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Lung Cancer and Occupation: A New Zealand Cancer Registry-Based Case–Control Study

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Background *There are many proven and suspected occupational causes of lung cancer, which will become relatively more important over time, as smoking prevalence decreases.*
Methods *We interviewed 457 cases aged 20–75 years notified to the New Zealand Cancer Registry during 2007–2008, and 792 population controls. We collected information on demographic details, potential confounders, and employment history. Associations were estimated using logistic regression adjusted for gender, age, ethnicity, smoking, and socio-economic status.*
Results *Among occupations of a priori interest, elevated odds ratios (ORs) were observed for sawmill, wood panel and related wood-processing plant operators (OR 4.63; 95% CI 1.05–20.29), butchers (OR 8.77, 95% CI 1.06–72.55), rubber and plastics products machine operators (4.27; 1.16–15.66), heavy truck drivers (2.24; 1.19–4.21) and workers in petroleum, coal, chemical and associated product manufacturing (1.80; 1.11–2.90); non-significantly elevated risks were also observed for loggers (4.67; 0.81–27.03), welders and flame-cutters (2.50; 0.86–7.25), pressers (5.74; 0.96–34.42), and electric and electronic equipment assemblers (3.61; 0.96–13.57). Several occupations and industries not of a priori interest also showed increased risks, including nursing associate professionals (5.45; 2.29–12.99), enrolled nurses (7.95; 3.10–20.42), care givers (3.47; 1.40–8.59), plant and machine operators and assemblers (1.61; 1.20–2.16), stationary machine operators and assemblers (1.67; 1.22–2.28), food and related products processing machine operators (1.98; 1.23–3.19), laborers and related elementary service workers (1.45; 1.05–2.00), manufacturing (1.34; 1.02–1.77), car retailing (3.08; 1.36–6.94), and road freight transport (3.02; 1.45–6.27).*
Conclusions *Certain occupations and industries have increased lung cancer risks in New Zealand, including wood workers, metal workers, meat workers, textile workers and drivers.* Am. J. Ind. Med. 54:89–101, 2011. *© 2010 Wiley-Liss, Inc.*

KEY WORDS: lung cancer; occupation; case–control study; wood workers; metal workers; welding; machine operators; food process workers

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INTRODUCTION

Lung cancer is the leading cause of cancer mortality in the world [Parkin et al., 2005]. In New Zealand, it is currently the most frequent cause of cancer death for men and it is projected to be the same for women by 2011 [Ministry of Health NZ, 2002]. Tobacco smoke has been established as the major risk factor for lung cancer since the 1950s, and the increases in tobacco consumption since the First World War have resulted in major increases in lung cancer incidence [Boffetta and Trichopoulos, 2002]. Although tobacco is the major risk factor for lung cancer globally, many other exposures can also increase lung cancer risk, both in smokers and non-smokers. In particular, a number of occupational exposures are known to be associated with this tumor, including asbestos, radon, inorganic arsenic, chromium, nickel, and polycyclic aromatic hydrocarbons [Spitz et al., 2006]. Many professional activities still entail exposure to these substances, and other occupational exposures are suspected lung carcinogens. For example, in New Zealand, an increased risk of lung cancer has been found in several different occupations including meat workers [McLean and Pearce, 2004] and wood workers [Kawachi et al., 1989].

We have conducted a population-based case–control study of lung cancer in New Zealand in order to assess whether previously reported occupational associations persist and to identify other occupations and occupational exposures that may also contribute to lung cancer risk. This study is part of an ongoing series of cancer registry-based case–control studies investigating occupational cancer in New Zealand which has also included studies of non-Hodgkin's lymphoma (NHL), bladder cancer and leukemia [Dryson et al., 2008; 't Mannetje et al., 2008; McLean et al., 2009]. We report here the lung cancer findings by occupation and industry.

METHODS

The general methodology has been described in reports on previous case–control studies in the series [Dryson et al., 2008; 't Mannetje et al., 2008; McLean et al., 2009], and will be described briefly here. Potential participants in the study comprised all incident cases of lung cancer aged 20–75 years from the New Zealand Cancer Registry during 2007 and 2008. After notification of a case by the Cancer Registry, both the treating clinician and general practitioner (GP) of the patient were sent a letter explaining the study and asking for consent to contact the patient. For 573 (35%) of the 1,630 notifications nationwide, both the clinician and the GP did not provide consent to contact the patient. Of the 1,057 remaining cases, 116 were not eligible (e.g., never worked in New Zealand, or lung cancer was not the primary cancer). A further 197 patients were deceased and could not be interviewed. From the 744 remaining cases, 283 (38%) declined to participate and 458 were interviewed. Thus, if the patients known to be ineligible for the study and the deceased patients are excluded, the response rate was approximately 53%.

The controls were recruited from the New Zealand Electoral Roll in two time periods, 2003 and in 2008. The former group of 473 controls had been recruited for the previously published studies of NHL, bladder cancer and leukemia [Dryson et al., 2008; 't Mannetje et al., 2008; McLean et al., 2009], whereas 323 controls were newly recruited for the current study during 2008. Controls were frequency matched for the age distribution of registration for these four cancer types in the New Zealand Cancer Registry. In total, a letter of invitation was sent to 2,000 individuals, of which 122 were returned to sender and thus considered ineligible. Of the remaining 1,878 individuals, contact could not be established for 744 (40%). Their addresses were subsequently compared with the most recent Electoral Rolls. Of the 744 non-responders, 104 did not appear, or appeared with another address, on the new Electoral Roll and were thus considered ineligible. Of the 1,134 for whom contact could be established, 119 were ineligible because of other reasons (e.g., never worked in New Zealand). Of the remaining 1,015 potential controls, 219 (22%) declined to participate, and 796 were interviewed. Thus, if those known to be ineligible for the study are excluded, the response rate in the controls was approximately 48%.

All cases and 364 new controls (46%) were interviewed on the phone, while the other 432 controls were interviewed face-to-face (this was the standard approach in the previous studies for which these controls were initially interviewed). All the interviews were conducted by trained interviewers. The questionnaire included demographic details, a full occupational history and information on potential confounders. Each job held since leaving school was listed, including the start date, the date of termination, the department, the job title, and the name, location and activity of the employer. Then, for each job with a minimum duration of 12 months, more details were asked, including a task description, use of machines and materials, self-reported exposures, workplace ventilation, and use of protective equipment.

Each job was coded according to the 1999 New Zealand Standard Classification of Occupations (NZSCO 1999) [Statistics New Zealand, 2001] (hereafter referred to as the occupational code) and the Australian and New Zealand Standard Industrial Classification (New Zealand use version 1996) [Statistics New Zealand, 2004] (hereafter referred to as the industry code). These two classifications, based on five and seven digits, respectively, increase the specificity of each occupation/industry with the number of digits. For example, NZCSO code 6 covers ''agriculture and fishery workers''; code 61 covers ''market oriented agriculture and fishery workers''; code 611 covers ''market farmers and crop growers.'' The occupational code was based on the full job

and task description, rather than on the occupational title alone, to ensure that the code covered the actual tasks of each job. The industry code was based on the activity of the employer. All coding was done blind to the case–control status of the participants.

Before the data analyses were conducted, two broad lists of a priori high-risk occupations and industries were constructed. The selection was based on the international literature and particularly on previous reviews which have listed occupations and industries known [Steenland et al., 2003] and suspected [Nurminen and Karjalainen, 2001] to entail exposure to lung carcinogens ['t Mannetje and Pearce, 2005]. Unconditional regression (SAS V9.1) was used to estimate the odds ratio (OR) and its 95% confidence interval (95% CI), for ever being employed in a certain occupation/industry, compared to never being employed in that occupation/industry. While ORs were calculated for all occupational codes and all industry codes, only those for the 436 occupations and 391 industries in which 5 or more study subjects had ever worked were presented here. ORs were adjusted for age (5-year age-groups), gender, Māori ethnicity, and smoking status (never, ex, current). The study subjects who reported having stopped smoking less than 2 years before the interview were considered as current smokers. Logistic regression models were also adjusted for socioeconomic status, using the occupational class of the longest held occupation. Occupational class was determined according to the New Zealand Socio-Economic Index (NZSEI), a classification of New Zealand occupations based on average levels of income and education in national census data [Davis et al., 1999]. Internal analyses were also conducted to establish whether the duration of employment in a certain occupation or industry was associated with an increased risk. A categorical variable for the duration of each job (<2, 2–10, and >10 years) was created and a test for trend for duration of employment was performed by fitting this categorical variable as a continuous variable in the model.

Semi-Bayes Adjustment

Because of the large number of occupations and industries being considered, this type of study involves multiple comparisons and therefore carries the risk that some of the statistically significant findings are due to chance. As in previous case–control studies in the series [Dryson et al., 2008; 't Mannetje et al., 2008; McLean et al., 2009], a semi-Bayes (SB) approach was then used to determine which of the findings were the most robust [Greenland and Poole, 1994]. The basic idea of SB adjustment for multiple comparisons is that the observed variation of the estimated ORs around their geometric mean will be larger than the variation of the true (but unknown) ORs. The SB method specifies an a priori value for the variation of the true ORs; this a priori value is then used to adjust the observed ORs [Steenland et al., 2000]. The adjustment consists in shrinking outlying estimates towards the overall mean of the observed estimates. The larger the individual variance of the estimates, the stronger is the shrinkage, that is, the shrinkage is stronger for less reliable estimates based on small numbers. Typical applications in which SB adjustments are a useful addition to traditional methods of adjustment for multiple comparisons include occupational case–control studies, such as the current study, where many relative risks are estimated with few or no a priori beliefs about which associations might be causal [Steenland et al., 2000].

SB estimates were calculated using R (free software for statistical computing and graphics) [R Foundation for Statistical Computing, 2006]. The inputs for SB adjustments were the maximum likelihood estimates of beta (logOR), resulting from the separate multiple logistic regressions for each occupation and industry. The variance of the true logOR was assumed to be 0.25. Assuming a normal distribution of the logORs, this choice implies that the true ORs are within a sevenfold range of each other [Greenland and Poole, 1994].

Occupations and industries were divided into groups according to the number of digits of the associated codes, and the shrinkage was performed within these groups. For those occupations (or industries) which were not considered a priori to be of increased risk for lung cancer, estimates were shrunk towards the mean for all such occupations (or industries). Similarly, for those occupations (or industries) which were considered to be of a priori increased risk for lung cancer, estimates were shrunk towards the mean for all such occupations (or industries).

The findings for all occupations and industries, both before and after SB adjustment, will be made available on web-based tables. Here we report the findings (both before and after SB adjustment) for a priori high-risk occupations and industries and for other occupations and industries that showed statistically significant elevated or decreased risks in the current analyses.

Ethical approval for the study was granted by the Multiregion Ethics Committee (AKL/99/172), and all participants gave informed consent to be interviewed.

RESULTS

The study included 458 interviews with lung cancer cases, and 796 interviews with general population controls. Of these, one case and four controls were excluded due to missing values in key variables, leaving 457 cases and 792 controls available for analysis (Table I). Cases were 50% male and controls were 54% male, with a mean age of 60.9 years in cases and 61.5 years in controls. ''Ever smoking'' was much more frequent among the cases (89%) than among the controls (52%) (OR 7.51, 95% CI 5.41–10.43), with ORs of 14.45 (95% CI 9.10–22.93) for current smokers and 6.62 (95% CI 4.66–9.41) for ex-smokers. Māori

TABLE I. Characteristics of the Study Participants

	Cases		Controls	
	N	%	N	%
Total	457	100.0	792	100.0
Gender				
Men	227	49.7	431	54.4
Women	230	50.3	361	45.6
Age at interview (year)				
20–50	43	9.4	81	10.2
51–60	118	25.8	184	23.2
61–70	284	62.1	424	53.5
≥71	12	2.6	103	13.0
Smoking				
Never	49	10.7	370	46.7
Ex	291	63.7	356	44.9
Current	115	25.2	52	6.6
Missing	2	0.4	14	1.8
Ethnicity				
Maori	79	17.3	22	2.8
Non-Maori	378	82.7	770	97.2
NZSEI				
Class 1 (75–90) highest	7	1.5	33	4.2
Class 2 (60–75)	52	11.4	94	11.9
Class 3 (50–60)	67	14.7	119	15.0
Class 4 (40–50)	114	24.9	164	20.7
Class 5 (30–40)	116	25.4	208	26.3
Class 6 (10–30) lowest	101	22.1	174	22.0

ethnicity was reported by 79 cases (17%) and 22 controls (3%). The occupational class distribution was similar for cases and controls. Logistic regression models were nevertheless adjusted for occupational class in order to be consistent with the previous studies of non-Hodgkin's lymphoma, bladder cancer and leukemia [Dryson et al., 2008; 't Mannetje et al., 2008; McLean et al., 2009].

Tables II and III list the findings for the a priori high-risk occupations and industries, whereas Table IV shows the statistically significant findings for other occupations and industries. Each table shows the findings both before and after SB adjustment, and all analyses are adjusted for the variables specified above. The findings discussed below focus on these high-risk occupations and industries (Tables II and III), but also include relevant findings (Table IV) for other occupations and industries which were not listed as a priori at risk.

Wood Workers

Employment as a wood-processing and papermaking plant operator was associated with an increased risk of lung cancer (OR 3.60, 95% CI 0.96–13.48 (not shown in tables)). An increased risk was also observed for sawmill, wood panel and related wood-processing plant operators. In particular, a statically significant association was found for timber processing machine operators (OR 4.63, 95% CI 1.05–20.29) with a positive relationship between duration of employment and the risk of lung cancer (ORs of 1.11, 4.95, and 14.11 for employment for <2, 2–10, and >10 years, respectively, P-value for linear trend $P = 0.03$ (not shown in tables)). An elevated risk was also observed for loggers (OR 4.67, 95% CI 0.81–27.03) and a statistically significant increased risk was found for men ever employed in the log sawmilling and timber dressing industry (OR 2.85, 95% CI 1.17–6.95 (not shown in tables)). No association with lung cancer was found for carpenters and joiners (OR 1.07, 95% CI 0.61–1.88). Occupations were also classified according to their level of exposure to wood dust using the New Zealand Job Exposure Matrix ['t Mannetje et al., 2004]. Occupations in which at least half of the workers were exposed to average wood dust levels in excess of 0.5 mg/m^3 were associated with a slightly elevated risk of lung cancer when compared with those in which wood dust exposure did not occur (OR 1.44, 95% CI 0.84–2.46).

Metal Workers

A statistically significant increased risk of lung cancer was observed for metal and mineral products processing machine operators (OR 4.10, 95% CI 1.37–12.32). Welders and flame-cutters had an increased risk (OR 2.50, 95% CI 0.86–7.25) without a clear association with the duration of employment, and ever being employed in metal ore mining was also associated with an elevated risk (OR 9.92, 95% CI 0.90–109.83 (not shown in tables)). There was little evidence of an increased risk among other metal workers.

Meat Workers

Statistically significant increased risks of lung cancer were observed for butchers (OR 8.77, 95% CI 1.06–72.55) and for meat and fish processing machine operators (OR 2.17, 95% CI 1.22–3.88). Within the last category, fish processing workers had an elevated risk (OR 7.73, 95% CI 0.98–61.13 (not shown in tables)). A statistically significant association was found between duration of employment as a meat and fish processing machine operator and the risk of lung cancer (ORs of 1.95, 3.18, and 1.69 for employment for <2, 2–10, and >10 years, respectively, $P = 0.02$ (not shown in tables)). Workers involved in seafood processing also presented a statistically significant increased risk of lung cancer (OR 4.45, 95% CI 1.02–19.37).

Textile Workers

An increased risk of lung cancer was found for textile products machine operators (OR 1.55, 95% CI 0.97–2.47

TABLE II. Odds Ratios (OR) and 95% CIs for A Priori High-Risk Occupations

A priori high-risk occupation for lung cancer	Cases/ controls (n)	Not semi-Bayes adjusted		Semi-Bayes adjusted	
		OR	95% CI	OR	95% CI
5151-Fire Fighters	3/5	0.76	0.17–3.45	1.20	0.51–2.83
61122-Grape Grower and/or Wine Maker, Worker	4/2	4.39	0.68–28.51	1.93	0.74–5.05
61311-Logger	4/3	4.67*	0.81–27.03	2.01	0.76–5.28
7112-Carpenters and Joiners	25/50	1.07	0.61–1.88	1.16	0.70–1.91
7124-Painters and Paperhangers	10/16	0.88	0.37–2.11	1.10	0.55–2.18
722-Blacksmiths, Toolmakers and Related Workers	7/8	1.79	0.58–5.50	1.51	0.71–3.21
72312-Motor Mechanic	17/25	1.22	0.59–2.51	1.32	0.73–2.39
733-Printing Trades Workers	9/17	0.87	0.36–2.13	1.06	0.53–2.11
73321-Bookbinder	2/4	0.90	0.14–5.56	1.37	0.56–3.33
7411-Butchers	8/1	8.77**	1.06–72.55	2.00	0.70–5.73
742-Cabinet Makers and Related Workers	7/7	2.11	0.63–7.09	1.59	0.72–3.54
811-Mining and Mineral Processing Plant Operators	6/11	0.98	0.32–3.03	1.16	0.55–2.48
8111-Mining Plant Operators	5/6	1.93	0.44–8.43	1.58	0.70–3.61
81111-Quarry and Mine Worker	5/5	1.97	0.44–8.78	1.66	0.73–3.79
8113-Drillers	1/6	0.25	0.03–2.17	1.08	0.38–3.06
8122-Metal Casters	3/2	1.82	0.24–13.81	1.52	0.63–3.68
81231-Welder and Flame-Cutter	12/7	2.50*	0.86–7.25	1.92	0.90–4.10
813-Glass and Ceramics Kiln and Related Plant Operators	7/9	1.60	0.51–5.03	1.44	0.68–3.04
8131-Glass and Ceramics Kiln Operators	4/7	1.15	0.27–4.89	1.35	0.60–3.05
81312-Clay Product Plant Operator	2/3	1.26	0.13–12.40	1.49	0.61–3.69
8132-Other Glass and Ceramics Workers	3/2	2.85	0.40–20.47	1.66	0.67–4.11
8141-Sawmill, Wood Panel and Related Wood-Processing Plant Operators	8/5	4.63**	1.05–20.29	2.07	0.82–5.23
815-Chemical Processing Plant Operators	8/9	1.43	0.47–4.32	1.37	0.66–2.86
8211-Machine-Tool Operators	8/2	4.44*	0.84–23.63	1.93	0.76–4.93
8212-Cement and Other Minerals Processing Machine Operators	7/3	3.73*	0.87–15.94	1.95	0.80–4.75
8222-Metal Finishers, Platers and Coaters	5/6	0.87	0.25–3.03	1.20	0.54–2.65
82221-Electroplater	2/4	0.63	0.11–3.55	1.24	0.49–3.14
8231-Tyre Production Machine Operators	4/2	2.45	0.36–16.65	1.62	0.67–3.94
8232-Other Rubber and Plastics Products Machine Operators	8/2	6.34**	1.08–37.15	2.05	0.76–5.59
8261-Spinning and Winding Machine Operators	3/3	1.77	0.29–11.00	1.52	0.64–3.61
8262-Weaving and Knitting Machine Operators	7/9	1.47	0.49–4.41	1.46	0.70–3.04
82624-Knitter, Knitting Machinist	2/3	1.63	0.23–11.71	1.56	0.65–3.75
82641-Launderer	9/5	2.29	0.60–8.73	1.77	0.79–3.99
82643-Dry-Cleaner	3/4	1.02	0.19–5.38	1.39	0.59–3.28
82644-Presser	6/2	5.74*	0.96–34.42	2.09	0.76–5.73
82651-Fibre Preparer	2/3	0.75	0.09–6.19	1.36	0.54–3.43
82812-Tanner, Splitter and Dyer	3/2	1.15	0.16–8.26	1.46	0.60–3.52
82922-Electric and Electronic Equipment Assembler	7/5	3.61*	0.96–13.57	2.08	0.87–5.02
83212-Light Truck or Van Driver	5/11	0.55	0.17–1.81	1.02	0.41–2.49
8322-Bus Drivers	5/12	0.46	0.13–1.68	0.96	0.39–2.36
8323-Heavy Truck Drivers	31/26	2.24**	1.19–4.21	1.97	1.13–3.43
83231-Heavy Truck or Tanker Driver	31/26	2.24**	1.19–4.21	2.01	1.15–3.50
8331-Motorised Farm Machinery Operators	5/10	0.72	0.22–2.36	1.09	0.49–2.46
8332-Earthmoving and Related Machinery Operators	9/13	1.01	0.37–2.76	1.22	0.59–2.49
83325-Roading and/or Paving Machine Operator	1/9	0.15	0.01–1.48	1.08	0.32–3.62
84117-Roofer	1/4	0.91	0.09–9.47	1.43	0.57–3.58
911-Building Caretakers and Cleaners	50/50	1.23	0.75–2.00	1.25	0.80–1.93

*$P < 0.1$.
**$P < 0.05$.

TABLE III. Odds Ratios (OR) and 95% CIs for A Priori High-Risk Industries

A priori high-risk industry for lung cancer	Cases/ controls (n)	Not semi-Bayes adjusted		Semi-Bayes adjusted	
		OR	95% CI	OR	95% CI
A01-Agriculture	99/183	1.01	0.73–1.40	1.03	0.75–1.40
C2111-Meat Processing	39/41	1.17	0.68–2.00	1.19	0.74–1.92
C226-Leather and Leather Product Manufacturing	5/7	0.96	0.25–3.70	0.84	0.37–1.91
C24-Printing, Publishing and Recorded Media	21/39	0.92	0.50–1.70	0.99	0.58–1.68
C25-Petroleum, Coal, Chemical and Associated Product Manufacturing	51/52	1.80**	1.11–2.90	1.66*	1.06–2.60
C2551-Rubber Tyre Manufacturing	4/3	1.60	0.30–8.46	1.36	0.58–3.19
C261-Glass and Glass Product Manufacturing	4/11	0.51	0.14–1.83	0.67	0.28–1.61
C264-Non-Metallic Mineral Product Manufacturing not elsewhere classified	3/4	1.67	0.33–8.39	0.96	0.33–2.80
C2711-Basic Iron and Steel Manufacturing	5/5	1.47	0.38–5.75	1.35	0.61–3.00
C272-Basic Non-Ferrous Metal Manufacturing	2/6	0.62	0.11–3.59	0.74	0.31–1.79
C2811-Motor Vehicle Manufacturing	13/16	1.19	0.51–2.74	1.23	0.65–2.32
C2821-Shipbuilding	3/2	2.95	0.44–19.60	1.53	0.58–4.05
C2859-Electrical Equipment Manufacturing not elsewhere classified	8/10	1.30	0.46–3.68	1.29	0.63–2.64
D362-Gas Supply	2/4	0.57	0.07–4.57	0.74	0.30–1.86

*$P < 0.1$.
**$P < 0.05$.

(not shown in tables)). Within this category, textile bleaching, dyeing and cleaning machine operators had a statistically significant increased risk of lung cancer (OR 2.35, 95% CI 1.03–5.39); and within this group, pressers were associated with a high lung cancer risk (OR 5.74, 95% CI 0.96–34.42). A duration–response association was found for textile products machine operators (ORs of 1.23, 1.75 and 3.24 for employment for <2, 2–10, and >10 years, respectively, $P < 0.01$ (not shown in tables)), especially for textile bleaching, dyeing and cleaning machine operators (ORs of 1.69, 2.54, and 4.19 for employment for <2, 2–10, and >10 years, respectively, $P = 0.04$ (not shown in tables)). Tailors and dressmakers (OR 2.24, 95% CI 0.84–6.01 (not shown in tables)) and launderers and dry-cleaners (OR 2.25, 95% CI 0.80–6.37 (not shown in tables)) also had increased risks of lung cancer. An elevated risk was observed for individuals employed in the textile product manufacturing industry (OR 1.89, 95% CI 0.88–4.10 (not shown in tables)), and this increased with duration of employment (ORs of 1.15, 1.30, and 11.15 for employment for <2, 2–10, and >10 years, respectively, $P = 0.02$ (not shown in tables)). Women working in textile product manufacturing had a statistically significant increased risk of lung cancer (OR 4.24, 95% CI 1.03–17.44 (not shown in tables)).

Mining Workers

Overall, there was no evidence of an increased risk of lung cancer for subjects involved in mining. There was also no increased risk associated with being employed as a mining and mineral processing plant operator (OR 0.98, 95% CI 0.32–3.03).

Drivers

Working as a driver or mobile machinery operator for at least 10 years was associated with a statistically significant increased risk of lung cancer (OR 2.55, 95% CI 1.31–4.96 (not shown in tables)). For this job category, the risk increased with duration of employment (ORs of 0.49, 0.85, and 2.55 for employment for <2, 2–10, and >10 years, respectively, $P = 0.08$ (not shown in tables)). The same applied for the subcategory of motor vehicle drivers, who had a statistically significant increased risk when they were employed for at least ten years (OR 2.73, 95% CI 1.22–6.07). In particular, statistically significant risks of lung cancer were observed for heavy truck drivers (OR 2.24, 95% CI 1.19–4.21) and for individuals ever employed in the road transport industry (OR 1.78, 95% CI 1.05–3.03) and especially in the road freight transport industry (OR 3.02, 95% CI 1.45–6.27). A duration–response association was shown for heavy truck drivers (ORs of 1.40, 2.20, and 3.44 for employment for <2, 2–10, and >10 years, respectively, $P < 0.01$ (not shown in tables)) and for subjects employed in road transport (ORs of 0.92, 1.49, and 4.35 for employment for <2, 2–10, and >10 years, respectively, $P < 0.01$ (not shown in tables)) and road freight transport (ORs of 0.97, 3.87, and 6.34 for employment for <2, 2–10, and >10 years, respectively $P < 0.01$ (not shown in tables)). Elevated risks were also found for earthmoving machine operators (OR 5.71, 95% CI 0.87–37.35 (not shown in tables)).

TABLE IV. Odds Ratios (OR) and 95% CIs for Occupations and Industries Not at A Priori High Risk (Excluding the A Priori High-Risk Occupations Listed in Tables II and III)

Not a priori high-risk occupation and industry for lung cancer	Cases/ controls (n)	Not semi-Bayes adjusted		Semi-Bayes adjusted	
		OR	95% CI	OR	95% CI
Occupations-reduced risk					
1-Legislators, Administrators and Managers	102/239	0.64**	0.47–0.87	0.66	0.49–0.89
12-Corporate Managers	101/235	0.65**	0.48–0.89	0.67	0.50–0.90
122-Specialised Managers	88/206	0.62**	0.45–0.85	0.65	0.48–0.88
1221-Production and Operation Managers	15/56	0.50**	0.27–0.95	0.61	0.35–1.04
1222-Finance and Administration Managers	9/40	0.32**	0.15–0.70	0.49	0.26–0.92
12222-Administration Manager	3/30	0.17**	0.05–0.58	0.52	0.23–1.15
2-Professionals	71/247	0.26**	0.18–0.39	0.31	0.21–0.46
21-Physical, Mathematical and Engineering Science Professionals	14/53	0.44**	0.23–0.85	0.55	0.32–0.97
214-Architects, Engineers and Related Professionals	11/36	0.47**	0.22–1.00	0.62	0.34–1.13
23-Teaching Professionals	25/115	0.25**	0.15–0.43	0.34	0.20–0.56
231-Tertiary Teaching Professionals	7/31	0.28**	0.11–0.71	0.51	0.25–1.02
23111-University and Higher Education Lecturer and/or Tutor	7/30	0.29**	0.12–0.72	0.52	0.26–1.05
232-Secondary Teaching Professionals	5/43	0.20**	0.07–0.55	0.46	0.22–0.96
23211-Secondary School Teacher	5/43	0.20**	0.07–0.55	0.47	0.22–0.98
233-Primary and Early Childhood Teaching Professionals	15/64	0.25**	0.13–0.50	0.40	0.22–0.72
2331-Primary Teaching Professionals	10/55	0.24**	0.11–0.52	0.41	0.21–0.77
23311-Primary School Teacher	10/55	0.24**	0.11–0.52	0.42	0.22–0.79
24-Other Professionals	11/67	0.23**	0.11–0.47	0.37	0.20–0.69
241-Business Professionals	9/40	0.29**	0.13–0.65	0.48	0.25–0.92
2411-Accountants	3/24	0.19**	0.05–0.68	0.52	0.23–1.18
24111-Accountant	3/24	0.19**	0.05–0.68	0.55	0.25–1.24
33-Other Associate Professionals	77/169	0.67**	0.48–0.95	0.70	0.50–0.96
4114-Secretaries	14/59	0.47**	0.24–0.90	0.58	0.33–1.02
41141-Secretary	14/59	0.47**	0.24–0.90	0.60	0.34–1.05
412-Numerical Clerks	22/58	0.54**	0.31–0.94	0.63	0.38–1.02
414-Library, Mail and Related Clerks	66/164	0.62**	0.43–0.89	0.66	0.47–0.93
4144-Office Clerks	53/141	0.57**	0.39–0.85	0.61	0.42–0.89
41443-General Clerk	51/131	0.58**	0.39–0.87	0.63	0.44–0.92
4212-Bank Officers	5/32	0.29**	0.11–0.78	0.53	0.26–1.09
42121-Bank Officer	5/32	0.29**	0.11–0.78	0.55	0.27–1.14
51233-Waiter	7/23	0.29**	0.11–0.77	0.55	0.27–1.11
51312-Health Assistant	2/10	0.19**	0.04–1.00	0.67	0.28–1.59
6122-Mixed Livestock Producers	2/27	0.14**	0.03–0.63	0.54	0.22–1.28
61221-Mixed Livestock Farmer, Mixed Livestock Farm Worker	2/27	0.14**	0.03–0.63	0.57	0.24–1.35
Occupations-increased risk					
3118-Draughting Technicians	4/3	8.70**	1.22–61.99	1.48	0.59–3.72
31181-Draughting Technician	4/3	8.70**	1.22–61.99	1.59	0.64–3.93
32-Life Science and Health Associate Professionals	32/32	1.89**	1.05–3.37	1.56	0.94–2.60
323-Nursing Associate Professionals	25/9	5.45**	2.29–12–99	2.58	1.29–5.19
32311-Enrolled Nurse	25/7	7.95**	3.10–20.42	2.99	1.44–6.22
51231-Bartender	15/11	2.98**	1.17–7.61	1.80	0.90–3.60
51316-Care Giver	20/10	3.47**	1.40–8.59	1.99	1.00–3.95
61213-Cattle Farmer, Cattle Farm Worker	7/3	5.56**	1.21–25.51	1.70	0.73–3.97
614-Fishery Workers, Hunters and Trappers	11/8	3.91**	1.24–12.37	1.77	0.82–3.83
7111-Bricklayers and Stonemasons	7/3	5.65**	1.24–25.83	1.60	0.68–3.81
71111-Bricklayer and/or Blocklayer	7/3	5.65**	1.24–25.83	1.71	0.73–4.00
74-Other Craft and Related Trades Workers	29/27	2.12**	1.14–3.93	1.67	0.98–2.85
8-Plant and Machine Operators and Assemblers	204/233	1.61**	1.20–2.16	1.54	1.16–2.04

(*Continued*)

TABLE IV. (*Continued*)

Not a priori high-risk occupation and industry for lung cancer	Cases/ controls (n)	Not semi-Bayes adjusted		Semi-Bayes adjusted	
		OR	95% CI	OR	95% CI
81411-Timber processing Machine operator	8/5	4.63**	1.05–20.29	1.64	0.71–3.79
82-Stationary Machine Operators and Assemblers	148/150	1.67**	1.22–2.28	1.58	1.16–2.13
821-Metal and Mineral Products Processing Machine Operators	15/5	4.10**	1.37–12.32	1.86	0.87–3.99
823-Rubber and Plastics Products Machine Operator	12/4	4.27**	1.16–15.66	1.69	0.75–3.79
82322-Plastics Machine Operator	8/2	6.34**	1.08–37.15	1.59	0.66–3.84
8264-Textile Bleaching, Dyeing and Cleaning Machine Operators	20/13	2.35**	1.03–5.39	1.61	0.84–3.09
827-Food and Related Products Processing Machine Operators	63/46	1.98**	1.23–3.19	1.73	1.12–2.68
8271-Meat and Fish Processing Machine Operators	45/27	2.17**	1.22–3.88	1.75	1.05–2.93
8292-Electrical Machinery Assemblers	14/12	2.84**	1.15–6.97	1.72	0.87–3.42
9-Elementary Occupations (incl. Residuals)	128/146	1.45**	1.05–2.00	1.39	1.02–1.89
91-Laborers and Related Elementary Service Workers	128/146	1.45**	1.05–2.00	1.39	1.02–1.89
915-Laborers	51/54	1.91**	1.19–3.05	1.69	1.10–2.60
91512-Builder's Laborer	20/11	3.15**	1.40–7.11	2.01	1.06–3.82
Industries-reduced risk					
A0123-Sheep-Beef Cattle Farming	7/31	0.30**	0.12–0.79	0.56	0.28–1.14
F46-Machinery and Motor Vehicle Wholesaling	11/37	0.43**	0.21–0.91	0.60	0.33–1.10
F462-Motor Vehicle Wholesaling	1/13	0.09**	0.01–0.73	0.68	0.27–1.70
G511-Supermarket and Grocery Stores	31/81	0.61**	0.37–0.98	0.67	0.44–1.04
K-Finance and Insurance	37/107	0.55**	0.36–0.85	0.60	0.40–0.90
K73-Finance	21/61	0.57**	0.32–0.99	0.66	0.40–1.08
K75-Services to Finance and Insurance	7/43	0.30**	0.13–0.71	0.52	0.27–1.02
K752-Services to Insurance	6/33	0.38**	0.15–0.97	0.62	0.31–1.23
L7842-Accounting Services	7/35	0.41**	0.17–0.98	0.63	0.32–1.23
M-Government Administration and Defense	87/186	0.67**	0.48–0.92	0.69	0.50–0.94
M81-Government Administration	62/136	0.63**	0.43–0.92	0.67	0.47–0.96
M811-Government Administration	57/129	0.61**	0.42–0.90	0.66	0.46–0.95
M8113-Local Government Administration	20/49	0.49**	0.27–0.91	0.61	0.36–1.04
N-Education	56/192	0.37**	0.25–0.55	0.42	0.29–0.61
N84-Education	56/191	0.38**	0.26–0.55	0.43	0.30–0.63
N842-School Education	35/134	0.34**	0.22–0.54	0.42	0.27–0.64
N8421-Primary Education	18/66	0.37**	0.20–0.68	0.50	0.29–0.85
N8422-Secondary Education	16/68	0.39**	0.20–0.73	0.52	0.30–0.91
N843-Post School Education	15/53	0.46**	0.24–0.91	0.60	0.34–1.06
N8431-Higher Education	5/32	0.26**	0.09–0.74	0.55	0.26–1.15
N844-Other Education	1/57	0.03**	0.00–0.21	0.52	0.20–1.34
Industries-increased risk					
A04-Commercial Fishing	12/6	5.60**	1.53–20.44	1.94	0.86–4.40
A041-Marine Fishing	9/3	6.33**	1.18–34.11	1.65	0.69–3.94
C-Manufacturing	255/354	1.34**	1.02–1.77	1.31	1.01–1.70
C2173-Seafood Processing	8/4	4.45**	1.02–19.37	1.67	0.72–3.84
C256-Plastic Product Manufacturing	17/10	3.11**	1.19–8.16	1.82	0.91–3.67
E4243-Tiling and Carpeting Services	8/2	9.53**	1.81–50.06	1.89	0.78–4.57
G531-Motor Vehicle Retailing	18/15	2.60**	1.19–5.70	1.83	0.98–3.40
G5311-Car Retailing	18/13	3.08**	1.36–6.94	2.00	1.06–3.80
I61-Road Transport	38/42	1.78**	1.05–3.03	1.58	0.99–2.54
I611-Road Freight Transport	25/17	3.02**	1.45–6.27	2.07	1.14–3.77
I6623-Port Operators	8/3	4.95**	1.08–22.66	1.68	0.72–3.92
K7422-General Insurance	12/9	2.88**	1.01–8.18	1.71	0.82–3.53
O8612-Psychiatric Hospitals	14/3	8.90**	2.07–38.25	2.08	0.89–4.88

**$P < 0.05$.

Other A Priori High-Risk Occupations

Statistically significant increased risks were found for other rubber and plastics products machine operators (OR 6.34, 95% CI 1.08–37.15) and for individuals employed in the petroleum, coal, chemical and associated product manufacturing industry (OR 1.80, 95% CI 1.11–2.90). Elevated risks were also observed for cement and other minerals processing machine operators (OR 3.73, 95% CI 0.87–15.94), for electric and electronic equipment assemblers (OR 3.61, 95% CI 0.96–13.57) and for machine-tool operators (OR 4.44, 95% CI 0.84–23.63). There was no evidence of an increased risk for the a priori occupations of painters and paperhangers, motor mechanics, printing trade workers, chemical processing plant operators, building caretakers and cleaners and for the a priori industries of motor vehicle manufacturing, agriculture, printing publishing and recorded media.

Semi-Bayes adjustment of the a priori high-risk occupations and industries

Ever being employed in one or more of the a priori high-risk occupations (Table II) was associated with a statistically significant increased risk for lung cancer ($OR_{a\ priori\ occupation}$ 1.94, 95% CI 1.44–2.61) whereas ever being employed in one or more of the a priori high-risk industries (Table III) was associated with only a slight increased risk ($OR_{a\ priori\ industry}$ 1.17, 95% CI 0.89–1.55). This generally resulted in an attenuation of the ORs. Only two of the ORs for the a priori high-risk occupations (8323-Heavy truck drivers, odds $ratio_{Semi\text{-}Bayes}$ (OR_{SB}) 1.97, 95% CI 1.13–3.43 and 83231-Heavy truck or tanker driver OR_{SB} 2.01, 95% CI 1.15–3.50), and one of the ORs for the a priori high-risk industries (C25-petroleum, coal, chemical and associated product manufacturing, OR_{SB} 1.66, 95% CI 1.06–2.60) remained significantly elevated after SB adjustment.

Other occupations and industries

Occupations and industries with an observed increased or decreased risk ($P < 0.05$), but not considered as a priori high risk, are listed in Table IV.

A number of these occupations and industries showed statistically significant decreased risks for lung cancer. The decreased risks remained statistically significant after SB adjustment for legislators, administrators, and managers (OR_{SB} 0.66, 95% CI 0.49–0.89) and the subcategories of corporate managers, specialized managers, finance and administration managers, for professionals (OR_{SB} 0.31, 95% CI 0.21–0.46) and the subcategories of physical, mathematical and engineering science professionals, teaching professionals, secondary teaching professionals, secondary school teachers, primary and early childhood teaching professionals, primary teaching professionals, primary school teachers, other professionals and business professionals, for other associate professionals (OR_{SB} 0.70, 95% CI 0.50–0.96), for library, mail and related clerks (OR_{SB} 0.66, 95% CI 0.47–0.93) and the subcategories of office clerks and general clerks, for the finance and insurance sector (OR_{SB} 0.60, 95% CI 0.40–0.90), for the government administration and defense sector (OR_{SB} 0.69, 95% CI 0.50–0.94) and the subcategories of government administration, and for the education sector (OR_{SB} 0.42, 95% CI 0.29–0.61) and the subcategories of school education, primary education, and secondary education. Statistically significant increased risks also appeared among several occupations and industries which were not mentioned above. The associations persisted after SB adjustment for nursing associate professionals (OR_{SB} 2.58, 95% CI 1.29–5.19), and the subcategory of enrolled nurses, for care givers (OR_{SB} 1.99, 95% CI 1.00–3.95), for plant and machine operators and assemblers (OR_{SB} 1.54, 95% CI 1.16–2.04) and the subcategories of stationary machine operators and assemblers and food and related products processing machine operators, for elementary occupations (OR_{SB} 1.39, 95% CI 1.02–1.89) and the subcategories of laborers and related elementary service workers, laborers, builder's laborers, and for the manufacturing industry (OR_{SB} 1.31, 95% CI 1.01–1.70) and for the car retailing industry (OR_{SB} 2.00, 95% CI 1.06–3.80).

DISCUSSION

This study of 457 incident lung cancer cases diagnosed in New Zealand during 2007 and 2008 and 792 population controls, aimed to identify occupations that entail an elevated risk for lung cancer. After adjustment for age, gender, smoking status, Māori ethnicity and occupational status, the analyses showed that wood workers, metal workers, textile workers, meat workers and drivers had increased risks for lung cancer, and that several other occupations and industries (including nursing associate professionals, laborers) also had an increased risk for lung cancer in the New Zealand population.

Before discussing the detailed study findings, the strengths and limitations of this study should be considered. The use of the New Zealand Cancer Registry and of the Electoral Roll to identify cases and to sample controls presented several advantages. The Cancer Registry covers all primary malignant cancers diagnosed in New Zealand and the Electoral Roll records virtually all New Zealand citizens and permanent residents aged 18 years and older (registration on the Electoral Roll is compulsory). They therefore provide reliable sources for the selection of cases and controls. The low response rate remains one of the most important limitations in this series of studies. However, the Electoral Roll records occupation, thus making it possible to compare the occupations of participating and non-participating controls. In previous studies, although there was little evidence of a systematic response bias, we have

found that participation rates were lower for the lowest occupational class. We therefore adjusted for occupational class in the analyses, as we have done in the current study, but this adjustment has made little difference to the study findings. In addition, we have adjusted for tobacco smoking in the analyses, and this has also made little difference to the study findings.

Although a strength of a study such as this is the efficiency of evaluating potential associations with many occupational categories, it also introduces the problem of multiple comparisons and the possibility that some statistically significant findings may be due to chance. For this reason, we used the SB adjustment method, which helped us to assess which findings were most robust. The validity of these SB adjustments depends on the assumption that the a priori identified occupations have associations that are ''exchangeable'' which may not always be the case, but this is unlikely to have appreciably affected the results. A further limitation of the current study is that the controls were recruited during two time periods, 2003 and 2008, whereas the cases were only recruited during the latter time period. However, the difference in the time periods was only 5 years, and there was little change in New Zealand employment patterns, or unemployment rates, during this time [Ministry of Social Development NZ, 2009]. Finally, we were able to adjust for smoking status, but not smoking duration; however, information on smoking status has previously been found to allow satisfactory control of confounding by smoking [Richiardi et al., 2005].

Wood Workers

Wood dust created by wood processing has been classified as a carcinogen by the International Agency for Research on Cancer [IARC, 1995b], particularly for sinus and nasal cancer. Some studies have also reported that wood dust exposure may be a risk factor for lung cancer [Jahn et al., 1999; Dement et al., 2003; Barcenas et al., 2005]. In New Zealand, increased risks of lung cancer have been previously reported for sawmillers and carpenters in a series of case–control studies [Kawachi et al., 1989]. In the current study, statistically significant elevated risks of lung cancer were observed for sawmill, wood panel and related wood-processing plant operators and especially for timber processing machine operators, but there was no evidence of an increased risk for carpenters and joiners. For timber processing machine operators, the risk of lung cancer went up with the duration of employment. Finally, a slightly increased risk was found among workers with regular exposure to wood dust at levels above 0.5 mg/m^3.

Metal Workers

Increased risks of lung cancer have already been reported for occupations in the metal industry [Morabia et al., 1992; Bruske-Hohlfeld et al., 2000; Matos et al., 2000; Bardin-Mikolajczak et al., 2007; MacArthur et al., 2009; Yenugadhati et al., 2009]. These occupations can entail exposure to asbestos, a well-known lung carcinogen, but also to potentially carcinogenic metal fumes and dust (e.g., arsenic, chromium) [IARC, 1990; Siemiatycki et al., 2004]. In the current study, the risk of lung cancer was increased only for welders and flame cutters. This association has been observed previously in a number of studies [Benhamou et al., 1988; Moulin, 1997; Jockel et al., 1998; Becker, 1999; Richiardi et al., 2004].

Meat Workers

Elevated risks of lung cancer have been reported for butchers and meat workers in several studies [Coggon et al., 1989; Fritschi et al., 2003; McLean and Pearce, 2004; Durusoy et al., 2006]. In New Zealand, slaughtering of sheep and cattle (in the ''freezing industry'') is a major economic activity, and workers are exposed to blood, feces, urine, and other biological exposures ['t Mannetje et al., 2008]. A New Zealand study [McLean et al., 2004] observed an excess risk of lung cancer (RR = 1.79) in a cohort of three meat processing plants. In the current study (which had no overlap of cases with the previous studies), statistically significant increased risk were observed for butchers, for meat and fish processing machine operators and for individuals employed in seafood processing.

Textile Workers

An elevated risk of lung cancer was observed for workers in the textile product manufacturing industry, for textile products machine operators, and particularly for textile bleaching, dyeing and cleaning machine operators and for pressers. Increased risks of lung cancer have already been found for pressers [Travier et al., 2002] and more generally for workers engaged in dry cleaning and laundering [Blair et al., 1979; Duh and Asal, 1984; Ruder et al., 2001; Richiardi et al., 2004]. These occupations entail exposure to organic solvents and textile dyes and some of these substances have been demonstrated to be carcinogenic [IARC, 1995a]. Decreased risks of lung cancer have been reported for cotton and wool textile workers in several studies [Mastrangelo et al., 2002, 2008; Su et al., 2004; Astrakianakis et al., 2007; Kuzmickiene and Stukonis, 2007]. However, the production of some textiles may also involve exposure to asbestos [Dement et al., 1994; Hein et al., 2007; Loomis et al., 2009], a recognized lung carcinogen.

Drivers

In this study, heavy truck drivers and workers employed in road transport and in road freight transport had a

statistically significant increased risk of lung cancer. The International Agency for Research on Cancer has defined diesel and gasoline vehicle exhaust as, respectively, probably and possibly carcinogenic to humans [IARC, 1989]. Several studies have reported elevated risks of lung cancer for motor vehicle drivers [Hayes et al., 1989; Steenland et al., 1990; Morabia et al., 1992; Finkelstein, 1995; Hansen et al., 1998; Menvielle et al., 2003].

Other Occupations and Industries

In the current study, elevated risks of lung cancer were observed for life science and health associate professionals and in particular for nurses. Health care workers have already been reported to be at risk for lung cancer in previous studies [Doebbert et al., 1988; Petralia et al., 1999], and exposure to ionizing radiation is one possible explanation. Employment as a laborer and particularly as a builder's laborer was also associated with an elevated risk in this study. Construction laborers are potentially exposed to asbestos, organic solvents and dust, and they have been shown in previous studies to have an excess risk of lung cancer [Milne et al., 1983; Morabia et al., 1992; Sun et al., 2002]. Several statistically significant decreased risks of lung cancer were also found for occupations held by white-collar workers and the corresponding industries.

CONCLUSIONS

These findings of this study indicate increased lung cancer risks associated with certain occupations and industries in New Zealand, including wood workers, metal workers, meat workers, textile workers, and drivers. Further analyses should be conducted to determine which particular carcinogenic exposures occur for individuals holding these occupations and how the intensity of these exposures affects the risk of lung cancer.

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