A Prospective Study on Mortality among Japanese Coal Miners

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Abstract: We conducted a prospective study to clarify mortality patterns among Japanese coal miners in a former coal mining area. Subjects included 1,796 coal miners and 4,022 non-coal-miners, who were identified by a mail survey between 1987 and 1989, and then followed up from the date of the survey to April 30th, 1994. We applied Cox's proportional hazards model to compare the mortalities between coal miners and non-coal-miners. Among the coal miners, significantly high risk ratios were observed in all causes of death (risk ratio = 1.4, $p < 0.05$) and all malignant neoplasms (risk ratio = 1.5, $p < 0.05$). Risk ratios for all causes of death and all malignant neoplasms also rose with the length of experience in coal mining. Analysis of the results for sites of cancer showed that coal miners had high risk ratios for stomach cancer (risk ratio = 1.6), liver cancer (risk ratio = 1.4) and lung cancer (risk ratio = 1.6), though these ratios were not statistically significant. When the risk ratio for lung cancer was analyzed according to the length of experience in coal mining, coal miners with at least 15 years' experience had a significantly high risk ratio (risk ratio = 2.4, $p < 0.05$), though coal miners with less than 15 years' experience had almost the same risk as non-coal-miners.

Key words: Mortality — Epidemiological Study — Coal Miners — Pneumoconiosis

INTRODUCTION

There have been many epidemiological studies on mortality among silicosis patients and workers exposed to dust, especially silica¹⁻¹³⁾. In these studies, particular attention has been paid to the association between dust exposure and cancer. Many studies have demonstrated that silicosis patients and workers exposed to dust have a high risk of lung cancer¹⁻¹²⁾. It has been suggested that exposure to dust

may be associated not only with lung cancer but also with other cancers¹⁻³. There have been a few epidemiological studies in Japan on cancer mortality among pneumoconiosis patients and workers exposed to dust^{1, 4-6}. These studies showed that exposure to dust was associated with lung cancer: relative to male Japanese in general, risks of lung cancer were raised 2.1-fold among ceramic workers with pneumoconiosis⁴, 2.9-fold among copper miners⁵, and 3.2 and 4.2-fold among pneumoconiosis patients^{1, 6}. Although smoking has been found to be a much more important risk factor for lung cancer than exposure to dust, these studies did not take the effect of smoking into account. Moreover, because they used national mortality rates as a standard in estimating the risk of lung cancer, they failed to take account of geographical variations in mortality, which may also affect risk. Our study of mortality, especially cancer mortality, among Japanese coal miners was designed to take these two points into consideration.

Japanese coal miners are exposed to relatively high concentrations of silica dust because most Japanese coal mines have thin coal seams. Therefore, they tend to suffer from silicosis¹³. Although the Japanese coal industry has been decline since around 1960, with the number of active coal miners falling sharply every year, there are still many former coal miners who have silicosis. In addition, a number of workers are exposed to silica dust in certain other industries. Therefore, an epidemiological study on mortality among coal miners remains of importance and of special interest.

MATERIALS AND METHODS

We selected three towns in a former coal mining area in Japan for an epidemiological study on mortality among coal miners. All coal mines in this area were shut down by 1973 because of the decline of the coal industry. The male population aged 40-69 in the three towns was 9,943. These males were identified from the municipal population registers. We mailed questionnaires to them during 1987-1989, obtaining information on their medical histories, smoking habits, drinking habits and occupational histories, especially any history of coal mining work. Of the 9,943 men, 5,818 (58.5%) responded to the questionnaire. We classified respondents into two groups according to whether they had worked as coal miners. These groups are referred to hereafter as the 'coal miner' and 'non-coal-miner' groups, respectively. Table 1 shows the age distribution of coal miners and non-coal-miners at the start of the follow-up period. Coal miners were, on average, older than non-coal-miners. Table 2 shows the distribution in years of experience in coal mining among 1,796 coal miners. The mean was 14.3 ± 9.8 years (mean $\pm$ SD).

The follow-up period extended from the date of the mail survey to April 30th, 1994. Emigrants were identified through the municipal population registers. We identified all cases of deaths from death certificates. During the follow-up pe-

Table 1. Age distributions of coal miners and non-coal-miners

Age	Coal miners	Non-coal-miners
40–49	122	1,652
50–59	595	1,344
60–69	1,079	1,026
Total	1,796	4,022

Table 2. Years of experience in coal mining

Years	Number	(%)
1–4	327	(18.2)
5–9	329	(18.3)
10–14	329	(18.3)
15–19	275	(15.3)
20–24	197	(11.0)
25 +	339	(18.9)
Total	1,796	(100)

riod, 169 of the coal miners and 168 of the non-coal-miners died. Causes of death were coded according to the 9th revision of the International Classification of Diseases (ICD).

Standardized mortality ratios (SMRs) were calculated, using 1991 age-cause-specific mortality rates for Japanese males. The observed periods were 8,834.5 person-years for coal miners and 19,241.3 person-years for non-coal-miners. Statistical significance was assessed by comparison with the Poisson distribution if the expected number of deaths was less than five and with the chi-square distribution if it was five or more.

We applied Cox's proportional hazards model to compare the mortalities between coal miners and non-coal-miners; risk ratios were then estimated for selected causes of death among coal miners, adjusted for age, smoking habits and other factors. We also divided coal miners into two groups according to how long individuals had worked as coal miners, and estimated risk ratios for each group. The SAS statistical package was used for data analysis.

RESULTS

1. Standardized mortality ratios for selected causes of death

Table 3 shows SMRs for selected causes of death among coal miners and non-coal-miners. Among coal miners, the overall SMR was 120, which was statisti-

Table 3. Standardized mortality ratios for selected causes of death

Causes of death	ICD	Coal miners			Non-coal-miners		
		Obs.	Exp.	SMRs	Obs.	Exp.	SMRs
All causes		169	140.9	120*	168	181.1	93
Tuberculosis	010–018	2	0.8	244	0	1.1	0
All malignant neoplasms	140–208	88	58.6	150***	75	72.9	103
Stomach	151	13	12.4	105	9	15.6	58
Colon & Rectum	153–154	6	6.3	95	10	8.0	125
Liver	155	25	9.4	266***	25	12.5	200***
Pancreas	157	4	3.3	123	1	4.1	24
Lung	162	19	12.5	152	13	14.2	92
Heart diseases	393–398, 410–429	22	22.8	96	20	28.7	70
Ischemic heart diseases	410–414	5	8.4	60	7	10.2	69
Cerebrovascular diseases	430–438	7	14.7	48	22	18.7	118
Pneumonia	480–487	10	8.0	125	6	8.5	71
Bronchitis, emphysema and asthma	490–496	1	2.2	45	2	2.3	88
Pneumoconiosis	500–508	9	/	/	/	/	/
External causes	E800–999	17	9.1	187**	17	16.5	103

* $p < 0.05$ ** $p < 0.01$ *** $p < 0.001$

cally significant ($p < 0.05$). Statistical significance was observed for all malignant neoplasms (SMR=150, $p < 0.001$), liver cancer (SMR = 266, $p < 0.001$), and external causes (SMR = 187, $p < 0.01$). There were 9 deaths from pneumoconiosis. Among non-coal-miners, the overall SMR was 95. Statistical significance was observed only for liver cancer (SMR = 200, $p < 0.001$).

2. Risk ratios for selected causes of death among coal miners

Table 4 shows risk ratios for selected causes of death among coal miners. As shown in Table 4, these risk ratios were adjusted for possible confounding factors such as age, smoking habits, drinking habits, and blood transfusion. Table 5 shows smoking habits and drinking habits among coal miners and non-coal-miners. Significantly high risk ratios were observed for all causes of death (risk ratio = 1.4, $p < 0.01$) and for all malignant neoplasms (risk ratio = 1.5, $p < 0.05$). Risk ratios for selected sites of cancer showed that coal miners had higher risk of stomach cancer, liver cancer and lung cancer than non-coal-miners, but these results were not statistically significant.

Tables 6–8 show risk ratios for all causes of death, all malignant neoplasms, and lung cancer among coal miners according to their length of experience in

Table 4. Risk ratios of coal mining for selected causes of death

Causes of death	ICD	Risk ratios	(95% confidence interval)
All causes		1.4 ^a	(1.1–1.7)**
All malignant neoplasms	140–208	1.5 ^a	(1.1–2.1)*
Stomach	151	1.6 ^a	(0.7–3.8)
Colon & rectum	153–154	0.8 ^a	(0.3–2.3)
Liver	155	1.4 ^b	(0.8–2.5)
Lung	162	1.6 ^a	(0.8–3.4)
Heart diseases	393–398, 410–429	1.7 ^a	(0.9–3.2)
Ischemic heart diseases	410–414	1.0 ^a	(0.3–3.3)
Cerebrovascular diseases	430–438	0.5 ^a	(0.2–1.2)
Pneumonia	480–487	1.7 ^a	(0.6–4.9)
External causes	E800–999	1.8 ^c	(0.9–3.7)

* p < 0.05 ** p < 0.01

a: Adjusted for age and smoking habits.

b: Adjusted for age, smoking habits, drinking habits and blood transfusion.

c: Adjusted for age.

Table 5. Cigarette smoking and alcohol drinking among coal miners and non-coal-miners

Smoking & Drinking	Coal miners (%)	Non-coal-miners (%)
Cigarette smoking		
Non-smokers	262 (14.6)	987 (24.5)
Ex-smokers	482 (26.8)	917 (22.8)
Current smokers		
1–19 [¥]	430 (23.9)	603 (15.0)
20+ [¥]	622 (34.6)	1,515 (37.7)
Total	1,796 (100)	4,022 (100)
Alcohol drinking		
Non-drinkers	564 (31.4)	968 (24.1)
Occasional drinkers	354 (19.7)	905 (22.5)
Regular drinkers		
< 27 g/day ^{\$}	109 (6.1)	303 (7.5)
27–53 g/day ^{\$}	351 (19.5)	964 (24.0)
> 53 g/day ^{\$}	418 (23.3)	882 (21.9)
Total	1,796 (100)	4,022 (100)

¥: Number of cigarettes/day

\$: Grams of ethanol/day

Table 6. Risk ratios of coal mining and other risk factors for all causes of death

Factors	Risk ratios	(95% confidence interval)
Age (10 year interval)	2.0	(1.7–2.3)***
Experience in coal mining		
Non-coal-miners	1.0	
< 15 years	1.2	(0.9–1.6)
≥ 15 years	1.5	(1.2–2.0)**
Cigarette smoking		
Non-smokers	1.0	
Ex-smokers	1.4	(0.9–2.0)
Current smokers		
< 20 cigarettes/day	1.7	(1.2–2.4)**
≥ 20 cigarettes/day	1.3	(0.9–1.8)

* $p < 0.05$ ** $p < 0.01$ *** $p < 0.001$

Adjusted for other variables in this table.

Table 7. Risk ratios of coal mining and other risk factors for all malignant neoplasms

Factors	Risk ratios	(95% confidence interval)
Age (10 year interval)	2.2	(1.7–2.9)***
Experience in coal mining		
Non-coal-miners	1.0	
< 15 years	1.3	(0.9–2.0)
≥ 15 years	1.6	(1.1–2.4)*
Cigarette smoking		
Non-smokers	1.0	
Ex-smokers	3.0	(1.5–6.0)**
Current smokers		
< 20 cigarettes/day	3.6	(1.8–7.2)***
≥ 20 cigarettes/day	3.6	(1.8–7.0)***

* $p < 0.05$ ** $p < 0.01$ *** $p < 0.001$

Adjusted for other variables in this table.

coal mining. In these analyses, age, smoking habits and experience in coal mining were included as independent variables. Risk ratios for all causes of death were 1.2 for coal miners with less than 15 years' experience (hereafter short experience) and 1.5 for those with at least 15 years' experience (hereafter long experience) ($p < 0.01$). Risk ratios for all malignant neoplasms also increased with the length of experience in coal mining, at 1.3 for coal miners with short experience and 1.6 for those with long experience ($p < 0.05$). Risk ratios for lung

Table 8. Risk ratios of coal mining and other risk factors for lung cancer

Factors	Risk ratios	(95% confidence interval)
Age (10 year interval)	3.2	(1.6–6.3)***
Experience in coal mining		
Non-coal-miners	1.0	
< 15 years	0.9	(0.3–2.6)
≥ 15 years	2.4	(1.1–5.3)*
Cigarette smoking		
Non-smokers	1.0	
Ex-smokers	5.9	(0.7–46.1)
Current smokers		
< 20 cigarettes/day	4.7	(0.6–39.1)
≥ 20 cigarettes/day	8.5	(1.1–64.7)*

* $p < 0.05$ *** $p < 0.001$

Adjusted for other variables in this table.

cancer were significantly higher among coal miners with long experience (risk ratio = 2.4, $p < 0.05$), but coal miners with short experience had almost the same risk (risk ratio = 0.9) as non-coal-miners.

Coal miners showed significantly higher SMRs for liver cancer and external causes, but risk ratios for these two causes of death revealed no statistical significance when compared with non-coal-miners.

DISCUSSION

There have been many cohort studies on mortality among silicosis patients and workers exposed to dust^{1–12)}. In many of these studies, estimates of risk were generally based on national age-cause-specific mortality rates^{1, 2, 4–6, 8, 12)}. Mortality patterns vary from area to area, however, so using national data as a standard can lead to biased conclusions. Thus, we did not rely solely on SMRs calculated using all-Japan age-cause-specific mortality rates as a standard; to avoid the effects of geographical variations in mortality, we compared mortality for coal miners and non-coal-miners living in the same area and sharing similar environmental factors.

Coal miners had significantly elevated risk for all causes of death, with their risk ratios for all causes of death rising with length of experience in coal mining. Although length of experience in coal mining is only an indirect index of exposure to dust, all 9 deaths from pneumoconiosis were among coal miners with longer experience, suggesting that this factor does reflect exposure to dust. Chen *et al.*¹²⁾ indicated a dose-response relationship between all causes of death and levels of exposure to dust.

Many epidemiological studies have reported increased risks of lung cancer

associated with exposure to silica^{1-11, 14, 15}). In our study, coal miners with long experience had a significantly high risk ratio for lung cancer. However, coal miners with short experience had no excess risk. This result could be due to chance, because the observed period was short and because few deaths from lung cancer were expected among coal miners with short experience. Japanese researchers^{1, 4-6}) have previously reported that pneumoconiosis patients and workers exposed to dust showed between 2.7-fold and 4.1-fold excess mortality from lung cancer, higher figures than in our study. None of these studies took the effect of smoking into account and all included numerous compensated pneumoconiosis patients as subjects. Workers exposed to dust reportedly tend to smoke more than the general population^{2, 7}), and the risk of smoking for lung cancer has been found to be much higher than that of exposure to dust^{7, 9}). These results were consistent with our study. With the decline in the Japanese coal industry from around 1960, coal miners left the mines to look for other work or to live on welfare benefits; all coal mines in the study area had shut down by 1973. Although we had little information on the work histories of the coal miners after leaving the mines, there are very few hazardous jobs involving exposure to carcinogens in the study area. It has been reported that the association between exposure to dust and lung cancer may also be influenced by other factors such as radon daughters and polycyclic aromatic hydrocarbons^{2, 3, 7, 9-11}). Although data on these factors were not available in our study, there are no reports indicating that coal mines in the study area had elevated radon daughter concentrations. British researchers^{16, 17}) have found no increased risk of lung cancer among coal miners. One possible explanation is that the respirable dust in British coal mines contains low levels of free silica^{9, 16}). Japanese coal miners are thus exposed to higher levels of free silica than British miners.

The relationship between exposure to dust and mortality from all malignant neoplasms is controversial^{1-5, 7, 8, 12, 14}). Some studies have found no excess neoplasm-related mortality among silicosis patients and workers exposed to dust^{1, 3, 4, 8, 12}). It may be that high mortality from pulmonary tuberculosis, pneumoconiosis and other respiratory diseases competes with cancer mortality, meaning that patients with severe silicosis could die prematurely from pulmonary tuberculosis, pneumoconiosis and other respiratory diseases before any cancer occurs. On the other hand, Finkelstein *et al.*²) and Zambon *et al.*⁷) have reported that silicosis patients had significant excess mortality from all malignant neoplasms. In our study, coal miners had a significantly high risk ratio for all malignant neoplasms because they had excess risk for stomach cancer, liver cancer and lung cancer, though not at statistically significant levels. Stomach cancer, liver cancer and lung cancer are the three leading causes of cancer death in male Japanese. A dose-response relationship was also found between risk ratios for all malignant neoplasms and the length of experience in coal mining. Ebihara *et al.*^{1, 18}) indicated that pneumoconiosis

patients had immunological abnormality and suggested that this may predispose pneumoconiosis patients to the development of malignancies of various organs. An association between coal mining and stomach cancer has been found in some epidemiological studies^{2, 19}). However, diet is closely related to stomach cancer²⁰), and hepatitis B virus (HBV) and hepatitis C virus (HCV) infections are major causes of liver cancer. One study showed that 86.2% of hepatocellular carcinoma patients were hepatitis B surface antigen positive or hepatitis C virus antibody positive²¹). In our study, risk ratios were calculated without adjusting for these confounding factors; although blood transfusion was adjusted for, HBV and HCV infections were not (risk ratio of blood transfusion for liver cancer = 5.0, $p < 0.001$). Therefore, it is possible that these confounding factors contribute to the increased risks observed for stomach cancer and liver cancer. SMRs for liver cancer were significantly high among both coal miners and non-coal-miners. This reflects a geographical variation in mortality from liver cancer. Mortality from liver cancer in the study area was much higher than that in Japan overall²²). Also, prevalence of HBs antigen positive and HCV antibody positive among blood donors was higher in the study area than in other areas, according to the data from the Japanese Red Cross²³).

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