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Original Article

Cancer Risks among Welders and Occasional Welders in a National Population-Based Cohort Study: Canadian Census Health and Environmental Cohort

Jill S. MacLeod [1,*], M. Anne Harris [1,2,3], Michael Tjepkema [4], Paul A. Peters [5], Paul A. Demers [1,3,6]

[1] Occupational Cancer Research Centre, Prevention and Cancer Control, Cancer Care Ontario, Toronto, Ontario, Canada
[2] School of Occupational and Public Health, Ryerson University, Toronto, Ontario, Canada
[3] Dalla Lana School of Public Health, University of Toronto, Toronto, Ontario, Canada
[4] Health Analysis Division, Statistics Canada, Ottawa, Ontario, Canada
[5] Departments of Sociology and Economics, University of New Brunswick Fredericton Campus, Fredericton, New Brunswick, Canada
[6] CAREX Canada, Faculty of Health Sciences, Simon Fraser University, Burnaby, British Columbia, Canada

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ABSTRACT

Background: Welders are exposed to many known and suspected carcinogens. An excess lung cancer risk among welders is well established, but whether this is attributable to welding fumes is unclear. Excess risks of other cancers have been suggested, but not established. We investigated welding cancer risks in the population-based Canadian Census Health and Environmental Cohort.
Methods: Among 1.1 million male workers, 12,845 welders were identified using Standard Occupational Classification codes and followed through retrospective linkage of 1991 Canadian Long Form Census and Canadian Cancer Registry (1992–2010) records. Hazard ratios (HRs) were calculated using Cox proportional hazards models based on estimated risks of lung cancer, mesothelioma, and nasal, brain, stomach, kidney, and bladder cancers, and ocular melanoma. Lung cancer histological subtypes and risks by industry group and for occasional welders were examined. Some analyses restricted comparisons to blue-collar workers to minimize effects of potential confounders.
Results: Among welders, elevated risks were observed for lung cancer [HR: 1.16, 95% confidence interval (CI): 1.03–1.31], mesothelioma (HR: 1.78, 95% CI: 1.01–3.18), bladder cancer (HR: 1.40, 95% CI: 1.15–1.70), and kidney cancer (HR: 1.30, 95% CI: 1.01–1.67). When restricted to blue-collar workers, lung cancer and mesothelioma risks were attenuated, while bladder and kidney cancer risks increased.
Conclusion: Excess risks of lung cancer and mesothelioma may be partly attributable to factors including smoking and asbestos. Welding-specific exposures may increase bladder and kidney cancer risks, and particular sources of exposure should be investigated. Studies that are able to disentangle welding effects from smoking and asbestos exposure are needed.

1. Introduction

There are > 3 million workers worldwide whose primary occupation is welding [1], and many more who perform welding as part of their work activities. With > 30 types of welding, welders use a wide variety of different processes under a broad range of conditions, leading to challenges in quantifying exposures and evaluating health outcomes for welders overall. Welding has been classified as possibly carcinogenic to humans [International Agency for Research on Cancer (IARC) Group 2B carcinogen] based on an evaluation of the human, animal, and mechanistic evidence for welding fumes conducted by the IARC [2]. Nearly two decades after the initial IARC evaluation and the publication of numerous studies exploring cancer risks associated with welding and welding fumes, there remain questions regarding the specific sources of excess risk, variations across welding processes, and types of metals and materials involved [1,3,4].

* Corresponding author. Occupational Cancer Research Centre, Prevention and Cancer Control, Cancer Care Ontario, 525 University Avenue, Toronto, Ontario M5G 2L3, Canada.
E-mail address: jill.macleod@occupationalcancer.ca (J.S. MacLeod).

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Excess cancer risk among welders has been reported in several cohort [5–7] and case–control [3,8–11] studies and in meta-analyses [4,12–14]. Contemporary epidemiological evidence points to an increased lung cancer risk, particularly among stainless steel welders [15]. Stainless steel welding fumes contain high levels of nickel and chromium VI compounds, which are established human lung carcinogens. Several studies have corroborated the excess risk among stainless steel welders [13]. However, an increasing body of evidence has also suggested a risk among welders who work with materials other than stainless steel [3,4,12], indicating additional or alternate sources of carcinogenicity. In addition to nickel and chromium exposure, common in stainless steel welding, welders are potentially exposed to hazardous agents including iron and manganese, common in mild steel welding [14], and known carcinogens including aluminum, cadmium, silica, lead, UV radiation, and asbestos [14,16]. A convincing body of evidence has recognized an elevated risk of lung cancer among welders, with the excess estimated at 20–40% [6,12,17]. However, despite some epidemiological evidence and proposed biological plausibility, there were insufficient data for welding fumes as a whole to establish a causal link.

In 2014, an IARC advisory group identified welding and welding fumes as a high priority for re-evaluation [18]. This re-evaluation was recommended in light of newer epidemiological evidence of increased cancer risk broadly among welders, and not only among stainless steel welders [3–6,12,19,20]. This recommendation was also motivated by new evidence from experimental animal and mechanistic studies suggesting lung carcinogenicity of welding fumes [14,21].

The extent to which lung cancer is attributable to the effects of welding fumes, asbestos exposure, and smoking behavior is unclear [22–25]. Differences in risk according to histological subtype could help clarify the roles of smoking, asbestos, and welding fumes as causal factors for lung cancer among welders. Although smoking is an established risk factor for all histological types of lung cancer, the association with smoking is strongest for squamous cell carcinoma and small cell carcinoma [26,27]. By contrast, several studies have suggested that asbestos exposure has most strongly been linked to adenocarcinoma [28–31].

Risks of other cancers among welders may also be increased by exposure to several known or suspected carcinogens including lead, nickel, hexavalent chromium, and cadmium [32–37]. Inorganic lead, a probable carcinogen, has been linked to cancers of the stomach, kidney, brain, and nervous system [38]. Nickel is an established carcinogen for lung and nasal cancer, and excess risk of nasal cancer has been previously documented among welders [39,40]. Occupational cadmium exposure has been causally linked with lung cancer [41], and some studies have suggested associated risks of kidney and bladder cancer [42]. A 2012 IARC review of the carcinogenicity of UV radiation found strong evidence attributing ocular melanoma to welding exposure [43]. Mesothelioma risk among welders has been attributed to asbestos in the working environment as well as the widespread historical use of asbestos in welding products and equipment [5,44], and it has been suggested that much of the excess lung cancer observed among welders might also be attributable to this asbestos exposure [12].

The primary objective of this study was to evaluate associations between welding and the risks of lung cancer and mesothelioma within the largest population-based working cohort in Canada. Secondary objectives included assessing risks of nasal, brain, stomach, kidney, and bladder cancers, ocular melanoma, and lung cancer histological subtypes, and to disentangle the effects of welding-specific exposures from potential confounders. This study was approved by the University of Toronto Health Sciences Research Ethics Board, Toronto, Canada.

2. Materials and methods

2.1. Study population

The present study was based on data from the Canadian Census Health and Environmental Cohort, derived from the linkage of the 1991 Canadian Census 2B (long form) with the Canadian Mortality Database (1991–2011), Canadian Cancer Registry (CCR) (1992–2010), and Tax Summary Files (1984-2011).

The cohort was originally created for the "Canadian Census Mortality Follow-up Study, 1991–2001" [45], from a randomly selected subsample of the 20% sample of Canadian households selected to complete the 1991 Canadian Long Form Census. Deterministic and probabilistic matching methods were used to link Census records to Tax Summary Files data using dates of birth and postal codes. The 2.7 million successfully linked individuals, equivalent to 15% of the Canadian noninstitutional resident population aged $\geq$ 25 years on census day (June 4, 1991), were linked to the Canadian Mortality Database through probabilistic methods [45].

Follow-up of this cohort was subsequently expanded to include cancer morbidity through linkage to the Canadian Cancer Database [46,47] and follow-up for cancer has since been extended to 2010 through linkage to the 1992–2010 CCR. Long Form Census respondents were asked to report their employment in the week prior to census day or their longest held job in the previous year. For the present study, the analytical cohort was restricted to a working cohort of individuals with a valid entry for occupation on the 1991 Long Form Census to minimize the healthy worker effect. The cohort was further restricted to minimize survival bias by excluding individuals older than 74 years on June 4, 1991.

2.2. Cancer assessment

Incident cancers diagnosed from cohort entry until the end of cancer follow-up (December 31, 2010) were classified in the CCR according to the ninth revision of the International Classification of Diseases (ICD-9) [48] and the third revision of the International Classification of Diseases for Oncology (ICD-O-3) [49] topography and histology codes. Both coding systems were used to identify incident cancer cases to account for provincial differences in cancer registration.

Cancers of primary interest were lung cancer and mesothelioma. Secondary sites of interest included nasal, brain, stomach, kidney and bladder cancer, and ocular melanoma. Histological subtypes of interest including adenocarcinoma, large and small cell and squamous cell lung cancer were also examined [50] (Appendix I).

2.3. Analysis

Information for each individual's age, sex, province of residency, highest level of education, and occupation and industry at baseline were obtained from the 1991 Census.

In this study, welders were those with Standard Occupational Classification 1991 (SOC-91) code J195 for welders and soldering machine operators [51]. Since welding is a common task in other jobs, individuals employed in occupations that were considered as potentially or occasionally involving welding were classified as occasional welders [9,52]. SOC-91 codes for occupational groups classified as occasional welders are presented in Appendix II. Welders and occasional welders were also stratified by industry groups in which welding processes are commonly used. Industry was coded according to the Standard Industrial Classification 1980 [53]. Industry groups in which welding exposure is common were adapted from Kendzia et al [9] and included construction, manufacture of machines and related equipment, manufacture of transport vehicles, shipbuilding and repair, repair of transport equipment, and other welding industries (Appendix III). The comparison group in statistical analyses was employed nonwelders, that is, individuals who were not primarily employed as welders and not employed in occupations involving occasional welding based on occupation reported in the 1991 Long Form Census.

Several comparisons were restricted to blue-collar workers only. Blue-collar workers were workers who were not reportedly involved in primary or occasional welding activities and who were employed in trades, transport and equipment operators and related occupations (SOC-91 Major Group H), occupations unique to primary industry (Group I), and occupations unique to processing, manufacturing and utilities (Group J) [53].

Hazard ratios (HR) and 95% confidence intervals (CI) for employment as a welder or occasional welder at baseline were estimated with Cox proportional hazards disease-free survival analysis. The reference group for these analyses were nonwelders according to occupations reported in the 1991 Long Form Census. Several analyses were also restricted to blue-collar workers to minimize potential confounding associated with socioeconomic differences.

Person–time at risk was counted for each cancer type from cohort entry on June 4, 1991 to date of disease diagnosis, date of death, date of loss to follow-up or end of follow-up on December 31, 2010, whichever occurred first. For analyses of any cancer, the first incident primary cancer of any type was considered, excluding nonmelanoma skin cancers.

HRs were adjusted for age group (25–34 years, 35–44 years, 45–54 years, and 55–74 years), province of residence and education (no high school diploma, high school with/without trade certificate, postsecondary nonuniversity diploma, or university degree). For analyses in which the reference group was restricted to blue-collar workers, HRs were adjusted for age group and region. We also explored risks of welding or occasional welding in various industries where welding is potentially common. Analyses were performed with SAS version 9.2 (SAS Institute, Cary, NC, CA).

In accordance with Statistics Canada disclosure guidelines, no counts < 5 or corresponding model outputs are reported. Although Statistics Canada allows for precise use of true data to generate risk estimates, they require that descriptive statistics for person–years and counts be randomly rounded to Base 5 for reporting. Results were also suppressed where counts < 5 would be identified due to additivity across subgroups.

3. Results

3.1. Study population

The working cohort included 2,051,315 individuals (54% male) aged 25–74 years at entry on June 4, 1991 (Fig. 1). In the cohort, 12,845 men (97.2%) and 370 women (2.8%) were classified as welders based on their occupation as indicated in the 1991 Long Form Census. Male welders contributed a total of 228,270 person–years and female welders contributed 6,760 person–years from cohort entry in 1991 to death, emigration, loss to follow-up, or 2010 end of cancer follow-up, whichever occurred first. Over this period, male and female welders contributed, on average, 17.8 years and 18.3 years of follow-up, respectively. Due to the small number of female welders, only results for male welders are reported unless otherwise specified.

Table 1 presents the distributions of male welders and all male workers by age group, province, and education level. Welders were most commonly employed in the manufacture of machines, equipment, and appliances (22.3%), construction (16.4%) and transport vehicle repair (13.0%). At baseline, welders were younger compared to the working cohort (40.6 years vs. 41.7 years). Highest level of education attained was lower among welders versus the entire working cohort; most welders completed high school with

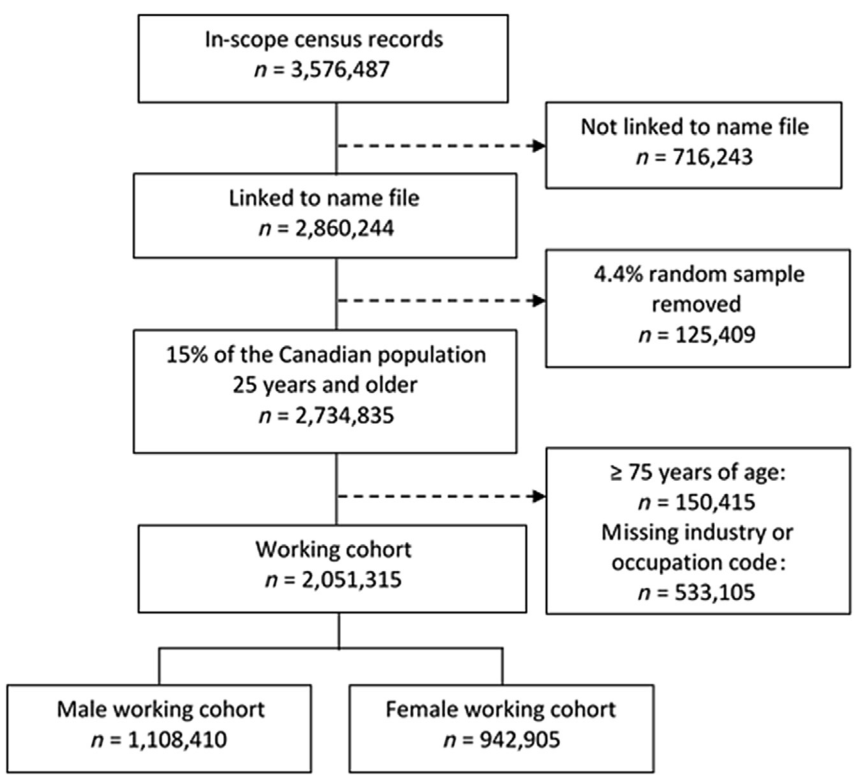

Fig. 1. Derivation of the working cohort in the Canadian Census Health and Environmental Cohort.

Table 1
Baseline characteristics of male welders and workers in the Canadian Census Health and Environmental Cohort, 1991

	Welders $n = 12{,}845$	All Workers $n = 1{,}108{,}410$
Industry group		
Construction	2,110 (16.4)	
Manufacture of machines, equipment, appliances	2,860 (22.3)	
Manufacture of transport vehicles	575 (4.5)	
Repair of transport vehicles	1,670 (13.0)	
Ship building & repair	365 (2.8)	
Other welding industries	3,980 (31.0)	
Other industries	1,285 (10.0)	
Mean age (y) (SD)	40.6 (10.4)	41.7 (11.3)
Age group (y)		
25−34	4,340 (33.8)	359,075 (32.4)
35−44	4,240 (33.0)	341,515 (30.8)
45−54	2,735 (21.3)	229,460 (20.7)
55−64	1,375 (10.7)	143,895 (13.0)
65−74	155 (1.2)	34,465 (3.1)
Province		
Newfoundland	205 (1.6)	21,815 (2.0)
Prince Edward Island	40 (0.3)	4,945 (0.4)
Nova Scotia	360 (2.8)	34,750 (3.1)
New Brunswick	400 (3.1)	27,600 (2.5)
Quebec	3,340 (26.0)	276,120 (24.9)
Ontario	4,725 (36.8)	404,130 (36.5)
Manitoba	515 (4.0)	47,375 (4.3)
Saskatchewan	385 (3.0)	42,050 (3.8)
Alberta	1,465 (11.4)	107,405 (9.7)
British Columbia	1,320 (10.3)	130,815 (11.8)
Yukon	40 (0.3)	2,465 (0.2)
Northwest Territory	50 (0.4)	6,330 (0.6)
Nunavut	0 (0.0)	2,600 (0.2)
Education		
No high school	3,560 (27.7)	322,190 (29.1)
High school with/without trade certificate	8,285 (64.5)	444,560 (40.1)
Postsecondary nonuniversity	925 (7.2)	154,165 (13.9)
University degree	75 (0.6)	187,495 (16.9)
Person−y of follow-up	228,270	19,635,045
Mean person−y of follow-up	17.8	17.7

Data are presented as *n* (%).
SD, standard deviation.

or without trade certification. An additional 87,460 male workers were employed in jobs involving occasional welding. These workers were most commonly employed in the repair of transport vehicles (32.2%) and construction (19.6%).

3.2. Cancer risks among welders

Of the 12,845 male welders, 1,385 (10.8%) were diagnosed with one or more incident primary cancers, excluding nonmelanoma skin cancers, between 1991 and 2010 (Table 2). Among the 370 female welders, 25 were diagnosed with at least one cancer during follow-up. Of these, five female welders were diagnosed with breast cancer, but no association with occupation was observed (HR: 0.68, 95% CI: 0.32−1.43). The number of female cancer cases for other cancer sites was too small for further analysis and female welders were excluded from subsequent analyses.

Among men, employment at baseline as a welder was associated with a 16% increased risk of lung cancer and 78% increased risk of mesothelioma (Table 2). Among the secondary cancer sites of interest, welders had a 40% greater risk of bladder cancer and a 30% greater risk of kidney cancer compared with nonwelders. Risks for stomach and brain cancer and ocular melanoma appeared elevated, but these estimates did not reach statistical significance. Too few nasal cancer cases were observed for analysis among welders.

Among workers in the transport vehicle repair industry, welders had a 40% greater risk of lung cancer than nonwelders (Table 3). Lung cancer risk was nonsignificantly elevated among welders employed in shipbuilding and repair. Risk of mesothelioma among welders in construction was 2.5 times greater compared with nonwelders. Bladder cancer risk appeared elevated for all industry groups. Welders employed in manufacturing of machines, equipment and appliances, had an almost twofold risk compared to nonwelders. Kidney cancer risk similarly appeared elevated for all industry groups for welders except for transport vehicle manufacturing where too few cases were detected for analysis. The highest risk was observed for welders in the shipbuilding and repair industry, representing a 3.5-fold increased risk when compared to nonwelders.

3.3. Cancer risks among occasional welders

Of the 87,460 male occasional welders, ~8,925 (10.2%) were diagnosed with at least one incident primary cancer during the follow-up period (Table 2). Compared to nonwelders, occasional welders were at lower risk of cancer than primary welders. Consistent with the risks observed among welders, occasional welders were 12% more likely than nonwelders to be diagnosed with lung cancer, and the risk of mesothelioma was elevated by 74%. Unlike primary welders, no excess risks of bladder or kidney cancers were detected among occasional welders. Analysis by industry group revealed risks consistent with primary welders (results not shown).

3.4. Cancer risks among welders and occasional welders versus other blue-collar workers

When the comparison was restricted to blue-collar workers, most risk estimates for welders and occasional welders were attenuated (Table 2). Relative to other blue-collar workers, welders had no excess risk of lung cancer and the risk of mesothelioma remained elevated, but not significantly. The risk of ocular melanoma was increased for welders compared to other blue-collar workers, but the risk estimate did not reach significance. For bladder and kidney cancer, however, risks were further elevated for welders compared to other blue-collar workers. The risk of mesothelioma observed among occasional welders remained significant in this blue-collar analysis, but the risk estimate was similarly attenuated.

3.5. Lung cancer risks by histological subtype

When examined by histological subtype of lung cancer, welders were 1.5 times more likely to be diagnosed with small cell lung cancer compared with nonwelders (Table 4). This risk was elevated to a lesser extent for occasional welders, but remained significant. Risk of squamous cell lung cancer was > 30% higher for occasional welders compared with nonwelders. A 20% increased risk of squamous cell lung cancer was observed for welders, but this association was not significant. The association with adenocarcinoma was weaker, while no association was observed with large cell lung cancers. When the comparison group was restricted to blue-collar workers, risk estimates were attenuated for all histological subtypes. Only the risk of squamous cell lung cancers among occasional welders remained significantly elevated.

4. Discussion

This study confirmed the established excess risks of lung cancer [4,5,7,9,12,52] and mesothelioma [7,25,54] among welders. The 16% excess risk of lung cancer observed among welders in this study is lower than previously reported; a large meta-analysis of 60 studies

Table 2
Cancer risks among male welders and occasional welders in the Canadian Census Health and Environmental Cohort, 1992–2010

	Welders			Occasional welders		
	$n = 12,845$			$n = 87,460$		
	Cases	HR (95% CI)†	HR (95% CI)‡	Cases	HR (95% CI)†	HR (95% CI)‡
Any cancer*	1,385	1.04 (0.99–1.10)	1.04 (0.98–1.09)	8,925	0.99 (0.97–1.01)	0.99 (0.97–1.01)
Lung	265	1.16 (1.03–1.31)	1.06 (0.94–1.20)	1,625	1.12 (1.07–1.18)	1.02 (0.96–1.07)
Mesothelioma	15	1.78 (1.01–3.18)	1.54 (0.86–2.78)	65	1.74 (1.34–2.26)	1.48 (1.13–1.96)
Stomach	45	1.25 (0.93–1.67)	1.12 (0.83–1.50)	230	0.91 (0.80–1.05)	*0.82* (0.72–0.95)
Bladder	100	1.40 (1.15–1.70)	1.47 (1.21–1.79)	515	0.99 (0.90–1.08)	1.03 (0.94–1.13)
Kidney	60	1.30 (1.01–1.67)	1.34 (1.04–1.73)	315	0.96 (0.85–1.08)	0.99 (0.87–1.12)
Brain	35	1.16 (0.83–1.63)	1.17 (0.83–1.65)	190	1.08 (0.93–1.26)	1.09 (0.93–1.27)
Nasal	< 5	–	–	25	1.25 (0.82–1.92)	1.15 (0.73–1.82)
Ocular melanoma	5	1.55 (0.64–3.76)	1.66 (0.68–4.09)	20	0.89 (0.57–1.38)	0.91 (0.56–1.47)

* Excludes nonmelanoma skin cancers.
† HR adjusted for age group, region, and education level; Reference Group: nonwelders (neither primarily or occasionally employed in welding).
‡ HR adjusted for age group and region; Reference Group: nonwelders (neither primarily or occasionally employed in welding) in blue-collar jobs only (occupations in SOC-91 major Groups H–J).
CI, confidence interval; HR, hazard ratio.

Table 3
Risk of cancers among male welders, by cancer site and industry group in the Canadian Census Health and Environmental Cohort, 1992–2010

	Welders (n = 12,845)		
	Cases	HR (95% CI)*	HR (95% CI)†
Lung			
Manufacture of machines, equipment, appliances	60	1.21 (0.93–1.56)	1.13 (0.87-1.46)
Construction	45	1.27 (0.96–1.67)	1.12 (0.84–1.48)
Repair of transport vehicles	35	1.41 (1.03–1.94)	1.28 (0.93–1.76)
Manufacture of transport vehicles	10	1.11 (0.58–2.14)	1.02 (0.53–1.96)
Ship building & repair	10	1.65 (0.91–2.98)	1.45 (0.80–2.63)
Other welding industries	70	0.99 (0.79–1.25)	0.92 (0.73–1.15)
Mesothelioma			
Manufacture of machines, equipment, appliances	< 5	–	–
Construction	5	2.54 (1.01–6.34)	2.28 (0.89–5.82)
Repair of transport vehicles	< 5	–	–
Manufacture of transport vehicles	< 5	–	–
Ship building & repair	< 5	–	–
Other welding industries	< 5	–	–
Bladder			
Manufacture of machines, equipment, appliances	25	1.85 (1.26–2.72)	1.95 (1.32–2.87)
Construction	20	1.30 (0.80–2.08)	1.37 (0.85–2.20)
Repair of transport vehicles	10	1.25 (0.69–2.25)	1.32 (0.73–2.39)
Manufacture of transport vehicles	5	1.92 (0.80–4.62)	2.00 (0.83–4.82)
Ship building & repair	< 5	–	–
Other welding industries	25	1.29 (0.90–1.86)	1.36 (0.94–1.96)
Kidney			
Manufacture of machines, equipment, appliances	10	1.26 (0.71–2.22)	1.29 (0.73–2.28)
Construction	10	1.33 (0.74–2.41)	1.38 (0.76–2.50)
Repair of transport vehicles	5	1.18 (0.56–2.48)	1.22 (0.58–2.56)
Manufacture of transport vehicles	< 5	–	–
Ship building & repair	5	3.54 (1.47–8.52)	3.68 (1.53–8.87)
Other welding industries	20	1.32 (0.86–2.03)	1.37 (0.89–2.11)

* HR adjusted for age group, region and education level; Reference Group: nonwelders (neither primarily or occasionally employed in welding).
† HR adjusted for age group and region; Reference Group: nonwelders (neither primarily or occasionally employed in welding) in blue-collar jobs only (occupations in SOC-91 major Groups H–J).
CI, confidence interval; HR, hazard ratio.

reported a 26% excess risk [12], and a pooled case–control study Kendzia et al [9] found odds ratios of 1.69 and 1.27 among welders and occasional welders, respectively. This is consistent with the suggestion by Ambroise et al [12] that effect estimates for lung cancer are lower among studies published in North America than in other countries. In our study, welders had a 78% greater risk of mesothelioma than nonwelders, which was similar to the risk observed among Nordic welders reported by Pukkala et al [7] (SIR 1.79, 95% CI 1.44–2.20).

When compared to blue-collar workers only, the excess lung cancer risk was diminished in the present study for both welders and occasional welders. As in this study, Kendzia et al [9] observed a reduction in lung cancer risk when comparisons were restricted to blue-collar workers. This attenuation in risk may support the hypothesis that excess lung cancer risks observed among welders are due to a common exposure to lung carcinogens among blue-collar workers rather than a welding-specific exposure. The risk of mesothelioma similarly became nonsignificant after the comparison was restricted to blue-collar workers. Although not statistically significant, the 1.5-fold risk, suggests a unique excess asbestos exposure among welders compared with other blue-collar workers, particularly historically, through use of asbestos-containing welding protective equipment including aprons or gloves [5], and emphasizes the extent to which asbestos likely contributes to cancer risks for this group.

When explored by lung cancer histological subtypes, the strongest association was observed for small cell and squamous cell cancers. Few studies have explored lung cancer risks among welders by histological subtypes, and findings have been inconsistent [7,9,52,55,56]. Since the strongest association between smoking and lung cancer is for squamous and small cell cancer [27], this finding may indicate that excess risks may be primarily related to smoking or the result of a synergistic effect between smoking and welding [57]. When the analysis was restricted to blue-collar workers, risk estimates were further attenuated, which indicates that some of this excess risk is likely attributable to residual confounding from smoking. Another interpretation, proposed by Vallières et al [52], suggests that welding fumes might operate through a similar mechanism as smoking, which is reflected in the comparable pattern of histological results. Kendzia et al [9] reported a similar conclusion, and suggested that the histological patterns observed in their study, and ours, and the progress in understanding of the development of lung cancer, may support a causal effect of welding fumes.

Table 4
Risk of lung cancer by histological subtype among male welders and occasional welders in the Canadian Census Health and Environmental Cohort, 1992–2010

Histological subtype	Welders ($n = 12{,}845$)			Occasional welders ($n = 87{,}460$)		
	Cases	HR (95% CI)*	HR (95% CI)†	Cases	HR (95% CI)*	HR (95% CI)†
Adenocarcinoma	75	1.12 (0.89–1.41)	1.07 (0.84–1.36)	455	1.07 (0.97–1.18)	1.06 (0.96–1.18)
Large cell	50	1.01 (0.76–1.34)	0.94 (0.70–1.26)	310	1.01 (0.90–1.14)	0.92 (0.81–1.04)
Small cell	45	1.54 (1.15–2.07)	1.31 (0.96–1.79)	220	1.16 (1.01–1.34)	1.02 (0.88–1.18)
Squamous cell	60	1.19 (0.92–1.54)	1.04 (0.80–1.35)	430	1.33 (1.20–1.47)	1.13 (1.02–1.25)

* HR adjusted for age group, region and education level; Reference Group: nonwelders (neither primarily or occasionally employed in welding).
† HR adjusted for age group and region; Reference Group: nonwelders (neither primarily or occasionally employed in welding) in blue-collar jobs only (occupations in SOC-91 major Groups H–J).
CI, confidence interval; HR, hazard ratio.

This study presents evidence that exposures specific to welding may contribute to the 40% increased risk of bladder cancer, since this risk persisted, and slightly increased, when the analyses were restricted to blue-collar workers, which likely accounted for some differences in smoking behavior across occupation groups. Several studies have previously indicated a possible increased risk of bladder cancer among welders [7,58–60], however, evidence has been limited and inconclusive [2,61]. Becker et al [62] reported an excess of bladder cancer among welders in Germany [Standardized Mortality Ratio (SMR): 3.04, 95% CI: 1.14–8.10], but this effect became nonsignificant with extended follow-up (SMR: 2.08, 95% CI: 0.67–4.84) [25]. Simonato et al [5] reported an excess of bladder cancer mortality among welders (SMR: 1.91, 95% CI: 1.07–3.15), although the absence of an association in their study with time since first exposure or duration of employment may point towards a risk factor that is not welding specific. Pukkala et al [7] concluded that some occupational associations with bladder cancer are most probably due to smoking.

Welders in our study were at a 30% increased risk of kidney cancer, which was also observed among Nordic welders by Pukkala et al [7] [Standardized Incidence Ratio (SIR): 1.25, 95% CI: 1.14–1.36]. However, there is no established link between welding fumes and kidney cancer. The excess risk for kidney cancer further increased for welders when the comparison was restricted to blue-collar workers. Occupational risk factors for kidney cancer are not well understood, but exposure to cadmium is known to cause renal disease, and evidence suggests that it may cause cancer even at lower levels of exposure found among environmentally exposed individuals [63]. A recent meta-analysis reported that occupational cadmium exposure was associated with a nearly 1.5-fold increased risk of kidney cancer (pooled OR: 1.47, 95% CI: 1.26–1.72 [64]. Exposure to fumes resulting from the process of welding cadmium-plated metals is a common workplace hazard among welders, and could be a source of the excess risk observed.

The increased risk of ocular melanoma observed among welders in our study was consistent although somewhat lower than previously reported [43].

This study was the largest, population-based cohort study of Canadian welders. A strength of the present study was the large number of observed cases for the more common cancer sites. This study observed 265 incident lung cancers among welders and 1,625 lung cancers among occasional welders, which provided sufficient power to detect associations by individual industry groups of welders and supported analysis by histological subtype. Most previous population surveys of welders captured < 200 lung cancer cases among welders and case–control and cohort studies captured < 100 [12].

This retrospective cohort study had several limitations. Exposure was determined on a one-time self-report of occupation at baseline. Welding exposure was assigned based only on employment at cohort entry, which could introduce error since duration of exposure could vary among workers and some workers classified as unexposed may have been previously or subsequently exposed. Since this misclassification is unlikely to be related to disease risk, effect estimates would be biased towards the null. In their study of Norwegian shipyard workers, Danielsen et al [65] found that accounting for previous employment information did not affect estimates of lung cancer risk among current welders. We do not know how frequently welders in this population left welding for other jobs during follow-up; again introducing possible misclassification to our estimates. We were also unable to examine welding-related risks of nonmelanoma skin cancer. In Canada, nonmelanoma skin cancer is not captured in the CCR because most cases are diagnosed and treated in a variety of settings including dermatologists' offices [66].

Since exposure to welding was based on job title, we were unable to examine particular sources of carcinogenicity based on material and processes used. Through stratifying welders by industry group we aimed to glean additional information regarding distribution of risks among welders. In defining industry groups in which welding exposure is likely, we relied on previous assessments [9] and expert review [PD].

Although the cancer risks observed can generally not be attributed to specific welding exposures, the excess risk of mesothelioma among welders in construction confirms the prevalent exposure to asbestos in that industry [67], where exposure to welders can occur through both handling asbestos-containing building materials and being in an environment where asbestos is used or disturbed. Cadmium-containing or cadmium-plated materials are widely used across industries, but are particularly suitable for use in the automotive and marine industries because of their high durability and resistance to corrosion [68]. Kendzia et al [9] noted that technological improvements in vehicle manufacturing have reduced exposure to welding fumes compared with shipyard welding. This could contribute to the excess kidney cancer risk observed in this study among welders employed in shipbuilding and repair. Welders in vehicle manufacturing may also have lower risks of exposure than those employed in vehicle repair to known carcinogenic exposures including iron-containing steel [6], chromium, nickel [9], and aluminum [69], as a result of improvements in ventilation equipment, use of robotic welders, and standardized processes.

The heterogeneity with respect to welding exposures across and within occupational and industry groups, could contribute to nondifferential misclassification, which may have attenuated observed associations. Welders may be exposed to harmful materials from the parent metal, the filler and its flux, shielding gases, grinding dusts, or substances present in the welding setting. The nature of these exposures and their health impacts are similarly impacted by a wide array of factors including welding position, ventilation and personal protective equipment, current intensity, and heat input [70–72]. This multitude of exposure circumstances poses challenges both for assessing welding-related health risks and for targeting risk prevention and reduction efforts.

We were limited by the lack of smoking data available for this cohort. Since several previous surveys have indicated that welders may smoke more than the general male population [12,13,19,65], smoking could be an important confounder, particularly for lung and oral cancers. It has been suggested that 20–50% of the excess lung cancer risk among welders could be attributable to smoking [4,9,19]. In some studies, risk associations were attenuated [9] or eliminated [15] after smoking adjustments. However, in other studies, both direct and indirect adjustment for tobacco use had little or no effect on risk estimates [3,7,12,62,65]. We attempted to disentangle effects of welding from confounders including smoking through two approaches. Firstly, models included an adjustment for education level, which is strongly correlated with smoking [73]. Secondly, in addition to the base model that compared welders and occasional welders to nonwelders, we also restricted the comparison group to blue-collar workers. When analyses were restricted to blue-collar workers, the elevated risks of lung cancer observed among welders and occasional welders were no longer significant. This finding does provide some support for the theory that elevated lung cancer risks observed among welders are not attributable particularly to welding-specific exposures, but are also common to other blue-collar workers. Without data on smoking, we were not able to determine if this common factor is smoking or some other lung cancer risk factor. While we observed elevated risks for several cancers that are generally considered to be smoking related, some of these (e.g., kidney and bladder cancers) had stronger relationships to welding than did lung cancer, suggesting that confounding by smoking alone could not explain these elevated risk estimates.

Asbestos exposure may be an even more important confounder. Studies examining the potential confounding due to asbestos exposure have been inconsistent, including several studies that found similar excess lung cancer risks among welders with no [19] or minimal [3,74] asbestos exposure, and little effect after adjustment for asbestos exposure [3,8,65]. However, several studies have based asbestos exposure on employment in shipyards [75,76], whereas the meta-analysis by Moulin [4] suggested that shipyard and nonshipyard welders had similar lung cancer risks, and mesothelioma incidence among other welders suggests that all welding activities appear to have risk of asbestos exposure [4,5].

This study found evidence to support the emerging hypothesis that lung cancer risk observed among welders cannot be attributed exclusively or directly to welding fume exposure, but may be largely attributable to nonwelding specific factors including possible occupational coexposures, including asbestos, or smoking. The extent to which these exposures contribute to increased risk among welding-exposed workers remains unclear. Welding risks for bladder and kidney cancer should be further investigated. Distinguishing the sources of risk among welders is important in order to ensure appropriate prevention approaches. Engineering controls of welding amperage, shielding gases, and position relative to smoke plumes can mitigate effects of welding fumes, but fail to protect welders from asbestos.

Conflicts of interest

The authors have no conflicts of interest to declare.

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Appendix I

Lung cancer histological subtypes, ICD-O-3*

Histological subtype	ICD-O-3 code
Adenocarcinoma	8140, 8211, 8230-8231, 8250-8260, 8323, 8480-8490, 8550-8551, 8570-8574, 8576
Large cell lung cancer	8010-8012, 8014-8031, 8035, 8310, 8046
Small cell lung cancer	8041-8045, 8246
Squamous cell lung cancer	8050-8078, 8083-8084

* ICD-O-3, International Classification of Diseases for Oncology, 3rd Edition.

Appendix II

Occasional welders, SOC-91*

SOC-91	Description
H111	Plumbers
H112	Steamfitters pipefitters & sprinkler system installers
H113	Gas fitters
H141	Roofers & shinglers
H312	Tool & die makers
H321	Sheet metal workers
H322	Boilermakers
H323	Structural metal & platework fabricators & fitters
H324	Ironworkers
H411	Construction millwrights & industrial mechanics – except textile
H412	Heavy-duty equipment mechanics
H413	Refrigeration & air conditioning mechanics
H414	Railway carmen—women
H415	Aircraft mechanics & aircraft inspectors
H416	Machine fitters
H417	Textile machinery mechanics & repairers
H418	Elevator constructors & mechanics
H421	Motor vehicle mechanics technicians & mechanical repairers
H422	Motor vehicle body repairers
H431	Oil & solid fuel heating mechanics
H433	Electrical mechanics
H434	Motorcycle & other related mechanics
H435	Other small engine & equipment mechanics
H533	Automotive mechanical installers & servicers
H732	Railway track maintenance workers
J121	Machine operators, mineral & metal processing
J192	Forging machine operators
J194	Metalworking machine operators
J196	Other metal products machine operators
J211	Aircraft assemblers & aircraft assembly inspectors
J212	Motor vehicle assemblers inspectors & testers
J213	Electronics assemblers fabricators inspectors & testers
J214	Assemblers & inspectors electrical appliance apparatus & equipment manufacturing

(*continued*)

SOC-91	Description
J215	Assemblers fabricators & inspectors industrial electrical motors & transformers
J216	Mechanical assemblers & inspectors
J221	Boat assemblers & inspectors
J312	Laborers in metal fabrication

* SOC-91, Standard Occupational Classification (SOC) 1991.

Appendix III

Industry groups in which welding processes are commonly used, SIC-80*

	SIC-80	Description
Construction	F	Construction industry
	H49	Other utility industry
	L751	Operators of buildings & dwellings
	L759-X	Real estate operator industry
	L76	Insurance & real estate agent industry
	M775	Architectural, engineering, other scientific/technical services
	N8	Government services industry
	O85	Educational service industry
	Q91	Accommodation service industry
Machine, equipment, appliances manufacture	E30-1	Fabricated metal products & machinery industry
	E33	Electrical & electronic products industry
Transport vehicle manufacture	E323-4	Motor vehicle, truck, bus body, & trailer industry
Ship building & repair	E327-8	Shipbuilding & boatbuilding & repair industry
	G454-5	Water transport industry & incidental services
Transport equipment repair	E321	Aircraft & aircraft parts industry
	E325-6	Vehicle parts/accessories & railroad rolling stock industry
	E329	Other transportation equipment industry
	G451	Air transport industry
	G453	Railway transport & related service industry
	G456-7	Truck transport &public passenger transit systems industry
	G458-9	Other transportation & incidental services
	G461	Pipeline transport industry
	G471	Grain elevator industry
	G479	Other storage & warehousing industry
	I	Wholesale trade industry
	J635	Motor vehicle repair shops
	J639	Other motor vehicle services
Other industries	A01	Agricultural industry
	D061-3	Metal, nonmetal, & coal mines
	D071	Crude petroleum & natural gas industry
	D08	Quarry & sand pit industry
	D091-2	Service industry incidental to crude petroleum, natural gas, & mining
	E15	Rubber products industry
	E26	Furniture & fixture industry
	E29	Primary metal industry
	E35	Non-metallic mineral products industry
	E37	Chemical & chemical products industry

* SIC-E, Standard Industrial Classification — Establishments.

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