visualize the area of the subcapsular posterior cataract. In this case, the extensive posterior subcapsular changes collectively occupy < 25% of the area of the lens. The arrows in Figures 2 and 3 show the opacities in the lens.

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<th>Table 1. Interventional Cardiologists: Cumulative Eye Dose, Lens Injuries, and Other Relevant Survey Results</th>
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SD = standard deviation.

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Given time constraints at the SOLACI congress and limited access to the contrast sensitivity testing apparatus, the contrast test sensitivity was restricted to only approximately 20% of the participants with observable lens changes on slit lamp examination. A representative example of a decreased contrast sensitivity function compared with the standardized normal curve is presented in Figure 4a and b. Figure 4a depicts the contrast sensitivity curve for one of the participants with normal vision. Both curves (solid and dotted lines) are similar. In Figure 4b, the test result for one of the participants with a significant loss of contrast sensitivity is shown with the normal curve. In this case, the curves, normal vision (dotted line) and the test result (solid line) appear significantly different.

DISCUSSION

The lens of the eye is one of the most radiosensitive tissues in the body, and exposure to ionizing radiation can cause cataract formation (3,4). Although initial, early stages of such opacification may not cause visual disability, the severity of such changes increases progressively with dose until vision is impaired, and cataract extraction surgery is required (3,4). The latency of such changes is inversely related to dose (3,4).

Cataract, or opacification of the lens, is one of the most common causes of visual impairment and blindness worldwide (25). Lens opacities can be classified into three main forms—nuclear, cortical, and posterior subcapsular—according to their anatomic location (4). Among the three major forms of age-related cataract, posterior subcapsular is the least common, although this form is usually associated with ionizing radiation exposure. Because of its location along the lens visual axis, relatively minor posterior subcapsular cataract can have a great impact on vision. In addition to ionizing radiation, other factors commonly associated with posterior subcapsular cataract are diabetes and the use of systemic steroids. After ionizing radiation exposure, changes generally first appear in the posterior region of the lens and consist of small dots and vacuoles, which, over time, aggregate to form larger opacities. Both radiation cataract severity and latency are related to dose (3,4,26).

This study specifically examined the prevalence of posterior lens changes in the study population. These posterior subcapsular opacities are consistent with, and characteristic of, ionizing radiation exposure. Because the study excluded subjects with diabetes, history of uveitis, or systemic steroid use, these confounders are unlikely to account for the observed increase in posterior lens changes in the study population. However, genetics and other
determinants of individual radiosensitivity are likely to influence the likelihood of developing radiation cataracts (27–29). Of interventional physicians, 50% showed detectable posterior lens opacities. This finding was statistically significant compared with a control group of individuals in which posterior lens changes were detected in only 10% of the population (8). In the exposed subjects, lens opacity scores ranged from 0.5 in one eye to 1.5 in both eyes. In comparison, posterior lens scores in controls who had detectable lens changes never were >0.5. When the score for both eyes was combined, 13 cases had a score of 0.5, 9 cases had a score of 1.0, 1 case had an additive score of 1.5, 3 cases had a score of 2.0, and 1 case had a total score of 3.0. The mean value of severity using this approach was 1.0 ± 0.6.

Analysis of years of work, percentages of subjects using protective screening or protective eyewear, and percentage of reported working time using these radiation protection tools is also presented in Table 1. All these measures show positive correlation between radiation exposure and lens opacification. Although there appears to be a relationship between the severity of the posterior lens change and the estimated cumulative eye dose in Figure 1, too many factors influence this correlation, the most important of which is the possible incompleteness of the data used to estimate the cumulative dose.

In many procedures such as hemodialysis, fistula treatment, or biliary interventions, interventional radiologists are closer to the irradiated volume of the patient than cardiologists and sometimes with very limited possibility of self-protection. These limited choices of protection cause more eye exposure of interventional radiologists, and careful dosimetry to evaluate lens doses and the use of protective eyewear should be pursued.

In the sample of paramedical personnel (Table 2), 41% of subjects had detectable posterior lens changes, but the relative severity was reduced by approximately 30% (0.7 ± 0.4 vs 1.0 ± 0.6) compared with interventional physicians. As with the interventional physicians, the number of individuals with posterior lens changes was statistically significant compared with the control group. Merriam-Focht scores ranged from 0.5–1.5 in one eye. The relative severity index (addition of the scores in each eye) was 19 cases with a score of 0.5, 7 cases with a score of 1.0, 1 case with a score of 1.5, and 1 case with a score of 2.0.

Values for working years, percentages of individuals using protective screens or protective eyewear, and percentage of the reported working time (years) using these protection tools are also shown in Table 2. Among paramedical personnel, a significantly greater percentage of individuals use personal dosimetry compared with cardiologists (89% vs 50%).

Correlation between severity of the lens changes and the estimated cumulative doses is weaker for paramedical personnel than for cardiologists (correlation factor < 0.1). One explanation for this discrepancy may be that the potential protective effect of protective screens is more difficult to estimate for nurses and technicians because their movement within and their entry and exit of the catheterization room is more variable, and sometimes these individuals may be located closer to the patient than the cardiologist, without the protection of lead screens.

An important finding to highlight is the irregular use of personal dosimeters and the poor adherence to the ICRP recommendation (30) to use double dosimetry to allow the estimation of lens doses. Only about 50% of the interventionists reported that they use personal dosimeters, and only 30% report the use on a regular basis (Table 1). Around 90% of nurses and technicians report the use of personal dosimeters, but regular use is reported by only around 40% (Table 2). Even when used, dosimeters were worn under the lead apron in most cases, making any retrospective evaluation of ocular radiation dose using these devices likely to be inaccurate. None of the participants (including the participants with lens
opacities) provided occupational personal dosimetry reports.

Lens changes noted in 50% of interventional cardiologists and 41% of nurses and technicians were posterior subcapsular lens injuries consistent with, and characteristic of, ionizing radiation exposure. These types of lens opacities are particularly associated with decrements in contrast sensitivity (31) and may be associated with greater risk of future visual disability. Figure 4b shows a good example of this decrement found in the group of participants with opacities.

Radiation-induced measurement of decrements in contrast sensitivity has not previously been reported in any study population despite ophthalmologic evidence that indicates only posterior subcapsular cataracts, the type of lens opacity most associated with radiation exposure, is likely to result in a change in contrast sensitivity (31). Because unexposed age-matched controls were not similarly examined, the results cannot be properly evaluated in the context of radiation exposure. These decrements in contrast sensitivity and their impact on image quality requirements should be investigated more in the future.

One crucial message communicated by numerous scientific articles during the last several years is that ocular radiation risk to workers in catheterization laboratories is easily controlled if radiation protection tools are properly used during procedures. Use of such devices, in particular, for specialists with high workloads, can maintain ocular doses well within the new recommended annual limit of 20 mSv (7,16,17).

We propose several recommendations to avoid radiation-induced lens injury:

- Acquire appropriate training and certification in Radiation Protection for interventionists and paramedical personnel working in catheterization laboratories as recommended by the ICRP (32) and interventional cardiology and interventional radiology scientific societies (33,34) and required by the European Medical Exposures Directive (35).
- Follow the Radiation Protection operational recommendations in daily routine practice (36) in regard to collimation, low-dose acquisition modes for fluoroscopy and cine runs, low rate of frames per second, short fluoroscopy and cine runs, image detector close to the patient, and heart at the isocenter to avoid panning. Recognize that some C-arm angulations produce more scattered dose than others (https://rpop.iaea.org/RPOP/RPop/Content/AdditionalResources/Posters/index.htm).
- Use Radiation Protection tools appropriately, in particular, ceiling suspended screens (in proper position) and protective eyewear.
- Always use personal dosimeters, one under the apron and a second over the apron to estimate dose to the eyes (28), and follow the monthly occupational dose values.
- Periodically obtain a comprehensive ophthalmologic examination, including a detailed dilated slit lamp examination of the posterior lens region, as part of regular medical evaluations recommended by regional or national regulations.

There are some limitations to the findings of this study. Most notably, eye radiation dose estimations may have inaccuracies, and real occupational measured lens doses were unavailable. When responders indicate the use of protective shielding, the physical attenuation has been applied, but sometimes this shielding is not properly used. The reported workload, typical fluoroscopy time, and number of acquired images (cine frames in cardiology) may also be quite different from the real values, especially for professionals working many years and with different x-ray systems. The approach used in this study is a pragmatic way to calculate ocular exposure when real eye dosimetry values are unavailable. Another limitation is that in some cases, answers to the questionnaires were omitted (eg, number of procedures per week, especially for paramedical personnel); in these cases, the mean number from other responders working in similar centers was used to calculate the dose estimation.

In conclusion, the estimated eye dose values for professionals working in catheterization laboratories is consistent with the observed high percentage of posterior lens changes noted in such individuals. When evaluated in the context of the new ICRP recommendations concerning reduced occupational eye dose limits, there is an urgent need for better radiation safety education and policy, with appropriate training, use of protection tools, and better occupational dosimetry. Lens radiation injuries can easily be avoided by the appropriate use of radiation protection tools, and such tools would further ensure the safety of individuals working in catheterization laboratories.

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REFERENCES


