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INFRARED RADIATION AND CATARACT I
EPIDEMIOLOGIC INVESTIGATION OF IRON- AND STEEL-WORKERS

by

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Running head: IR radiation and cataract I

ABSTRACT

The aim of the presented study was to establish if occupational exposure to infrared (IR) radiation increases the risk of developing cataract, and to correlate the lens findings to the degree of exposure. The eyes of 208 IR-exposed workers and 208 controls, all from six Swedish iron and steel manufacturing plants, were examined. An increased prevalence of wedge-shaped opacities was found in IR-exposed persons 60 years of age and older. This type of lens opacity is normally considered to be a purely senile change. Acceleration of senile changes by IR-radiation is suggested. Stratification of the material with regard to exposure was made on different grounds but failed to show a dose-effect-correlation.

KEY WORDS

Infrared radiation, dose determinations, iron and steel workers, lens opacities, cataract, exfoliation of the lens capsule, epidemiologic study.

INTRODUCTION

Cataract in glass blowers and blacksmiths was described as early as in the 18th century (Wentzel 1786). The radiation emitted from the molten glass or metal was supposed to be the cause. Vogt (1919) induced lens opacities in experimental animals with short wave infrared (IR) radiation, and this observation was later confirmed by other authors (Goldmann 1930, Pitts & Cullen 1981).

The typical glass blowers' cataract has been described as a posterior subcapsular opacity in the pupillary area (Robinson 1903, Huber 1914). Exfoliation of the anterior lens capsule was first described by Elschnig (1922), and is considered to be pathognomonic for IR induced lens damage (Jaensch 1955, Barthelmess & Borneff 1959). The exfoliation is a lamellar split of the anterior capsule. The superficial portion peels off from the periphery and coils up in the anterior chamber.

Many early reports were published on glass blowers' cataract (Meyhöfer 1886, Pröbsting 1899, Robinson 1903), but for a long time it was doubt if there was a similar condition in metal workers. Cridland (1915) reported the first case of typical blowers' cataract in a "puddler" (iron-smelter). A few years later St Clair Roberts (1921) described 25 cases of subcapsular cataract in chain makers. Several reports followed of single cases of cataract in persons with different occupations in the metal industry (Brinton 1922, Sichel 1923, Deutschmann 1926, Jaensch 1955). Schnyder (1926) examined 32 workers in an iron rolling mill and found nine of them having lens changes. Barthelmess & Borneff (1959) registered 40 cases or aphakia in 168 iron workers. However, only one of these cases was considered as possibly occupational in origin, whereas the rest were considered to be ordinary senile cataracts. Healy (1921) found 144 cases of lens opacities in 424 workers from tin plate rolling mills. All these investigations were made without control groups. Control materials were included in the investigations by Coates & Keatinge (1955), d'Onofrio & Mosci (1959), and Wallace et al (1971). None of the published studies of workers in the iron and steel industry showed a clear correlation between cataract and occupational IR-exposure.

An extensive study has recently been made of the exposure to IR radiation for workers in different processes in six Swedish iron and steel works (Lydahl et al 1984). Recordings of irradiance, as a function of time, were made with a pyroelectric radiometer. A dose per shift was calculated for each job in the processes examined.

The aim of the present study was

- to establish whether lens opacities were more frequent in workers exposed to IR radiation than in non IR-exposed workers
- to document the connection between lens opacities and the degree of exposure to radiation in the spectral region of interest.

MATERIAL AND METHODS

Examined workers

IR-exposed group

A study of the IR-exposure to the eyes of workers in 96 different jobs in six iron and steel manufacturing plants has been made (Lydahl et al 1984). All the persons who, for a considerable part of their active lives, held those jobs that were selected for IR-measurements were included in the study. The minimum time of exposure was set to five years. Pensioners were included when possible. Altogether 239 IR-exposed workers were selected. Out of these 19 did not turn up for the examination. Ten persons were excluded. Five of these had less than five years of exposure, while in four the occupational interview could not be carried out. The remaining person was excluded because of longstanding miotic therapy, which resulted in inadequate dilatation of the pupils for examination. Two of the examined IR-exposed persons could not be used for the analysis as no age matched controls were available. Thus, 208 IR-exposed workers remained for the analysis. All the examined persons were men.

Control group

Controls were chosen from the same plants but from departments without occupational IR-exposure, for instance mechanical workshops and building departments. For each exposed person a control was picked from the registers of employment and matched with respect to age as close as possible. The maximum age difference accepted was two years. 23 of the selected controls did not turn up and 14 had to be excluded because of occupational IR-exposure. Two persons were excluded because of eye disease. One of these had been operated for retinal detachment in one eye and for a perforating injury in the other. The other excluded control had been on prolonged miotic therapy in both eyes. As the examination proceeded additional controls were picked from the registers to match those exposed persons left without controls. Another 15 persons were thus selected and included in the examinations. In the end seven controls could not be used for the analysis as there was no age matched exposed person available. The industrial medical officers of all the companies were asked if they knew of any employee, who had to change jobs or retire prematurely because of cataract. No such cases were reported.

Dose calculations

The lifetime dose of each individual was calculated with the help of

- the occupational history
- the measured doses per shift
- information on the changes of the working conditions over the years.

The occupational history was penetrated according to a set questionnaire. All interviews were carried out by the same assistant. For exposed persons, the interview included the number of years in different positions and the wear of spectacles, protective glasses, and other types of eye protection. The size, type, and the temperature of the radiating source was noted. This was used as a basis for estimating the exposure in cases where the persons had worked in departments that were no longer in use. The occupational history of the controls was penetrated with the purpose of excluding persons with IR-exposure. Exposed and controls were asked about exposure to other types of radiation (ionizing, ultraviolet or microwaves) and toxic substances at work or in their free time. Only negligible such exposure was reported.

It was not possible to measure exposure in all the jobs that the examined workers had been employed in, because some jobs no longer existed and considerable changes had taken place in others. In some instances, where automation had increased the distance to the radiating source, it was still possible to make recording as the worker demonstrated how the work was done earlier. In other instances, where the whole process was no longer in use, the exposure was estimated from measurements in another plant with a similar process. For 129 of the exposed workers, only measurements in the present works were used for calculating the lifetime doses. For the remaining persons corrections for earlier methods or values from a similar process were used in addition.

The calculated lifetime doses include the wave length region 300-2600 nm. Different parts of this region have different actions on the eye depending on their absorption characteristics. The doses have therefore been subdivided into four spectral intervals according to Planck's law of radiation from a black body.

1. 300-400 nm, "near UV", is to a large extent absorbed by the lens (Boettner & Wolter 1962). This part of the spectrum is suspected to play a role in the development of senile cataract (Zigman 1977).

2. 400-760 nm is visible radiation (light).

3. 760-1400 nm is "near IR".

Most of the radiation in regions 2 and 3 passes the ocular media (Boettner & Wolter 1962), but is absorbed in pigmented tissues. This part of the spectrum has been reported to produce cataract in animal experiments (Goldmann 1930, Pitts & Cullen 1981).

4. 1400-2600 nm is absorbed in the cornea and the aqueous. This could theoretically result in secondary heating of the lens.

The calculated doses were reduced according to the filter factors of the specific type of eye protection that had been used by a few of the workers (Lydahl et al 1984). For each worker the highest irradiance that had been registered in a job helt by him was also noted down.

Selection of subgroups for analysis

The material was, for the analysis, stratified with respect to age and IR-exposure. Groups of highly exposed workers were extracted from the material for separate analysis. Three different criteria of exposure were used for this selection: lifetime dose, highest irradiance and exposure time. 20% with the highest exposure were selected for each of these criteria. The following groups were analysed:

Group 1. All IR-exposed persons.

Group 2. Exposed persons under 50 years of age.

Group 3. Exposed persons 50-59 years of age.

Group 4. Exposed persons 60 years of age and older.

Group 5. 20% of the exposed persons who had been exposed to the largest lifetime doses within 300-2600 nm.

Group 6. Persons in group 5, 60 years and older.

Group 7. 20% of the exposed persons who had been exposed to the highest irradiances.

Group 8. Persons in group 7, 60 years and older.

Group 9. 20% of the exposed persons who had been working in exposed positions for the longest time.

Group 10. Persons in group 9, 60 years of age and older.

The comparison between exposed and controls was made in groups. Thus, the age matched pairs were not kept together in the analysis.

For comparison with group 1 the whole control group was used and for groups 2, 3, 4, 6, 8 and 10 all controls of the corresponding age groups. For comparison with groups 5, 7 and 9 the entire control material was used, but it was weighed with regard to the age distribution in the corresponding exposed group. Five year intervals were used in this procedure. The sizes of all the analysed groups are given in table 1.

Table 1. Sizes of the analysed groups

Group	Exposed	Controls
1. Total material	208	208
2. Age < 50	106	104
3. Age 50-59	55	55
4. Age 60+	47	49
5. Large lifetime dose	41	*
6. Large lifetime dose age 60+	24	49
7. High peak irradiance	41	*
8. High peak irradiance	27	49
9. Long exposure	43	*
10.Long exposure age 60+	32	49

*The whole controlmaterial weighed with regard to the age distribution in the exposed group.

Ophthalmological examinations

All selected persons were examined on the factory premises. They were examined randomly, the examiners being unaware of the group they belonged to. The examinations were made by the two authors using the same protocol for grading and registering findings as in an earlier epidemiologic study (Elofsson et al 1980). A comparison was then made between their individual markings of the same persons and a very good accordance was found.

The visual acuity and the refraction were determined. The pupils were dilated to 7-8 mm with tropicamid 0.5%. If dilatation was inadequate, phenylephrine hydrochloride 10% and cyclopentolate hydrochloride 1% were given. The anterior segment of the eye was examined with a Nikon slit lamp microscope. The central fundus was examined with direct ophthalmoscopy and the intraocular pressure was measured with applanation tonometry. The slit lamp examination was especially detailed concerning the lens. The extent of the lens examination is given in table 2. The colour of the iris was also noted.

The medical history was penetrated with the purpose of registering possible causes of cataract. The protocol included questions about family history of cataract, about general disease, eye disease, and earlier eye injuries. Medication with corticosteroids and long term therapy with any other drug was also registered. The protocol is presented elsewhere (Lydahl 1984).

Data analysis and statistical methods

On analysing the results of the eye examinations, each parameter was treated separately. The value for the most affected eye was used. An exception from

Table 2. Lens examination

<u>Anterior lens capsule</u>	
Pigmentary deposits Pseudoexfoliation Exfoliation	Presence noted
<u>Subcapsular region</u>	
Anterior vacuoles Anterior opacities Posterior vacuoles Posterior opacities	Presence noted, marked in a schematic drawing of the lens
<u>Cortex</u>	
Punctuate opacities	Counted in a slit beam section of about 0.2 mm width
Larger distinct opacities Wedge shaped opacities	Presence noted, marked in a schematic drawing of the lens
The zones of discontinuity in the anterior cortex	Counted
<u>Nucleus</u>	
Punctuate opacities along the suture lines	Presence noted
Larger distinct opacities	Presence noted, marked in a schematic drawing of the lens
Turbidity Yellow - brown colour	Graded 1-5

this rule was the visual acuity in cases where visual impairment in one eye was due to other causes than cataract. In those cases the acuity value of the other eye was used.

The statistical analysis was made with chi-square test. When at least one of the expected frequencies was below five, Fisher's exact test (one-tail) was used instead. For the statistical comparison with the highly exposed groups (5, 7 and 9) the corresponding control groups, with their age weighed frequencies, were given the same sizes as the exposed groups. A difference was considered significant when the probability of the difference being caused randomly was five percent or less ($p \leq 0.05$). The confidence interval of the relative risk was calculated according to Miettinen (1974).

RESULTS

Dose calculations

The distribution of the calculated lifetime doses in the material is given in fig 1. The doses are here given within the spectral region 300-2600 nm.

Fig 1 shows that most of the examined workers had been exposed to doses in the lower range, 48% being esposed to doses smaller than 10^{6} J x cm^{-2}. After the determination of the individual exposure for each worker the highly exposed groups were selected. The lower exposure limit for group 5 was a lifetime dose of 4.0×10^{6} $Jxcm^{-2}$, for group 7 an irradiance of 550 mW x cm^{-2} and for group 9 an exposure time of 31 years. Exposure data for all analysed groups are given in table 3. For the lifetime doses in the different spectral regions and for the highest registered irradiance median

Table 3. Exposure data for analysed groups

	2. <50	3. 50-59	4. 60+	5. large dose	6. large dose 60+	7. high irr.	8. high irr 60+	9. long exp.	10. long exp.60+
Age (years) mean	37.6	55.6	65.4	58.7	66.2	54.4	65.7	63.8	66.0
Exposure time (years)									
mean	14.4	25.2	35.2	32.6	37.3	27.7	35.9	40.0	40.8
max	31	43	51	50	50	51	51	51	51
min	5	5	14	5	16	5	15	31	31
Lifetime dose 300-400nm ($Jxcm^{-2}$)									
median	0.066	0.12	0.15	0.30	0.30	0.21	0.23	0.23	0.20
Q1	0.00	0.00	0.020	0.21	0.15	0.029	0.089	0.024	0.024
Q3	0.16	0.48	0.49	0.74	0.68	0.73	0.73	0.51	0.51
Lifetime dose 400-760nm ($Jxcm^{-2}x10^{3}$)									
median	1.4	2.1	5.3	7.8	7.8	5.1	5.0	5.6	6.0
Q1	0.063	0.11	0.44	6.0	6.1	1.2	0.27	0.68	0.49
Q3	3.3	6.7	8.9	15	15	9.7	11	9.8	12
Lifetime dose 760-1400nm ($Jxcm^{-2}x10^{5}$)									
median	1.4	1.9	5.2	7.9	8.6	5.0	5.0	5.4	6.2
Q1	0.026	0.027	0.58	6.6	7.1	1.1	0.35	0.88	0.63
Q3	3.1	5.5	8.6	11	16	8.2	9.0	9.9	13
Lifetime dose 1400-2600nm ($Jxcm^{-2}x10^{6}$)									
median	0.74	0.75	3.3	4.9	5.4	2.1	2.1	3.3	3.9
Q1	0.028	0.084	0.45	3.8	4.7	0.74	0.29	0.51	0.47
Q3	1.7	2.9	5.4	7.5	10	4.8	5.8	6.6	8.4
Lifetime dose 300-2600nm ($Jxcm^{-2}x10^{6}$)									
median	0.93	0.94	3.8	5.7	5.9	2.4	5.4	4.0	4.6
Q1	0.031	0.087	0.52	4.6	5.3	0.88	2.4	0.65	0.55
Q3	2.0	3.4	6.2	8.7	12	5.5	10.2	7.5	9.8
Peak irradiance ($mWxcm^{-2}$)									
median	350	470	530	530	540	870	710	530	540
Q1	140	240	350	430	430	550	550	260	390
Q3	450	830	630	550	550	1200	1200	550	630

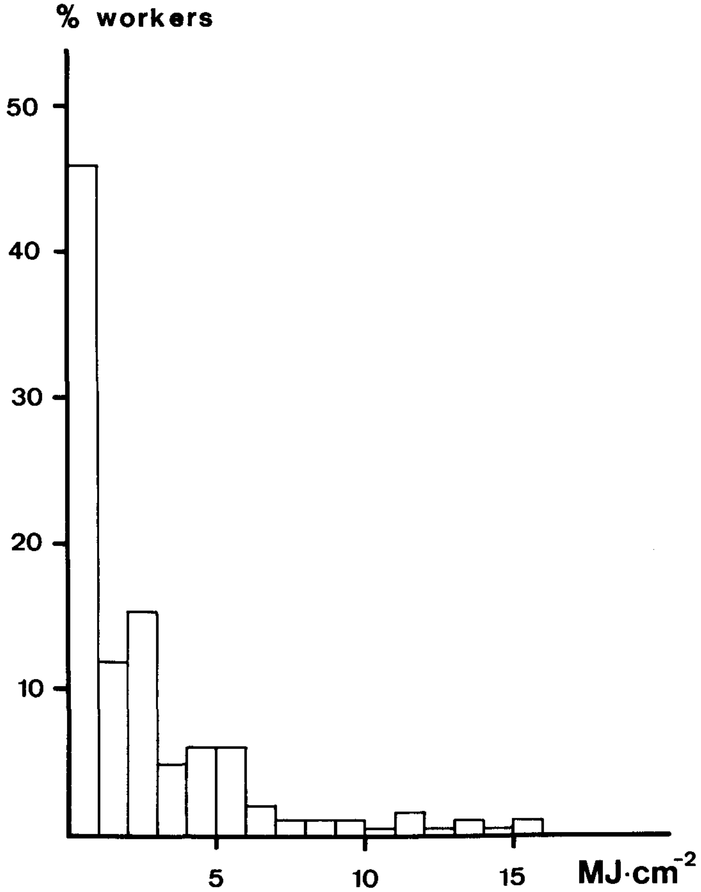


Fig. 1. The distribution of the lifetime dose of radiation in the wave length region 300-2600 nm in the examined group of iron and steel workers (n=208).

values and the values Q1 and Q3 are presented. 25% of the values are below Q1 and 25% are above Q3. Mean values are given for age and exposure time.

Ophthalmological examinations

Result are reported of the analysis of the ophthalmological examinations of 208 age matched pairs. In two cases only one eye could be used for the analysis. One of these persons had signs of a perforating injury and the other had secondary glaucoma following thrombosis in the excluded eye. All eye diseases and eye injuries reported by the other workers were mild and could not have influenced the lens. Four exposed persons and six controls gave a history of diabetes. However, none of these were found to have any pathological lens changes. None of the examined persons had taken corticosteroids for a long period of time.

The frequencies of subcapsular and wedge shaped opacities are presented in table 4. In the oldest age group (60+) and in the highly exposed groups 7, 8 and 10 a significantly increased frequency of wedge shaped opacities was found in the exposed. For all other parameters the differences between exposed and controls were small and variable. The complete results of the lens examination will be presented elsewhere (Lydahl 1984). Table 5 shows those who have, in at least one eye, any of the three major types of cataract i.e. subcapsular, cuneiform or nuclear cataract (defined as diffuse turbidity grade 4 or 5). The changes however, do not in all cases interfere with vision. The frequency of cataract thus defined was significantly increased in exposed workers in the oldest age group and in all the highly exposed groups.

Table 4. Presence of posterior subcapsular and wedge shaped lens opacities

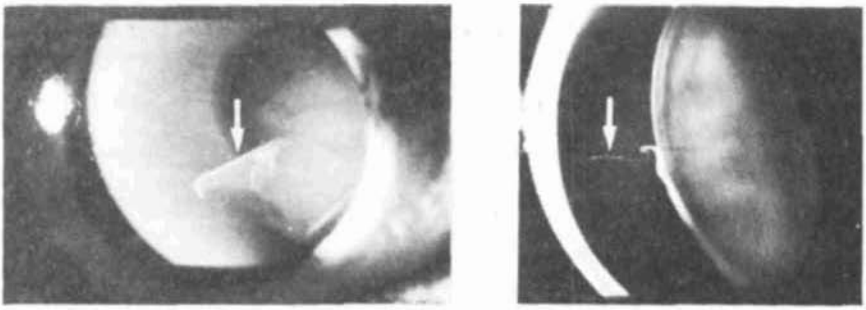
Group	Posterior subcapsular opacities exp (%)	cont (%)	p ≤0.05	Wedge shaped opacities exp (%)	cont (%)	p ≤0.05
1. All	2	2		11	6	
2. <50	0	1		0	0	
3. 50-59	4	4		13	11	
4. 60+	4	4		32	12	0.02
5. large dose	10	4		24	20	
6. large dose 60+	8	4		29	12	
7. high irr.	7	3		24	8	0.04
8. high irr. 60+	7	4		41	12	0.004
9. long exp.	5	3		28	13	
10. long exp. 60+	3	4		34	12	0.02

Table 5. Presence of subcapsular, cuneiform or nuclear cataract (>grade 3).

Group	Exposed (%)	Controls (%)	p ≤0.05
1. all	12	7	
2. < 50	0	1	
3. 50-59	15	12	
4. 60+	36	14	0.01
5. large dose	32	12	0.03
6. large dose 60+	38	14	0.02
7. high irr.	29	10	0.03
8. high irr. 60+	48	14	0.001
9. long exp.	33	14	0.04
10. long exp. 60+	38	14	0.02

The frequencies of pathological lens changes were not significantly higher in the highly exposed groups than in the oldest age group. Three IR-exposed persons and one control had a cataract that reduced visual acuity to 0.7 or less. None of the examined persons was aphakic.

One case of exfoliation of the anterior lens capsule was observed. This was a 62-year old man. who had worked with forging for 40 years, giving him such a high exposure that he was included in all the highly exposed groups. He did not complain of any visual disturbance and his visual acuity was 1.0 in both eyes. Both lenses showed a typical picture of exfoliation (fig 2) and small posterior subcapsular opacities.



2a. 2b.

Fig 2. Slit lamp photographs of exfoliation of the anterior lens capsule in a 62-years old blacksmith. Fig 2a is taken with a wide slit beam and shows a big sheat of detached capsule (indicated by arrow). Fig 2b is taken with a thin slit beam and shows the exfoliation (arrow) extending close to the cornea.

Careful examination with high magnification was made of the posterior subcapsular region of the lens. Small irregularities in this region were seen in all examined persons and thus considered normal.

For the other parameters that were registered, the intraocular pressure, corneal findings, iris and fundus changes, no significant differences between exposed and controls were found in any of the analysed groups.

The results can be summarized in the following relative risk: For iron and steel workers, 60 years of age and older, the risk of developing a cataract is increased 2.5 times. The 95% confidence interval is 1.2-5.2. This relative risk is based on the frequencies of cataract, defined as in table 5. Cataract was present in 17 out of 47 exposed persons and in seven out of 49 controls. The risk of having a cataract that gives reduced vision is however not significantly increased.

DISCUSSION

The examination shows an increased prevalence of wedge shaped opacities in IR-exposed workers 60 years of age and older. No additional difference between exposed and controls was found in highly exposed groups that were selected on the basis of three different criteria of exposure. Consequently, a dose - effect relationship could not be found in this material.

A possible reason that we did not find many persons with advanced cataract among the examined workers could be that a reduction of vision would disable them for work. No such instances were however reported by the medical officers of the included plants.

The dose calculations contain considerable uncertainty, especially the calculation of lifetime doses for those workers who have had jobs in now closed down factories or departments, or where changes have taken place because of automation of the processes.

According to most of the earlier reports (Robinson 1903, St Clair Roberts 1921, Schnyder 1926) posterior subcapsular cataract is the type which is found in IR-exposed workers. However, in the present study this type of opacity was seen in only four exposed persons as in five controls.

The case of exfoliation of the anterior lens capsule seen in this study, showed the typical picture as described in the literature (Elschnig 1922 and 1923, Kubik 1923, Schnyder 1926) and can most certainly be considered as an IR-induced lens damage.

The wedge shaped opacity is normally considered senile in origin. This fact, together with the observation that there is no detectable dose-effect relationship may indicate, that what we have found is a number of senile cataracts, by chance placed in the IR-exposed group. There is, however, also a possibility that IR radiation accelerates senile changes. Healy (1921), in his examination of tinplate millmen, found wedge shaped opacities in about half of those having lens changes. He even considered this type of opacity pathognomonic for tinplate millmen.

Coates and Keatinge (1955) found discrete changes in the posterior lens capsule in 26 out of 44 workers in an iron rolling mill. The same type of change was seen in 16 out of their 104 controls from a mental institution. The prevalence of actual lens opacities was similar in the two groups. We have looked very carefully at the posterior subcapsular region of the lens and we found that there were always small irregularities close to the capsule. Wallace et al (1971) published an extensive study of the workers in a steel works in Wales. They found an increasing frequency of small anterior and posterior subcapsular opacities behind the iris with increasing age. This type of opacity was reported in 63% of the workers that were considered most exposed and in 48% of non exposed workers. We were not able to see any opacities that conform with this description. Wallace et al also found one case of posterior subcapsular cataract that interfered with vision. Other types of opacities were not reported.

The results of the present study show an increased prevalence of senile lens opacities in elderly IR-exposed workers. This calls for examination of more old persons having a very long occupational exposure to IR radiation, to make it possible to draw more extensive conclusions about the effect of IR radiation in combination with age.

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