

# **RISK OF OCCUPATIONAL RADIATION-INDUCED CATARACT IN MEDICAL WORKERS**

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## **ABSTRACT**

**Objective.** The objective of this study was determination of criteria for recognition of a pre senile cataract as a professional disease in healthcare personnel exposed to small doses of ionizing radiation.

**Method.** The study included 3240 health workers in medical centers of Serbia in the period 1992-2002. A total of 1560 workers were employed in the zone (group A) and 1680 out of ionizing radiation zone (group B). Among group A, two groups had been selected:

1. Group A-1: Health workers in the ionizing radiation zone who contracted lens cataract during their years of service while dosimetry could not reveal higher absorbed dose (A-1=115);
2. Group A-2: Health workers in the ionizing radiation zone with higher incidence of chromosomal aberrations and without cataract (A-2=100);

**Results.** More significant incidence of cataract was found in group A,  $\chi^2=65.92$ ;  $p<0.01$ . Radiation risk was higher in health workers in radiation zone than in others, relative risk is 4, 6.

Elevated blood sugar level was found in higher percentage with health workers working in radiation zone who developed cataract.

**Conclusion.** Low doses of radiation are not the cause of occupational cataract as individual occupational disease. X-ray radiation may be a significant cofactor of cataract in radiological technicians.

**Key words:** *Low doses ionizing radiation, occupational cataract.*

## **INTRODUCTION**

The cataract is the most common degenerative opacity of the crystalline lens, developing with aging.

The interior capsule of the lens is lined with transparent layer of epithelial cells, which maintains the function of lens, what is accomplished by cell division at the equator of crystalline lens and moderate growth towards the center. Multiple factor may interfere with division process and growth of lenticular epithelial cells, especially in case of genetic predisposition (1-3).

Damaged cells are moved towards the posterior pole of the crystalline lens, forming irregularly the young lenticular fibers which lose their transparency and prevent straight light movement, what is manifested by opacification in the posterior subcapsular region (4-7).

Risk evaluation of presenile cataract revealed that it was in relation to phenotype produced by the expression of several different genes and exposure to environmental noxae (8, 9).

Physical agents causing the cataract may be as follows: infrared, ultraviolet and microwave non-ionizing radiation, electric power and ionizing radiation (6).

Exposure to sunlight may be a risk factor of cataract development. Exposure to the ultraviolet-B (UVB) component of light may be associated with the severity of cortical opacities in men, 43 to 84 years of age (2, 4, and 7).

The X-rays are the largest threat to crystalline lens. Mostly higher doses, over 500 mSv caused the cataract, and only in 15% of cases the doses were low, below 100 mSv (10).

Other risk factors of cataract are the following: alcohol abuse, tobacco smoke, systemic diseases (endocrine and metabolic), impaired eye circulation, ocular pressure, refractory eye abnormalities (myopia), blood pressure, heart conditions (3, 5, 9), low food antioxidant level. Antioxidative prophylaxis such as intake of vitamins C and E over 10 years and more, had the impact on lowering the risk of cataract (11).

The symptoms of cataract onset are slow, progressive and painless impairment of vision, sensitivity to light, more defective color perception and diplopia. All these directly diminish the working and living ability, and given it may be of occupational origin, the analysis of risks of cataract and possibilities of its detection and treatment are significant for rights protection workers and their return to work places.

The workers with manifested cataract within and beyond the area of ionizing radiation were analyzed and compared with the intent to evaluate the effect of low doses to development of cataract.

## **METHODOLOGY**

The study involved 3240 health workers of Medical Centers in Serbia in the period 1992-2002, who used to work within and beyond the area of ionizing radiation.

The annual periodical-preventive controls of health workers included the eye examination as well. After visual acuity measurement, the lens was examined by retroillumination method (red reflex) and using the biomicroscope. In case of impaired visual acuity or presence of cloudy lens, the examination was performed in mydriasis.

The factors causing the cataract of the crystalline lens were analyzed: age, sex, occupation, duration of occupational exposure, metabolic disorders (glycemia),

cardiovascular diseases (high blood pressure and heart conditions – arrhythmia), etc. Data on smoking, alcohol consumption and corticosteroid therapy as well as exposure to chemical and other physical noxae, genetic burden, were obtained from their medical histories entered in periodical control charts. A total of 1560 (Group A) health workers of different occupation, age and sex were employed in the ionizing radiation zone, and 1680 (Group B) out of the zone. The percentage of smokers was nearly equal in both groups (31% and 33%). Alcoholism, toxins and medicaments were excluded as well as occupation exposition to other radiation. Food regime, i.e., antioxidants in food, obesity, genetic factor and sun-exposure varied equally in both groups.

Two subgroups were singled out from the Group A:

1. Group A-1 of exposed 115 workers with cataract chronically exposed to low doses of radiation, mean age of 46 years, both genders, i.e. 56 females and 59 males –; and
2. Group A-2 of exposed 100 workers without cataract, selected on the basis of higher incidence of chromosomal aberrations due to chronic exposure to low doses, mean age 41 years, sexes, 54 females and 46 males –.

The Group B consisted of health workers with different occupations and employed at different working places within public health institutions, which were not exposed to ionizing radiation. The subjects with cataract were singled out from this group as a controls (Group B-C), n=26, mean age 40 years, genders, 7 females and 19 males.

By vocation, the subjects from groups B-C and A-2 were: radiographers, radiologists, pneumo-phthisiologists, nuclear medicine workers, dental radiographers, nurses,

anesthesiologists and other medical technicians who were, within their job description, present in the ionizing radiation area. They are exposed to X-ray radiation (in X-ray diagnostics, radiotherapy, and interventional radiology) and gamma and  $\beta$  radiation (in nuclear medicine).

The controls B-C consisted of physicians, medical technicians, nurses and lab technicians at working places beyond the ionizing radiation area.

Absorbed dose on body surface of the exposed subjects in groups A-1 and A-2 was measured by thermoluminescent personal dosimeters (TPD) worn during the entire shift in the radiation zone, below the protective gown and they were read on monthly basis. Doses were expressed as annual or 5-year equivalent to absorbed dose, in millisievert (mSv). Equivalent doses at working places and exposition dose in the air were measured as well.

Chromosomal aberrations in lymphocytes were analyzed. Chromosomal aberrations are useful for evaluation of radiation risk in occupation exposure to ionizing radiation.

Dicentric form of chromosome is a specific, radiation-induced change of DNA. The presentation of chromosomal aberrations (dicentrics) indicates higher exposition to lower doses. Higher frequency of dicentric suggests higher radiobiological risk of disease due to ionizing radiation exposure at working place (complete biomarker). Dicentric frequency was measured in 200 mitoses of lymphocytes sampled and prepared from blood of subjects in groups A-1, A-2 and B-C.

Owing to exposure of all people to some kind of natural radiation, dicentrics are possible even in occupationally non-exposed individuals, but such dicentric frequency is below 1%.

### ***Statistical analysis***

The study used methods of descriptive statistics: central tendency measures: arithmetical mean ( $\bar{X}$ ), variability measures: variation interval (max-min) and standard deviation ( $\pm$ SD); analytical statistics: to assess the significance of difference: Student's t-test and  $\chi^2$  test and methods of correlation significance: Spearman's rank correlation coefficient.

The incidences (I) ( $I = \text{rate}/100,000/1 \text{ year}$ ) were compared and represented as relative risk, RR.

### **RESULTS**

Equivalent doses at working places of subjects in the ionizing radiation zones were low, ranging from 0.5  $\mu\text{Sv/h}$  to 8  $\mu\text{Sv/h}$ , and 0.41 Bq/100cm<sup>2</sup> to 330 Bq/100cm<sup>2</sup> at working surfaces, what was tolerated limit for occupationally exposed individuals; exposure dose in the air was at the level of natural phon at all working places of subjects in Groups A and B.

Absorbed doses in exposed subjects with cataract, measured by thermoluminescent personal dosimeter (TPD) ranged from 2.64 (min.) to 48.10 (max), mean value:  $7.58 \pm 4.78 \text{ mSv/5 years}$  ( $1.59 \pm 30 \text{ mSv/year}$ ), and were not different from mean absorbed annual doses in the exposed subjects without cataract ( $1.63 \pm 1.45 \text{ mSv/1g}$ ), being below maximally tolerated dose of 100 mSv/5 years 920-50 mSv annually).

In Group A-1, there was a total of 100 dicentrics in 23.000 mitoses (115 subjects x 200 lymphocytes); frequency of chromosomal aberrations  $f = 0,43\% \rightarrow f < 1\%$ .

In group A-2, the frequency of chromosomal aberrations was 1.5%  $\rightarrow f > 1\%$  (300 dicentrics per 20.000 mitoses;  $f_{\text{min}} 0.5\% - f_{\text{max}} 2,5\%$ ).

Dicentric type aberrations were not found in Group B-C.

Radiation risk was significant in Group EA-2 on account of highest frequency of chromosomal aberrations.

There was a significant difference ( $\chi^2=65,92$ ;  $p<0.01$ ) of the crystalline lens cataract between the studied groups employed in public health institutions, i.e. Group A in the zone and Group B out of the ionizing radiation zone.

Cataract was 4-5 times more common in Group A; relative risk RR was 4.6 (IA/IB=700:150).

Mean age of subjects with cataract developed during the occupational ionizing radiation exposure (Group A-1) was higher than the mean age of cataract patients who did not work in the ionizing radiation zone (Group BC, Table 1) as well as exposed workers with no developed cataract (Group A-2, Table 2),  $p \leq 0.01$ .

Occupationally exposed health workers (Group A-1) who developed cataract had approximately longer years of service in the ionizing radiation zone in comparison to exposed workers of Group A-2 (Table 3). However, the correlation of cataract incidence and duration of exposure was not linear: in 10 years of exposure, the incidence was 31,3%; 11-20 years – 31,3%; 20-30 years – 30,4% and the rest of 7% was found in older workers with over 31 years of service.

The cataract was most frequently diagnosed in the age 41 to 50 years in Group E, and thereupon the incidence of cataract tended to decline. The lowest was in the age up to 31 years and over 60 years. In the control group B-C, cataract incidence correlated with the age, covering the age period of 41 to 70 years (Graph 1). The incidence of cataract tended

to be higher with the age both in the exposed and control group, but such correlation was not linear in the exposed group. The peak of the highest cataract incidence in workers in the ionizing radiation was shifted by 10 years forward, to younger age in relation to the controls (Graph 1).

Among cataract patients, the prevalence of males was higher. Nevertheless, the ratio of genders and cataract incidence was significantly overturned in favor of female sex ( $p < 0,05$ ), when they were exposed to ionizing radiation, i.e. in the Group A-1 (Table 4).

There was no difference of gender in the exposed workers with and without cataract (Groups A-1 and A-2) (Table 5).

Significant was the difference in occupations (working places) of workers who developed and did not develop cataract during their duration of occupation exposure ( $p < 0,05$ ).

Higher percentage was found in workers with cataract exposed to x rays (radiographers, radiologists and pneumo-phthisiologists), and the lowest percentage was verified in those exposed to radionuclides in nuclear medicine (iodine and technetium), i.e. gamma and beta rays (Table 6).

The frequency of chromosomal aberrations did not correlate with age and sex, coefficients of correlation were approximately: 0,09 ( $p=0,47$ ) and 0.01 ( $p=0,93$ ), respectively.

Equivalent doses measured by TLD did not correlate with age ( $p=0,09$ ) and sex ( $p=0,29$ ), too.

Among cataract patients affected during the occupational exposition, radiological technicians were the most prevalent (63,5%), while the physicians – radiologists and

pneumo-phthysiologists were the second and third, respectively. Time interval of exposition when the cataract was primarily diagnosed in the majority of cases in radiographers was 11-20 years (21% out of 63,5%, or 1/3 of the time), while all other cases were diagnosed in the period 1 to 10 years and 21 to 40 years of service in the ionizing radiation zone, and the least number was identified over 31 years (7%). In addition, the smallest number of cataracts was recorded in younger and oldest age, which is, only 1,7% up to 30 years and 2,6% in over 60 years of age, while the diseased radiographers most commonly were 40-49 years of age.

Among doctors, distribution of contracting the disease by time exposure intervals was approximately the same.

There was a significant difference in cataract morphology between the exposed group E and control group B-C ( $p < 0,01$ ;  $\chi^2 = 12,55$ ). In Group A-1, the incidence of cortical cataract was 80% (n=92). In the controls B-C, with 53,8% of nuclear cataract (n=14), the cortical one was prevalent in 46,2% (n=12).

The effects of other risk factors, such as glycemia, blood pressure and heart conditions, were also analyzed.

Elevated blood sugar level was found in higher percentage with health workers, working in radiation zone, who developed cataract ( $p \leq 0.01$ ) (Table 8).

Neither cardiovascular diseases nor blood pressure differed in studied groups of workers in radiation zone (A-1/A-2:  $\chi^2 = 1,14$ ;  $p = 0.28$ , and  $\chi^2 = 1,45$ ;  $p = 0,48$ , respectively) as well as between the exposed and control group (A-1/B-C:  $\chi^2 = 1,39$ ;  $p = 0.24$ , and  $\chi^2 = 2,92$ ;  $p = 0,23$ , respectively).

## **DISCUSSION**

There have been diverse opinions on ionizing radiation dose sufficient to cause the cataract (12, 13). In our subjects, absorbed doses measured by TPD were very low, far from limit values for occupationally exposed individuals. However, many ophthalmologists think that there is no harmless dose for the crystalline lens (4, 6, 14, 15). Cataract is a dose-related manifestation, but it may develop after perennial exposure to low doses due to impaired metabolism and albumin denaturation as the result of cumulative effects of radiotoxins, free radicals, exhausted antioxidative reserve and DNA damage in the lens epithelial cells.

The initial dotted opacity in the posterior lens pole subsequently keeps on spreading, and cumulative damage due to radiation exposure gradually involves the entire lens, resulting in cataract and vision loss. Damaged epithelial cells are retained in the lens even after its removal for lens replacement surgery; therefore, chromosomal aberrations can be detected in these cells which otherwise cannot be found in peripheral blood lymphocytes of these subjects, as indicator of earlier increased exposure. DNA changes in these epithelial cells may be construed as stochastic, dose-non related effect of radiation (15, 16).

Regardless of low doses, they could directly or indirectly cause the lens opacification as cumulative effect of long-term exposure to radiation (12-16).

The controls consisted of health workers out of radiation zone who developed cataract after all, but in older age and different by morphology, probably due to effect of other risk factors (9, 11, 14, 15).

It is not necessary for all workers at higher radiobiological risk (higher frequency of chromosomal aberration – dicentrics) to get occupational disease. Development of cataract as occupational disease depends upon several factors (10, 12, 13, 16).

The largest proportion of health workers without developing the cataract in spite of higher frequency of chromosomal aberrations were those engaged in nuclear medicine, and the lowest proportion was among the x-ray workers. On the contrary, among exposed workers with developed cataract, the majority was employed in the x-ray room, i.e., radiological technicians, who generally have the largest work burden in the x-ray radiation zone. Moreover, it is possible that low LET (Linear energy transfer) radiation such as x-ray has higher penetrating power and longer range, and consequently, it causes the crystalline lens damage much easier than high LET radiation, such as corpuscular ( $\beta$ -ray) radiation with shorter range but higher radiobiological effect on most sensitive DNA material, especially in case of contamination which is likely when handling with radionuclides in nuclear medicine.

Sex and age had no effect on chromosomal aberrations, but interfered with higher risk of cataract. Longer life and years of service contribute to longer exposure to ionizing radiation, as well as to other factors having the impact on oxidative damage of the crystalline lens. In our subjects, risk of cataract depended upon the type of radiation (x), occupation (radiographers), working place (x-ray room, radiology department), age, duration of occupational exposure, gender, glycemia, etc. The majority of subjects got sick between 40 and 50 years of age, and the least up to 30 and over 60 years. However, in relation to duration of exposure, the highest incidence was noted between 11 and 20 years, but the cataract also developed with shorter duration of occupational exposure, in

younger age. It is known that hereditary cataract may develop even after the age of 20, and senile cataract after the age of 60, while the age of 45 is quite adequate for development of cataract due to environmental risk factors (13-15). Moreover, approximately one-third of subjects with cataract in both groups (exposed and control) were smokers.

Risk of cataract due to smoking is relative and related to smoking intensity and years of smoking, although the effect of smoking on cortical cataract, which was more frequent in the exposed workers, could not be verified (14).

Radiologists and technicians exposed to x-rays in interventional radiology were at highest risk of occupational, radiation cataract if they spent more time in direct beam without wearing protective glasses (12). The initial opacification in posterior subcapsular region (PSC) was reported in even 37% of radiologists, while cataract after long latent period was developed in 8% of the time, and upon retirement in the older age, even 20.6% of cases (12, 13). Protection, which primarily implies reduction of radiation dose at working places (17), is an imperative, because otherwise the cataract could be avoided even if it were developed after termination of working life.

Most commonly, the initial localization of cataract was in posterior subcapsular region – PCS, with gradual development as cortical (7, 17). In our subjects exposed to ionizing radiation, the incidence of cortical cataract was significantly higher. Typical majority, i.e. 90%, of senile cataracts belong to other types of opacity. Different risks correspond to different morphological types.

Diabetes enhances the risk of posterior subcapsular cataract, as well as ionizing radiation, but it also has impact on other forms, cortical and mixed forms. Among other factors

contributing to cataract risk, higher glycemia level had impact on our subjects, too.

Higher risk of cortical cataract was described in women. In our study, sex ratio was in favor of females, if they were employed in radiation zone. The level of blood pressure had different influence to cataract development in males (5). Hypertension had no effect on PSC cataract. Nevertheless, in our study, neither blood pressure nor heart conditions had any effect to development of cataract.

The incidence of nuclear form of cataract was significantly lower in our subjects working in the ionizing radiation zone. Nuclear cataract is commonly caused by non-occupational exposure to various noxae, such as smoking, obesity, excessive exposure to sun light, while long-term wearing of glasses and myopia increases the risk of mixed cataract.

## **CONCLUSION**

It is evident that chronic exposure to low doses is not the cause of occupational radiation cataract as an independent occupational disease. The effects of radiation to biological DNA material failed to be proven on cataract development, it was rather related to type of radioactive emission, mode and type of radiation, working burden and working conditions as well as type of job.

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**Table 1. Ago in exposed and non exposed medical workers with lens cataract**

Group	N	Ago
		X ±SD
A-1	115	46.35 9.78
B-C	26	40.30 12.19
t-test		2.71
p≤0.01		0.01

A-1 - exposed medical workers with cataract

B-C - non exposed medical workers with cataract

Table 2. Ago in exposed medical workers with and without lens cataract

Group	N	Ago
		X± SD
A-1	115	46.35 9.78
A-2	100	41.44 8.41
t-test		3.91
p≤0.01		0.01

A-1 - occupationally exposed medical workers with cataract

A-2 - occupationally exposed medical workers without cataract

Table 3. Duration of occupational exposure medical workers with and without lens cataract

Group	N	DOE
		X±SD
A-1	115	16.86 9.59
A-2	100	14.22 8.37
t-test		2.13
p<0.05		0.03

A-1 - occupationally exposed medical workers with cataract

A-2 - occupationally exposed medical workers without cataract

DOE - Duration of Occupationally Exposure

Table 4. Sex in occupationally exposed and non exposed medical workers with lens cataract

Group	N	Sex			
		Male		Female	
		N	%	N	%
A-1	115	59	51.3	56	48.7
B-C	26	19	73.1	7	26.9
$\chi^2$ -test		4.07			
p<0.05		0.04			

A-1 - occupationally exposed medical workers with cataract

B-C - non exposed medical workers with cataract (control)

Table 5. Sex in exposed medical workers with and without lens cataract

Group	N	Sex			
		Male		Female	
		N	%	N	%
A-1	115	59	51.3	56	48.7
A-2	100	46	46.0	54	54.0
$\chi^2$ -test			0.60		
p			0.44		

A-1 - occupationally exposed medical workers with cataract

A-2 - occupationally exposed medical workers without cataract

Table 6. Occupationally exposed medical workers with and without lens cataract accordance to different occupational (place of work)

Group	N	Occupational (place of work)															
		<i>Roentgen-technicians</i>		<i>Radiologist</i>		<i>Pneumonic-Phtysiologist</i>		<i>Specialists in nuclear medicine</i>		<i>Dental technician</i>		<i>Medical technicians (Nurses)</i>		<i>Anesthesiologist</i>		<i>Other workers in zone</i>	
		n	%	N	%	n	%	N	%	N	%	N	%	n	%	n	%
A-1	115	73	63,5	18	15,7	12	10,4	2	1,7	1	0,9	4	3,5	1	0,9	4	3,5
A-2	100	57	57,0	12	12,0	5	5,0	11	11,0	0	0	9	9,0	0	0	6	6,0
$\chi^2$ -test								15,63									
p < 0.05								<b>0,03</b>									

A-1 - occupationally exposed medical workers with cataract

A-2 - occupationally exposed medical workers without cataract

Table 7. Frequency of cataract in exposed workers accordance to different professionals during the work in zone of irradiations

DOE* Year	Occupational (place of work)																	
	Roentgen-technicians		Radiologist		Pneumonic-phtysiologist		Specialists in nuclear medicine		Dental technician		Medical technicians (Nurses)		Anesthesiologist		Other workers in zone		Total	
	N	%	N	%	N	%	n	%	n	%	N	%	N	%	n	%	n	%
1-10	20	17,4	6	5,2	4	3,5	0	0	1	0,9	2	1,7	0	0	3	2,6	36	31,3
11-20	24	20,9	5	4,3	4	3,5	2	1,7	0	0	1	0,9	0	0	0	0	36	31,3
21-30	21	18,2	6	5,2	4	3,5	0	0	0	0	1	0,9	1	0,9	1	0,9	34	29,6
31-40	8	6,9	1	0,9	0	0	0	0	0	0	0	0	0	0	0	0	9	7,8
All	73	63,5	18	15,7	12	10,4	2	1,7	1	0,9	4	3,5	1	0,9	4	3,5	115	100

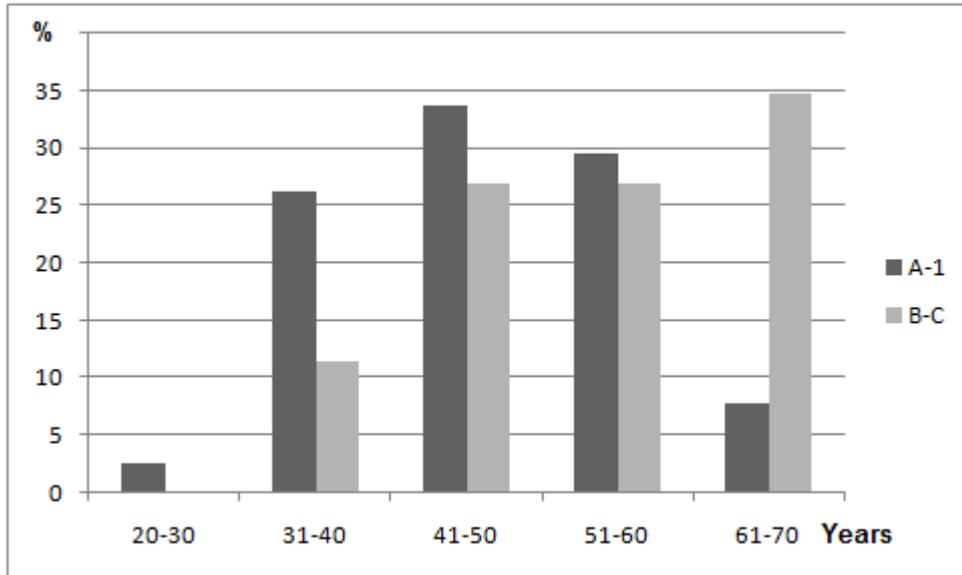
DOE\* -duration of occupationally exposition to ionizing radiation

Table 8. Blood sugar level in exposed medical workers with and without lens cataract

Group	N	Glucose in blood			
		3.1-6.0 mmol/l		6.1-11.0 mmol/l	
		N	%	N	%
A-1	115	87	75,7	28	24,3
A-2	100	90	90,0	10	10,0
$\chi^2$ -test			7,57		
p $\leq$ 0.01			0,01		

A-1 - occupationally exposed medical workers with cataract

A-2 - occupationally exposed medical workers without cataract



**Graph 1. Age until to diagnostic the cataract in exposed and control group**

A-1 - occupationally exposed medical workers with cataract

B-C - non exposed medical workers with cataract (control)