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Risks of Developing Cancer Relative to Living near a Municipal Solid Waste Landfill Site in Montreal, Quebec, Canada

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ABSTRACT. In this study, we sought to determine whether men who lived near the Miron Quarry municipal solid waste landfill site in Montreal, Quebec, Canada, were at higher risk for developing cancer than individuals who lived at more remote locations. Subjects were selected from a previously completed population-based, interview, cancer case-control study of men who lived in metropolitan Montreal. Thirteen sites of cancer (n = 2 928 subjects) and a population-based control group (n = 417) were analyzed. We used the exact street address at the time of diagnosis to classify subjects by geographic zones and distance from the site. We used unconditional logistic regression to estimate odds ratios (ORs) and associated 95% confidence intervals (CIs) for each site of cancer, adjusted for key covariates. In the exposure zone nearest to the site, elevated risks were found for cancers of the pancreas (adjusted OR = 1.4 [95% CI = 0.8, 2.6]); liver (OR = 1.8 [95% CI = 0.8, 4.3]); and prostate (OR = 1.5 [95% CI = 1.0, 2.1]). A high risk was also found for pancreatic cancer (OR = 1.7 [95% CI = 0.9, 3.5]) and the non-Hodgkin's lymphomas (OR = 1.5 [95% CI = 0.8, 2.6]) in a subexposure zone approximately downwind from the site. We used distance from the site as another exposure metric, and higher-than-expected risks were found for pancreatic cancer (OR for living within 1.25 km of the site [$OR_{<1.25km}$] = 2.2 [95% CI = 1.0, 4.6]); liver cancer ($OR_{<1.5km}$ = 2.1 [95% CI = 0.8, 5.3]); kidney cancer ($OR_{<2\ km}$ = 1.4 [95% CI = 0.9, 2.3]); and the non-Hodgkin's lymphomas ($OR_{<1km}$ = 2.0 [95% CI = 1.0, 4.0]). Data from this study and from a previous investigation at the same site suggest that men who lived near this landfill site may have been—and may continue to be—at excess risk of cancers of the liver, kidney, pancreas, and non-Hodgkin's lymphomas.

MUNICIPAL SOLID WASTE LANDFILL SITES generate large quantities of methane and other gases,[1-5] including a rich mixture of volatile organic compounds (VOCs), some of which are accepted or suspected human carcinogens.[6,7] In a previous communication,[8] we reported a geographic analysis of the incidence of cancer among persons who lived near the Miron Quarry municipal solid waste landfill site in Montreal, Quebec, Canada. Incidence rates among men were higher than expected in the area surrounding the site for cancers of the stomach, liver, prostate, and lung; among women, rates of stomach cancer and cervix uteri cancer were elevated, and breast-cancer incidence was lower than expected. Limitations of that study included (a) use of geographic areas defined by administrative, rather than exposure, criteria; (b) inability to account for key risk factors; (c)

unavailability of residential histories; and (d) the relatively short period from first exposure (i.e., 1968) to cancer onset (i.e., 1981–1988). In the current study, we explored the same problem; however, we used a previously completed case-control study[9] for which key risk factors were obtained, and classification of exposure by distance from the landfill site was allowed.

Subjects and Method

Background. Details regarding the characteristics of the site were provided in our previous studies.[8,10] In summary, the Miron Quarry municipal solid waste landfill site is located in a densely populated area. In 1968, it opened as a repository for domestic, commercial, and industrial wastes. The site is approximately 750 000 m^2 in area and 50–80 m in depth, and in January 1993 it contained about 36 million tons of domestic, commercial, and industrial wastes. Inasmuch as it remains in operation, it has not been capped. The main health considerations derive from the continuous release of biogas into ambient air and soil. Biogas is a complex chemical mixture of mainly methane and carbon dioxide, but it also contains important quantities of approximately 35 different VOCs, including the accepted human carcinogens benzene, vinyl chloride monomer,[6,7] and some suspected human carcinogens.[8,10] Other emissions include diesel fumes, combustion products from burning biogas, and fine and coarse particulates from these sources.

Cancer case-control study. This multisite, interview-based, cancer case-control study[9] was conducted in the greater metropolitan area of Montreal from 1979 to 1985. We obtained ethical approval to conduct the study from participating hospitals and universities in 1978 and 1979. Originally, we sought to identify occupational risk factors from analyses of lifetime job descriptions obtained through in-depth, face-to-face interviews. The subjects, who were men aged 35–70 y, were diagnosed with cancers at 20 different sites in the body. We limited the present analysis to the following 13 largest case groups: (1) esophagus (topographic code from the International Classification of Diseases, 9th revision [ICD9] 150); (2) stomach (ICD9 151); (3) colon (ICD9 153); (4) rectum (ICD9 154); (5) liver (ICD 9 155); (6) pancreas (ICD9 157); (7) lung (ICD9 162); (8) skin melanoma (ICD9 172); (9) prostate (ICD9 185); (10) bladder (ICD9 188); (11) kidney (ICD9 189); (12) non-Hodgkin's lymphomas (ICD9 200 and 202); and (13) Hodgkin's disease (ICD9 201). All diagnoses were confirmed histologically. Detailed information was obtained from 3 730 respondents or surrogates (response rate = 8.15%), as well as from a noncancer, population-based control group of 533 subjects (response rate = 69.3%). The original case-control study included subjects who resided on the Island of Montreal and in nearby suburbs, but we restricted the present analysis to individuals who lived on the island (i.e., approximately 80% of the study population). Occupational histories, nonoccupational risk factors, and current full street address were obtained during each interview.

Exposure metrics. We used the exact street address at the time of diagnosis to define two indices of proximity to the site. Initially, we converted the street addresses to the 6-character Canadian postal code that typically refers to a "face" of 1 street block. For purposes of comparing results to those in our previous report,[8] we assigned subjects to 4 geographic areas that were proximal and distal to the quarry (hereafter "high," "medium," and "unexposed" exposure zones). In addition, the high-exposure zone was subdivided into 2 overlapping regions (i.e., high-A and high-B) that were approximately downwind and upwind from the site, respectively (prevailing westerly winds blew approximately 60% of the time).

We calculated distances from each residence to the boundary of the site as follows. First, we linked the 6-character postal code to a file that contained the latitude and longitude of the centroid of the postal code area. We expressed latitude and longitude to 4 decimal places. At 45.5° latitude and 73.6° longitude, the distance separating 2 points by 1/10 000 of a degree is approximately 9 m. The maximum distance from each residence to the centroid of the postal code area was about 50 m. Second, we obtained the latitude and longitude of the boundary of the site (circumference = 5.75 km) at 50-m intervals from a computerized mapping system. We then calculated distance from the site to each subject's residence at the time of interview as the minimum distance between the set of coordinates defining the boundary of the site and the location of the centroid of the postal code area. The expression for distance (i.e., in meters) between any two points (a,b), defined by their latitude (lat, in radians) and longitude (long, in radians) follows:[11]

$$\text{Distance (m)} = 6{,}370{,}997 \times \arccos\{[\sin(\text{lat}_a) \times \sin(\text{lat}_b)] + [\cos(\text{lat}_a) \times \cos(\text{lat}_b) \times \cos(\text{long}_a - \text{long}_b)]\}.$$

Statistical methods. For each site of cancer analyzed, the control group included other selected sites of cancer and the population control group.[9] Given the small numbers, we did not use the following sites of cancer as cases, but we included them in the control pool: small intestine, gallbladder, mesothelioma, penis, eye melanoma, and multiple myeloma. Multiplicative logistic regression[12] was carried out for each of the 13 sites of cancer, and we calculated 95% confidence intervals (CIs) assuming that the log odds were distributed normally.

We used categorical variables, with the unexposed zone as a reference, to conduct the analysis by exposure zones. We analyzed distance from the site as a categorical variable and as a continuous linear variable. We used fairly small intervals (i.e., approximately 250 m), so as to show patterns in the data in the analysis of distance as a categorical variable. There were small numbers of subjects in each category; therefore, we regrouped adjacent categories that had similar odds ratios (ORs) and overlapping confidence intervals. This regrouping resulted in a larger number of cases and narrower confidence intervals. For the analyses in which distance was used as a continuous variable, we reported ORs per change in distance of

Table 1.—Distribution of Cases of Cancer and Population Control Subjects, by Proximity to the Miron Quarry Municipal Solid Waste Landfill Site at Montreal, Quebec (1979–1985)

Site of cancer	No.*	Sites excluded from cancer control series†	Cases				Controls‡			
			High zone		< 500 m		High zone		< 500 m	
			No.*	%	No.*	%	No.*	%	No.*	%
Esophagus	87	Stomach	8	9.2	1	1.1	311	13.6	21	0.9
Stomach	202	Esophagus, small intestine	27	13.4	2	1.0	311	13.6	20	0.9
Colon	406	Rectum, small intestine, peritoneum	49	12.1	2	0.5	284	13.6	20	1.0
Rectum	207	Colon, small intestine, peritoneum	32	15.5	2	1.0	203	13.8	14	1.0
Pancreas	101	Liver, gallbladder, peritoneum	17	16.8	2	2.0	319	13.2	21	0.9
Liver and intrahepatic bile ducts	41	Pancreas, gallbladder, peritoneum	9	22.0	0	0.0	315	13.1	23	1.0
Trachea, bronchus, and lung	685	Pleura, peritoneum	80	11.7	6	0.9	197	13.1	11	0.7
Prostate	367	None	60	16.3	3	0.8	220	13.0	17	1.0
Bladder	396	Kidney	49	12.4	5	1.3	264	13.6	18	0.9
Kidney	146	Bladder	17	11.6	1	0.7	287	14.0	18	0.9
Skin melanoma	79	None	7	8.9	2	2.6	338	13.7	22	0.9
Hodgkin's disease	43	Lymphomas, myeloma, sarcomas	4	9.3	0	0.0	315	13.5	22	0.9
Lymphomas	168	Hodgkin's disease, myeloma, sarcomas	28	16.7	2	1.2	315	13.5	22	0.9

*Refers to number of case subjects.
†Lung was excluded as a control site for all sites of cancer.
‡Includes (1) all other cancer sites (except where excluded); (2) subjects with other sites of cancer (i.e., small intestine [n = 20], gallbladder [n = 25], mesothelioma [n = 11], penis [n =10], eye melanoma [n = 14], multiple myeloma [n = 20], testis [n = 15], pleura [n = 8]); and (3) 417 population-based control subjects.

1 km and the p value from the likelihood ratio test in which we compared the model with covariates and the linear exposure term to the one containing only the covariates.

The statistical models included age at time of interview, family income, cumulative cigarette smoking (daily amount × duration), and total alcohol consumption. In addition, in some sites of cancer for which there were excess risks, we included other potential confounding variables, including (depending on the site of cancer) ethnicity, place of birth, consumption of vitamin A, body mass index, history of hepatitis, and an index of the dirtiness of the jobs held. We interpreted this last variable to be representative of our attempt to distinguish "clean" work histories from "dirty" histories (i.e., white-collar histories from blue-collar histories). This procedure was based on an evaluation by our team of chemists and industrial hygienists of the dirtiness of the job corresponding to each 4-digit job category in the Canadian occupational classifications system. Each job was scored from 0 to 6, and we obtained the overall dirtiness score by averaging annual scores across the subject's lifetime of work.

Results

The analysis of each site of cancer included different numbers of subjects, depending on which sites of cancer were included in the site-specific control groups (Table 1). The case series of 13 sites included 2 928 subjects, and there were an additional 417 population control subjects and 183 subjects with other cancers who were also included in the control pool. The numbers of case and control subjects who lived near the site are also shown in Table 1.

The results of the analyses for only those sites of cancer in which suggestions of increased risks were found are shown in Table 2 (detailed tabulations for all sites are available from the authors upon request). The total numbers of cases in the high-A and high-B exposure zones were greater than the number in the high exposure zone, inasmuch as these two subzones overlapped. Adjusted odds ratios did not differ greatly from the unadjusted ones (data not shown). With respect to cancer of the pancreas, elevated ORs were found in the high-exposure zone (OR = 1.4), the high-A exposure subzone (OR = 1.7), and for persons who lived within 1.25 km of the site (OR = 2.2). For cancer of the liver, the ORs exceeded 1.5 in all three proximal exposure zones, and there was a suggestion that risks increased with decreasing distance from the site ($OR_{\text{per 1-km decrease}} = 1.05$), although confidence intervals included unity. The risk of developing cancer of the prostate was greater than unity in all exposure zones, with the highest OR occurring in the high-B exposure subzone (OR = 2.0). Most men with prostate cancer (i.e., cases) lived more than 2 km from the site (i.e., 63 of 78 cases and 26 of 60 cases in the medium- and high-exposure zones, respectively).

Table 2.—Associations for Selected Sites of Cancer, by Geographic Zone and Distance of Subjects' Residences at Time of Diagnosis to the Miron Quarry Municipal Solid Waste Landfill Site at Montreal, Quebec (1979–1985)*

Site of cancer	*Exposure metric*	Categories	No. cases	Adjusted OR*	95% CI
Pancreas	Geographic zone	Unexposed	61	1	
		Low	10	1.2	0.6, 2.5
		Medium	13	0.7	0.4, 1.4
		High	17	1.4	0.8, 2.6
		High-A	12	1.7	0.9, 3.5
		High-B	8	1.2	0.5, 2.6
	Distance (m)	≥ 3 000	77	1	
		1 250–2 999	15	0.9	0.5, 1.5
		< 1 250	9	2.2	1.0, 4.6
		Continuous†		1.00	0.96, 1.04 (p = .866)
Liver and intrahepatic bile ducts	Geographic zone	Unexposed	24	1	
		Low	2	0.7	0.2, 3.1
		Medium	6	0.9	0.4, 2.4
		High	9	1.8	0.8, 4.3
		High-A	5	1.5	0.5, 4.4
		High-B	4	1.5	0.5, 4.8
	Distance (m)	≥ 3 000	28	1	
		1 500–2 999	7	1.3	0.6, 3.2
		< 1 500	6	2.1	0.8, 5.3
		Continuous†		1.05	0.97, 1.13 (p = .219)
Prostate	Geographic zone	Unexposed	202	1	
		Low	27	1.1	0.7, 1.8
		Medium	78	1.6	1.1, 2.2
		High	60	1.5	1.0, 2.1
		High-A	30	1.2	0.7, 1.9
		High-B	38	2.0	1.3, 3.0
	Distance (m)	≥ 3 000	270	1	
		2 000–2 999	47	0.9	0.9, 2.0
		1 250–1 999	33	1.2	0.8, 1.9
		750 – 1 249	9	0.6	0.3, 1.2
		< 750	7	1.5	0.6, 3.6
		Continuous†		1.01	0.99, 1.04 (p = .317)
Kidney	Geographic zone	Unexposed	90	1	
		Low	8	0.7	0.3, 1.6
		Medium	31	1.3	0.8, 2.1
		High	17	0.9	0.5, 1.6
		High-A	11	0.9	0.4, 1.8
		High-B	8	0.8	0.4, 1.7
	Distance (m)	≥2 000	123	1	
		< 2 000	23	1.4	0.9, 2.3
		Continuous†		1.04	1.00, 1.08 (p = .034)
Non-Hodgkin's lymphomas	Geographic zone	Unexposed	98	1	
		Low	16	1.1	0.6, 1.9
		Medium	26	0.8	0.5, 1.4
		High	28	1.2	0.8, 2.0
		High-A	19	1.5	0.8, 2.6
		High-B	12	0.9	0.5, 1.8
	Distance (m)	>1 750	149	1	
		1 000–1 749	8	0.6	0.3, 1.3
		< 1 000	11	2.0	1.0, 4.0
		Continuous†		0.98	0.95, 1.02 (p = .376)

Notes: OR = odds ratio, and CI = confidence interval. The authors assigned subjects to 4 geographic regions that were proximal and distal to the quarry (i.e., high, medium, low, and unexposed exposure zones). The high-exposure zone was subdivided into 2 overlapping regions (i.e., high–A and high–B), both of which were approximately downwind and upwind from the site, respectively. The prevailing westerly winds blew approximately 60% of the time.

*Covariates were age, family income, ethnicity, cigarette smoking, and alcohol consumption. The control group for each index site included other selected cancer sites and population controls (see Table 1).

†Adjusted ORs for the continuous distance variable were based on a logistic model and were expressed per decrease in distance of 1 km. ORs greater than unity indicated that risk increased as distance from the site decreased. The p values originated from likelihood ratio tests, after we added the linear term for distance to the model containing the covariates.

There was no evidence that risks increased as distance from the site decreased. Although no associations between kidney cancer and geographic exposure zones were found, risks increased with decreasing distance from the site ($OR_{per\ 1\text{-}km\ decrease} = 1.01$). Finally, there was a suggestion of increased risks for the non-Hodgkin's lymphomas in the high-A exposure subzone (OR = 1.5), and higher risks were found for subjects who lived within 1 km of the site (OR = 2.0).

Discussion

This population-based study included new, histologically confirmed cases of cancer among men who lived in the greater metropolitan area of Montreal between 1979 and 1985. We used face-to-face interviews and obtained high-quality information about many key risk factors. Rates of response were relatively high, and there was little evidence of response bias in the data set.[9] Adjustments for the most important a priori risk factors made little difference in the results; therefore, it was unlikely that the estimates of risk were distorted by extraneous factors. Although there may be concern that inclusion of other sites of cancer in the control series may have attenuated estimates of risk if exposure was associated with more than 1 site of cancer, analyses in which we used only the population-based control series demonstrated that the results were robust (data not shown).

The main limitations of this study were the absence of complete lifetime residential histories, the relatively short period from first exposure (1968) to cancer onset (1979–1985), and the use of geographic measures of proximity to the site in lieu of defining geographic zones based on measurements of exposure.

Given that the landfill site has been in operation since 1968, and the data covered the period 1979–1985, latency and exposure periods overlapped. Moreover, the maximum period from first exposure was only 17 y, which, for solid tumors, is rather brief,[13] unless the effect of exposure occurs at a late stage in the carcinogenic process. We also lacked residential histories, and these would have been valuable for the development of indices of geographic proximity since 1968. We could have used these histories to determine whether there was migration into or out of the region around the quarry at the approximate times of diagnoses. However, if migration were to lead to biased estimates of risk, it would have had to be differential across sites of cancer, which seems unlikely.

There is little data about exposures to biogas around the site. The geographic zones were designed for our original investigations[8,10] in which only broad geographic areas of residence were available on the administrative databases that we used. The main reasons that we used these geographic zones in this study was (a) an ability to compare the results with those of our previous studies, and (b) in the absence of measured dispersal patterns of biogas, to provide a metric that covered the areas that surrounded the landfill site. Although one might expect different patterns of risk between these two indices, results for cancers of the pancreas, liver, prostate, and non-Hodgkin's lymphomas were relatively consistent. The apparent lack of consistency in the estimates of risk for kidney cancer across the two metrics of exposure was, in part, the result of the geographic distribution of cases in the nonsymmetrical high-exposure zone; 13 of the 23 cases who lived within 2 km of the site were also in the medium-exposure zone. It is very likely that heterogeneity with respect to long-term exposure from dispersal of biogas into the community in these broad geographic zones, as well as by distance from the site, would lead to an attenuation of estimates of risk.

To estimate ambient exposures to biogas in the residential area surrounding the site, we conducted a small pilot study in 1995 in which measurements onsite and within 2 km of the site were taken. This monitoring program was conducted after a major overhaul of the biogas capture system occurred, the result of which was greatly reduced emissions of biogas. Nevertheless, we found that exposure to methane—a marker for biogas—was significantly higher downwind than upwind from the site (study in preparation for publication). The data were insufficient, however, for us to detail the profile of ambient concentrations of biogas around the quarry. Therefore, inasmuch as no direct assessments of exposure to biogas were available, the interpretation of the results from this study could not be made relative to exposure to biogas.

In summary, the results of the analyses suggest possible associations for liver cancer, kidney cancer, pancreatic cancer, and non-Hodgkin's lymphomas, but the statistical evidence is not persuasive. We can compare these results with those of our previous investigation of incidence rates of cancer in the same exposure zones.[8] With respect to stomach cancer, the results of that previous study[8] indicated a weak excess, but this was not evident in the current study. In both studies there was little evidence of an association for lung cancer and for prostate cancer. There is concordance between estimates of risk of liver cancer in the high-exposure zones (relative risk from previous study of 1.5 [95% CI = 1.2, 2.0] versus OR_{High} = 1.8 [95% CI = 0.8, 4.3]). Finally, there was some evidence of associations for non-Hodgkin's lymphomas and kidney cancer only in the present study.

The increased risk of liver cancer in men is intriguing given that vinyl chloride monomer, a recognized liver carcinogen,[6,7] is present in the biogas.[3-5,14,15] It is unlikely that the excess risks may have resulted from other risk factors (e.g., alcohol consumption, hepatitis-B virus) inasmuch as these factors or surrogates were controlled for in the analysis.

Our two cancer investigations are the only ones of their kind that have been conducted around municipal solid waste landfill sites. Given the many sites worldwide,[4,16,17]—many of which are in close proximity to large populations—and their potential toxicity, investigators should conduct additional studies to confirm the findings of these studies.

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