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MORTALITY PATTERN IN THE COHORT OF WORKERS EXPOSED TO CARBON DISULFIDE

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Abstract. The objective of the study was to assess mortality in the cohort of the viscose factory workers occupationally and environmentally exposed to carbon disulfide. Male workers employed for at least one year during 1950–1985 in the production or maintenance departments, living in the vicinity of the plant, were enrolled into the study. Of the 2878 workers in the cohort, 2762 were successfully traced, yielding 76,465 person-years. Mortality assessment was based on the standardized mortality ratio using a person-years method. The general male population of Poland was considered as a reference group.
Total mortality in the cohort was higher than in the general male population in Poland (SMR = 108). A significantly increased risk of deaths was observed for all cardiovascular (SMR = 114) and cerebrovascular (SMR = 208) diseases. Analyses showed a significantly elevated risk of death from the circulatory system diseases in the men of the "highly exposed" group, spinners and those who were first employed before 1974. A statistically significant trend of mortality from all cardiovascular diseases in relation to the level of exposure (assessed qualitatively) was evident. No clear relationship between duration of exposure and the risk of death was found.

Key words:
Carbon disulfide, Mortality, Cardiovascular diseases, Cohort study

INTRODUCTION

Carbon disulfide (CS_2) is one of the occupational chemical agents, whose causal role as a risk factor for ischemic heart disease has been extensively investigated. Experimental studies revealed atherosclerotic changes in arterial walls in animals exposed to CS_2, and the thesis that CS_2 induces an increased synthesis of cholesterol in the liver and its deposition in the artery wall was introduced [1,2]. Most recent *in vitro* studies showed that CS_2 can modify particles of low density lipoprotein (LDL), which resemble then oxidatively modified LDL [3]. It has also been reported that oxidation of CS_2-modified LDL may result in further changes in its physico-chemical properties, leading to its increased cytotoxicity [4].

In some, but not in all cross-sectional studies of workers employed in rayon factories, the association between CS_2 exposure and coronary heart disease risk factors, like increased levels of total cholesterol and LDL-cholesterol; lower levels of high density lipoprotein (HDL); and increased blood pressure, has been reported [5–9]. However, the results of the studies of the prevalence of ischemic heart disease or its symptoms in these groups of workers are inconsistent [8,10–13]. The epidemiological studies carried out in Great Britain, Finland, the Netherlands and the USA showed an increased risk of death from cardiovascular disease and/or from ischemic

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heart disease in the cohorts of the viscose rayon workers [14–18].

In 1996, we published the results of the mortality study in the cohort of workers with chronic CS_2 poisoning reported to the Registry of Occupational Diseases in Poland [19]. Significantly increased risk of death from cardiovascular diseases, particularly from cerebrovascular and ischemic heart diseases among men, and significant excess of risk of death from atherosclerosis in women were the relevant findings of this study. The aim of the present study was to evaluate mortality in the production and maintenance workers of the viscose factory with particular attention paid to deaths from the circulatory system diseases.

MATERIALS AND METHOD

Description of the plant and exposure

The study plant, located in the central part of Poland, started its operation in 1912. In the factory, rayon filament, viscose film, cords and rayon staple fibers were manufactured. During the years 1935–1979, CS_2 was synthesized, supplying local production, as well as the production of viscose rayon in some other viscose plants in Poland. The production of viscose involves exposure to CS_2, one of the main reagents used in the production processes. Exposure to hydrogen sulfide (H_2S) in the production departments was also observed, but according to the data from the hygiene measurements carried out at the plant the H_2S concentrations have always been low, below the MAC value (10mg/m^3). The air monitoring in the synthetic fiber plants was initiated in 1945/46 [20]. At that time, CS_2 exposure was very high, for example in the staple fiber department the concentration reached 1180mg/m^3 with its background of 200–300mg/m^3 [21]. In the beginning of the 1960s the team of workers of the Institute of Occupational Medicine carried out hygiene survey in different areas of the plant. Stationary area samples taken in the spinning department indicated high concentration of CS_2 with average background CS_2 concentration ranging from 30 to 80 mg/m^3. The spinners were exposed to the highest CS_2 concentration of TWA 130 mg/m^3 [22]. In 1977 and 1978 both stationary measurements and personal sampling were repeated by the workers of our Institute. The measurements showed that CS_2 concentrations varied considerably between departments, particular jobs and also between the same jobs on different days. The highest exposure was noted for spinners in the viscose film manufacturing department with average concentration between 29.1 and 33.5 mg/m^3 [23]. The measurements based on personal samples systematically indicated higher exposures then those revealed by stationary measurements. Again the spinners were mostly exposed with the average CS_2 exposure of 25.8 mg/m^3 in the rayon production department; 45.5 mg/m^3 in the cord production department; and 24.4–38.2 mg/m^3 in the viscose film manufacturing department.

In the vicinity of the plant, the environmental standards for CS_2 and H_2S were exceeded. In 1972, the plant emitted 7,500 Mg of dust and 12,000 Mg of gases, mainly CS_2 and H_2S. In 1993, according to the data of the sanitary and epidemiological station, the average 30-min measurement of environmental concentration for CS_2 and H_2S was 28.4 μg/m^3 (the then environmental standard – 3.8 μg/m^3). Historically, the environmental exposure to CS_2 and H_2S of the town inhabitants should have been even higher, since the total production was the most extensive in the 1960s and 1970s.

Cohort definition and data collection

To evaluate mortality of workers occupationally exposed to CS_2, the retrospective cohort study was carried out. The cohort members were identified through the plant's personnel files. The data obtained from personnel records included: the name, the date of birth, the place of residence, the date of employment, the department and job for each period of employment. All files of workers employed during the years 1950–1985 were reviewed for the eligibility for the study. In the selection process the following eligibility criteria were used:

- continuous work for at least 12 months during the years 1950–85,

- employment only in production and maintenance departments,
- residence in the town during the employment.

The study population was limited to the residents of the town because of the general environmental exposure in the vicinity of the plant. In this paper the results of the study covering only men are reported.

The vital status of the subjects was ascertained on the basis of data obtained from the local register of the town residents. The causes of deaths were provided by the municipal register office, on the basis of death certificates for all deceased in the town. The causes of death were coded according to the International Classification of Diseases and Causes of Death (ICD-9).

The follow-up covered the period from 1 January1950 to 31 December 1995.

Statistical analysis

Mortality data were analyzed using standardized mortality ratios (SMR) according to a standard person-years method. Only person-years and deaths of subjects aged up to 80 years were included in the analysis. A computer program PYRS3 developed by the International Agency for Research on Cancer (IARC) was used for calculations [24]. Ninety-five percent confidence intervals (95% CI) were computed with an assumption of the Poisson's distribution. Expected numbers of deaths were derived from mortality rates for the general population of Poland, which are gender-, age- and cause-specific in ten-year calendar intervals.

Total and cause-specific mortality in the total population of employees was investigated. Additional analyses included duration of employment, calendar period of hire and levels of exposure categorized qualitatively. The duration of employment was analyzed as a time-dependent variable. Three categories of employment duration were adopted: 1–10 yrs, 11–20 yrs and 21 yrs and more. Based on the assumption of different exposure levels in different phases of the factory operation, three calendar periods were distinguished: until 1959, 1960–1974 and 1974–1985. In order to analyze the relationship between the exposure level and the magnitude of risk, three categories were established: "high exposure", "intermittent exposure" and "non exposure". The "high exposure" category included workposts with CS_2 concentration exceeding the MAC values (during the observation period 10 and 25 mg/m^3) where regular area monitoring was carried out. All workers employed for at least one year at these workposts were included in this category. It was found that spinners made 54% of this group. The maintenance workers (eg. electromechanics, locksmiths) worked temporarily at chemical production departments and were only occasionally exposed to CS_2. They were classified in the "intermittent exposure" category. Finally all those who did not work for at least one year at workposts with "high" or "intermittent exposure" formed the "non-exposed" group. The significance of linear trend across the exposure categories was computed to assess the dose response relationship.

RESULTS

The distribution of the study population by follow-up status is given in Table 1. Of the 2878 workers in the cohort, 2762 were successfully traced yielding 76,465.5 person-years; 1010 subjects died at the age under 80; and 116 (4.1%) were lost to follow-up, and thus excluded from the analysis. The characteristic of the study population is presented in Table 2. On average workers were first hired at the age of 25.2 years and worked at the factory for 17.3 years. More then half of the workers started employment before 1959 and 51.2 % of the cohort were employed at "high exposure" workposts.

Observed and expected numbers of deaths, SMRs and 95% CI for selected causes of deaths are shown in Table

Table 1. The distribution of the endpoints of the follow-up in the cohort of workers exposed to carbon disulfide

	Men	
	No.	%
Traced	2762	95.9
Alive	1752	60.9
Deceased	1010	35.0
Lost to follow-up	116	4.1
Total group	2878	100.0

Table 2. The characteristics of the traced population of men employed in the artificial fiber plant

Characteristics	Men	
	No.	%
Duration of employment		
1–10 yrs	818	29.6
11–20 yrs	738	26.7
21 – > yrs	1206	43.7
Average duration of employment	17.3	
Calendar period of start of the employment		
- 1959	1426	51.6
1960–1974	872	31.6
1975–1985	464	16.8
Average age at first employment	25.2	
Level of exposure:		
Nonexposed	692	25.0
Intermittent exposure	657	23.8
High exposure	1413	51.2
Spinners (% of high exposure)	766	54.2

3. The total number of observed deaths was 1010 comparing to 938.4 expected deaths, which indicated an increase in overall mortality. The circulatory system diseases were the most prevalent causes of deaths and the significant excess of deaths due to cardiovascular diseases occurred. Over a twofold increase in deaths from cerebrovascular dieseases was also observed. There was insignificant excess of deaths from ischemic heart disease and significant deficit in cause-specific mortality from atherosclerosis and hypertensive disease. Mortality from all cancers was significantly lower than expected.

Table 4 presents the results of the analysis of total mortality and cardiovascular causes of deaths by duration of employment. Total mortality was similar and insignificant in the first two categories of employment duration, the lowest SMR value was observed in the category of workers employed for more than 21 years. The results indicated the increased mortality from all circulatory system diseases, ischemic heart disease and cerebrovascular disease among workers with a 11–20 year duration of employment, but only the results for all circulatory system diseases and cerebrovascular disease reached statistical significance.

In the analysis by calendar period of first employment the significant excess of deaths occurred among those first employed before 1974 (Table 5). Among those first employed before 1959, a significant (11%) excess of deaths from all circulatory diseases, and more then twofold excess from cerebrovascular diseases, could be

Table 3. Observed and expected deaths, SMRs and 95% CI for selected causes of deaths in the cohort of male workers of the artificial fiber plant

Cause of Death (ICD – 9)	No. of Deaths		SMR	95% CI
	Obs.	Exp.		
All causes (001-999)	1010	938.4	108	101–115
Diseases of the nervous system and sense organs (320-389)	12	9.2	130	67–227
Diseases of circulatory system (390-459)	456	399.5	114	104–125
Hypertensive disease (401-405)	5	15.0	33	11–77
Ischemic heart disease (410-414)	141	123.3	114	96–134
Cerebrovascular disease (430-438)	105	50.5	208	170–252
Atherosclerosis (440)	60	90.0	67	51–86
Malignant neoplasms (140-208)	174	211.4	82	70–95
Lung (162)	57	69.2	82	62–106
Nonmalignant respiratory disease (460-519)	37	55.2	67	47–92
Diseases of digestive system (520-579)	28	39.8	70	47–101
Chronic liver disease and cirrhosis (571)	8	14.9	54	23–106
Diseases of genitourinary system (580-629)	6	15.0	40	15–87
Ill-defined conditions (780-799)	55	46,3	119	90–155
Senility (797)	9	8.5	106	48–201
Injury and poisoning (800-999)	85	101.3	84	67–104

Table 4. Observed deaths, SMRs and 95% CI for all causes and cardiovascular causes of deaths in the cohort of male workers of the artificial fiber plant by duration of employment

Causes of Death (ICD–9)	Duration of employment (yrs)								
	1–10			11–20			21 and more		
	Obs.	SMR	95%CI	Obs.	SMR	95% CI	Obs.	SMR	95%CI
All causes (001-999)	281	112	99–127	233	112	98–127	496	104	95–114
Diseases of circulatory system (390-459)	101	112	91–136	104	125	102–151	251	111	98–126
Hypertensive disease (401-405)	1	29	1–164	0	—	—	4	48	13–123
Ischemic heart disease (410-414)	37	120	85–166	36	135	95–187	68	103	80–131
Cerebrovascular disease (430-438)	25	216	140–318	27	258	170–375	53	187	140–245
Atherosclerosis (440)	13	79	42–135	14	86	47–144	33	58	40–81

Table 5. Observed deaths, SMRs and 95% CI for all causes and cardiovascular causes of deaths in the cohort of male workers of the artificial fiber plant by calendar period of start of employment

Causes of Death (ICD – 9)	Calendar period								
	-1959			1960–1974			1975–1985		
	Obs.	SMR	95%CI	Obs.	SMR	95% CI	Obs.	SMR	95% CI
All causes (001-999)	812	102	95–109	150	152	129–178	48	125	92–166
Diseases of circulatory system (390-459)	393	111	100–123	51	161	120–212	12	96	50–168
Hypertensive disease (401-405)	4	31	8–79	1	73	2–407	0	—	—
Ischemic heart disease (410-414)	108	104	85–126	28	199	132–288	5	100	32–233
Cerebrovascular disease (430-438)	97	218	177–266	6	141	52–307	2	120	15–433
Atherosclerosis (440)	57	68	52–88	3	78	16–228	0	—	—

Table 6. Observed deaths, SMRs and 95% CI for all causes and cardiovascular causes of deaths in the cohort of male workers of the artificial fiber plant with the distinguished group of spinners by the level of exposure

Causes of Death (ICD–9)	Level of exposure											
	Non exposed			Intermittent exposure			High exposure			Spinners		
	Obs.	SMR	95%CI	Obs.	SMR	95% CI	Obs.	SMR	95% CI	Obs.	SMR	95% CI
All causes (001-999)	267	102	90–115	190	98	85–113	553	116	107–126	324	119	106–133
Diseases of circulatory system (390-459)	110	97	80–117	90	111	89–136	256	126	111–142	143	124	105–146
Hypertensive disease (401-405)	0	—	—	0	—	—	5	64	21–149	2	45	5–163
Ischemic heart disease (410-414)	34	106	73–148	29	113	76–162	78	119	94–149	49	131	97–173
Cerebrovascular disease (430-438)	33	233	160–327	18	174	103–275	54	209	157–273	30	204	138–291
Atherosclerosis (440)	12	46	24–80	11	60	30–107	37	81	57–112	19	75	45–117
Cerebrovascular disease + Hypertensive disease + Atherosclerosis	45	101	74-136	29	91	61–131	96	135	109–165	51	115	86–151

observed. Among those first employed during the period 1960–1974, a significant excess of total mortality and excess of deaths from all circulatory diseases (52% and 61%, respectively), as well as almost two-fold excess of deaths from ischemic heart disease were noted.

Table 6 summarizes the results of the qualitative assessment of the exposure level in the cohort with the distinguished group of spinners. Total mortality and the risk of death from all circulatory diseases were significantly increased only in the ”high exposure” category and in the group of spinners. The risk of death from circulatory diseases increased from SMR = 97 in the ”non exposed” to SMR = 126 in the ”high exposure” category. The trend was statistically significant (p = 0.022). Similar pattern

emerged for ischemic heart disease and atherosclerotic disease: increase from SMR = 106 to SMR = 119, and from SMR = 46 to SMR = 81, respectively. Mortality from cerebrovascular diseases was significantly increased in each exposure level category.

DISCUSSION

Our study showed significant (8%) increase in total mortality among male employees exposed to CS_2. The excess of deaths was greatly attributed to higher then expected number of deaths from circulatory diseases and cerebrovascular diseases in particular. The highest total mortality was observed among male employees who had ever worked as spinners. In this category of workers the overall risk of death was by 19% higher than in the general population. Our finding on a higher risk of death in the total cohort of men and particularly in the "high exposure" category is consistent with our previous findings from the study of the workers of the synthetic fiber industry with reported chronic CS_2 poisoning [19]. Higher than in the reference population mortality from all causes of deaths was also found in the British study reporting a significant (36%) increase in risk among spinners [14].

The excess of deaths from circulatory diseases was anticipated in view of the previous cohort studies conducted in Finland, Great Britain, the USA, the Netherlands and also in our previous report [14–19]. In the total cohort of men presented here, the risk of death from circulatory disease was 14% higher than in the general male population of Poland, the risk increased by 26% in the "high exposure" category, and by 24 % among spinners while in the "non exposed" category, mortality from all circulatory disease was at the reference level. The number of deaths from ischemic heart disease was higher than expected, but the result was statistically significant only in the group of workers who were first hired during the years 1960–1974.

The remarkable finding in our study was significant, more than twofold, excess mortality from cerebrovascular diseases in the total cohort, "high exposure" category in spinners, but also significantly higher mortality in the "non-exposed" category. The latter observation would suggest weak relationship between CS_2 exposure and this particular cause of death. However, in the "high exposure" category the excess of deaths from cerebrovascular diseases was accompanied by excess mortality from all cardiovascular diseases while in the "non-exposed" category, mortality from all circulatory diseases was at the reference level. The additional analysis, in which deaths from cerebrovascular diseases were combined with those from atherosclerosis and hypertension, revealed the significant increase in the "high exposure" category (SMR = 135) and no excess in the "non exposed" category (SMR = 101.6).

The relationship between CS_2 exposure and cerebrovascular deaths is feasible in view of the previous data. One of the earliest reports that indicate cerebrovascular disorders resulting from long-term CS_2 exposure comes from the 1950s. In 1954 Vigliani described cerebrovascular damage with "focal lesions of atherosclerosis" among 43 men with CS_2 poisoning [25]. The men were employed for a longer period in the areas with high CS_2 exposure. It was suggested that encephalopathy with possible strokes might occur after chronic exposure to CS_2 [26]. In our previous study, based on cases with CS_2 chronic poisoning, significantly (88%) increased mortality from cerebrovascular diseases in men aged 50 years or more was observed [19]. The increased risk of deaths from these diseases was reported in proportional mortality study based on the mortality data among workers in Canada [27].

No clear trend of mortality, depending on duration of employment, was observed in our study. Slightly higher, relative to the shortest duration of employment, mortality from diseases of circulatory system and specific cardiovascular causes was found in the category of employees working for 11–20 years, but in the category with the longest duration of employment, the mortality ratios were lower than in the intermediate duration of employment. Better background health status of workers with the longest duration of work comparing to both the reference population and the category of workers employed in the plant for a shorter period of time could explain this finding. In the cohort study of the U.S. workers with heavy and intermittent exposure to CS_2, similar pattern was observed, however, different categories preclude direct comparisons with our

results [17]. In this study, the increased mortality from arteriosclerotic heart disease was observed in workers with 15–24 years of exposure and lower in the category of employees working for 25 years or more.

The important risk factor considered as a confounder in the occupational studies of relationships between given exposure and cardiovascular outcome is smoking. The retrospective character of our study precluded direct analysis of the influence of smoking on the study results. In 1996, we carried out the cross-sectional study of the male employees of the same plant aimed at investigating cardiovascular risk factors in this population [28]. The survey revealed that in the male population almost 69% of workers were current smokers. This frequency was higher than in the general population of Poland (in 1996, 57.3% of men reported current smoking; data from random sample survey) [29]. However, we did not find the increased mortality from another smoking-related disease, lung cancer. It is unlikely that smoking itself was responsible for an increased risk of cardiovascular diseases and cerebrovascular disease in particular.

The relationship between the level of exposure measured qualitatively and indirectly by calendar period and mortality from cardiovascular causes was found in our study. In conclusion, the results of our study provide the evidence that the relationship between CS_2 exposure and the risk of death from cardiovascular diseases does exist.

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