Radon Exposure and Cancers other than Lung Cancer in Swedish Iron Miners

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Data are presented on the risks of cancers other than lung cancer in a cohort of iron miners from northern Sweden occupationally exposed to elevated levels of the radioactive gas radon. Compared with rates for the four northernmost counties of Sweden, mortality was increased for all cancers other than lung cancer (ratio of observed to expected deaths 1.21, 95% confidence interval 1.03–1.41), stomach cancer (ratio of observed to expected deaths 1.45, 95% confidence interval 1.04–1.98), and rectal cancer (ratio of observed to expected deaths 1.94, 95% confidence interval 1.03–3.31). Despite these overall increases, mortality was not significantly associated with cumulative exposure to radon, either for all cancers other than lung cancer or for any site of cancer other than lung cancer individually. However, the data from this cohort on its own have limited power; and for several sites of cancer the data in this study would be consistent with a radon-related increase. Further study of cancers other than lung cancer in populations exposed to radon is required. — Environ Health Perspect 103(Suppl 2):45–47 (1995)

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Introduction

It is well established that underground miners of several substances, including uranium, tin, iron, and fluorspar, tend to be at increased risk of lung cancer due to exposure to the radioactive gas radon (^{222}Rn) and its short-lived progeny (*1*). Relatively little attention has been given to the possibility that exposure to radon and radon progeny may cause other cancers. However, a detailed investigation of radon exposure and cancers other than lung cancer has recently been carried out in a cohort of West Bohemian uranium miners (*2*). That study found that the number of deaths from cancers other than lung cancer was 11% higher than the number expected from age- and calendar-year-specific Czechoslovak national rates (95% confidence interval: –2%, 24%), but that mortality did not increase with cumulative exposure to radon. Among the individual sites of cancer, significantly increased risks were observed for liver cancer and cancer of the gallbladder and extrahepatic bile ducts when compared with national mortality rates. For liver cancer, mortality was not related to cumulative radon exposure; but for cancer of the gallbladder and extrahepatic bile ducts mortality increased with increasing cumulative radon exposure. Mortality from multiple myeloma, which was not increased overall, also increased with increasing cumulative exposure to radon in the West Bohemian cohort.

To investigate further the possibility of a relationship between radon exposure and cancers other than lung cancer we present data from cancers other than lung cancer in a cohort of iron miners from northern Sweden, who were previously shown to have a radon-related excess of lung cancer (*3*). The major source of exposure to radon and its progeny in these mines came from radon gas dissolved in water seeping from underground springs, and the men received exposures close to currently accepted occupational limits.

Methods

Lung cancer mortality up to 1976 has previously been studied in miners who worked at iron mines owned by the Luossovaara-Kiirunavaara Aktiebolaget (including the Koskullskulle mine) in the Malmberget area of northern Sweden (*3*). The follow-up of these men has now been extended to 1 January 1990. Further details will be given elsewhere (EP Radford et al., in preparation). The entire cohort includes 1415 miners who were born between 1880 and 1919, who were alive in 1930, and who worked underground in more than one calendar year between 1897 and 1976; but the present article includes only the 1294 miners who were alive on 1 January 1951. These men worked underground for an average of 18.7 years.

Each man was entered into the analysis when he started work at the mine or on 1 January 1951, whichever was later, and was removed from the analysis on the earliest of date of death, emigration from Sweden, reaching age 85, or 1 January 1990. A total of 10 deaths from cancers other than lung cancer were known to have occurred in men aged 85 or more, and these were attributed to cancers of the stomach, colon, liver, pancreas, prostate (three deaths), non-Hodgkin's lymphoma, chronic myeloid leukemia, and metastatic cancer. The numbers of deaths expected were estimated from mortality rates for the four northernmost counties of Sweden in single calendar years. For the years 1969 to 1989 these were available directly, but for earlier years they were estimated from Swedish national rates by comparison of the rates in the four northernmost counties with those of Sweden as a whole for the years 1969 to 1973. Confidence intervals and two-sided significance tests of the departure of the ratios of observed to expected deaths from unity were calculated by assuming that the number of deaths observed was drawn from a Poisson distribution with mean equal to the expected number of deaths.

For each man, an estimate of his exposure to radon gas and its progeny received in each year of his employment in the

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mines was made by considering calendar-year-specific estimates of the concentration of radon daughters by mine (Koskullskulle versus others) (*3*). The men's average exposure on leaving the mine was 89 working-level months (WLM).* Tests for a trend in mortality with exposure were carried out by classifying observed and expected deaths according to cumulative exposure to radon progeny into four groups (< 50, 50–99, 100–199, and 200+ WLM). Cumulative exposure was calculated as a time-dependent quantity with a lag of 5 years (cancers other than leukemia) or 0 years (leukemia). To allow for any healthy worker effect in the period shortly after commencement of employment (*4*) deaths and person years less than 10 years after starting work were excluded. Tests for a trend in mortality with cumulative exposure were based on the model $E(\alpha+\beta d)$, where E is the number of deaths expected, d indexes the exposure groups and took values 25, 75, 150, and 225 WLM, α is a parameter that allows for differences in the baseline cancer rate between the cohort and the general population, and β is the excess relative risk per WLM. Two-sided significance levels were based on the score statistic.

Results

A total of 162 deaths from cancers other than lung cancer were observed in men aged under 85, compared with 134.03 expected from rates for northern Sweden. This 21% excess was statistically significant (O/E = 1.21; 95% confidence interval: 1.03–1.41; Table 1). Among the individual sites of cancer there were significant excesses for cancer of the stomach (O/E = 1.45; 95% CI: 1.04–1.98) and rectum (O/E = 1.94; 95% CI: 1.03–3.31).

When mortality from all cancers other than lung cancer was examined in relation to cumulative radon exposure, the ratios of observed to expected deaths were higher in men with exposures of 100 to 199 WLM and 200+ WLM than in men with lower cumulative exposures (Table 2), but the trend was not significant ($p = 0.26$). O/E ratios by cumulative radon exposure are also given in Table 2 for cancers of the stomach and rectum, the two sites of cancer for which an overall excess was seen in this cohort; for cancer of the gallbladder and extrahepatic bile ducts and multiple myeloma, the two sites for which mortality was significantly related to cumulative radon exposure in the West Bohemian uranium miners; and for leukemia. For stomach cancer, cancer of the gallbladder

Table 1. Observed deaths (O), expected deaths (E), and ratio of observed to expected deaths (O/E) in men aged less than 85, by site of cancer.

Type of cancer (9th revision ICD code)	O	E	O/E	95% CI
Tongue and mouth (141, 143–145)	0	0.58	0.00	0.00–6.36
Salivary gland (142)	0	0.16	0.00	0.00–23.06
Pharynx (146–149)	0	1.22	0.00	0.00–3.02
Esophagus (150)	4	2.95	1.36	0.37–3.47
Stomach (151)	40	27.51	1.45*	1.04–1.98
Intestine (152–153)	9	10.21	0.88	0.40–1.67
Rectum (154)	13	6.71	1.94*	1.03–3.31
Liver primary and unspecified (155)	8	4.14	1.93	0.83–3.81
Gallbladder and extrahepatic bile ducts (156)	3	2.13	1.41	0.29–4.12
Pancreas (157)	7	11.93	0.59	0.24–1.21
Nose (160)	0	0.39	0.00	0.00–9.46
Larynx (161)	0	0.57	0.00	0.00–6.47
Bone (170)	0	0.88	0.00	0.00–4.19
Connective tissue (171)	0	0.49	0.00	0.00–7.53
Malignant melanoma (172)	0	1.31	0.00	0.00–2.82
Other skin (173)	2	0.28	7.14	0.87–25.80
Prostate (185)	29	24.10	1.20	0.81–1.73
Testis (186)	0	0.19	0.00	0.00–19.42
Bladder (188, 189.3 –189.9)	5	5.10	0.98	0.32–2.29
Kidney (189.0–189.2)	6	7.07	0.85	0.31–1.85
Brain and central nervous system (191,192)	7	3.15	2.22	0.89–4.58
Thyroid (193)	0	0.82	0.00	0.00–4.50
Non-Hodgkin's lymphoma (200, 202)	3	3.95	0.76	0.16–2.22
Hodgkin's disease (201)	4	1.48	2.70	0.74–6.92
Multiple myeloma (203)	7	3.64	1.92	0.77–3.96
Leukemia (204 –208)	6	5.69	1.05	0.39–2.30
Other and unspecified sites	9	7.38	1.22	0.56–2.32
All cancers other than lung (140–161, 163–208)	162	134.03	1.21*	1.03–1.41

*, $2p < 0.05$

Table 2. Observed deaths (O), expected deaths (E), and ratio of observed to expected deaths (O/E) for selected sites of cancer by cumulative radon exposure.

Site of cancer		Cumulative radon exposure (WLM)[a] <50	50–99	100–199	200+	Two-sided p-value for trend (direction of trend)[b]
Stomach	O	10	10	16	4	0.27
	E	7.86	7.69	9.81	1.68	(+)
	O/E	1.27	1.30	1.63	2.38	
Rectum	O	6	5	1	1	0.12
	E	2.00	1.89	2.32	0.41	(–)
	O/E	3.00	2.65	0.43	2.44	
Gallbladder	O	1	0	1	1	0.32
and extrahepatic	E	0.63	0.60	0.72	0.17	(+)
bile ducts	O/E	1.59	0.00	1.39	5.88	
Multiple myeloma	O	2	1	3	1	0.46
	E	1.07	1.01	1.26	0.25	(+)
	O/E	1.87	0.99	2.38	4.00	
Leukemia	O	4	1	1	0	0.09
	E	1.65	1.57	1.95	0.40	(–)
	O/E	2.42	0.64	0.51	0.00	
All sites	O	46	43	57	16	0.26[c]
other than lung	E	39.27	37.57	46.57	8.79	(+)
	O/E	1.17	1.14	1.22	1.82	

[a]Deaths 10+ years after start of employment. Cumulative radon exposure calculated with 5-year lag for cancers other than leukemia, and 0 lag for leukemia. [b]+, mortality rate increases with increasing exposure. –, mortality rate decreases with increasing exposure. [c]For none of the cancer sites shown in Table 1 was the trend significant.

* The working level is defined as any combination of radon daughters in one liter of air that will result in the ultimate emission of 1.3×10^5 MeV potential alpha energy. Exposure of a miner to this concentration for 170 hr (or twice this concentration for half as long, and so on) is defined as a WLM.

and extrahepatic bile ducts, and multiple myeloma mortality tended to increase with increasing cumulative exposure, while for rectal cancer and leukemia mortality tended to decrease with increasing exposure. However, for none of these sites was the trend statistically significant. In addition, when the analysis was repeated for all the other individual sites of cancer shown in Table 1 for which there were at least two deaths, in no case was a significant trend observed.

Discussion

The miners in this study were exposed to radon at rates in the range 0.5 to 6.9 WLM per year (average 4.8 per year). Although precise comparison is impossible, the bronchial dose received from exposure to 1 WLM in a mine is about the same as the dose received per year from a home with a radon gas concentration of 225 Bq m^{-3} (*5*). Thus the exposures received by the miners are high by domestic standards.

Although the miners in this study experienced a clear excess of cancers other than lung cancer when considered as a single group, there is no strong evidence that this overall excess was related to cumulative radon exposure. In addition, for leukemia, the site of cancer which has been most closely linked to exposure to X- and γ-rays (*6,7*), the number of deaths observed was close to the number expected from mortality rates for northern Sweden; and mortality tended to decrease slightly with increasing cumulative radon exposure.

For cancers of the stomach and rectum, the two sites for which there were significant increases in the number of deaths observed, mortality was not strongly related to cumulative radon exposure; for cancer of the rectum, mortality tended to decline slightly with increasing cumulative exposure, while for cancer of the stomach, mortality tended to increase slightly. The increase in stomach cancer mortality may be due to the fact that there were a considerable number of Finns in the workforce, and stomach cancer rates for males in Finland generally, and especially northern Finland, are considerably higher than in Sweden (*8*).

For cancer of the gallbladder and extrahepatic bile ducts, and for multiple myeloma, the two sites of cancer for which mortality was significantly related to cumulative radon exposure in the West Bohemian miners, the ratios of observed to expected deaths were greater than unity, but not significantly so (gallbladder and extrahepatic bile ducts: O/E = 1.41, 95% confidence interval 0.29–4.12; multiple myeloma: O/E = 1.92, 95% confidence interval 0.77–3.96). For neither of these diseases was mortality significantly related to cumulative radon exposure, but for both of them mortality tended to increase with increasing exposure and, although based only on one death each, the ratios of observed to expected deaths for those with cumulative exposures of at least 200+ WLM were high (Table 2). Thus, although these data provide no firm evidence linking cancers other than lung cancer with radon exposure, further study of cancers other than lung cancer in radon-exposed populations is needed.

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