ORIGINAL RESEARCH

Sex-specific risks and trends in lung cancer mortality across occupations and economic activities in Switzerland (1990–2014)

Nicolas Bovio ,[1] David B Richardson,[2] Irina Guseva Canu[1]

► Additional material is published online only. To view please visit the journal online (http://dx.doi.org/10.1136/oemed-2019-106356).

[1]Department of Occupational and Environmental Health, Center for Primary Care and Public Health (unisanté), University of Lausanne, Lausanne, Switzerland
[2]Department of Epidemiology, School of Public Health, University of North Carolina at Chapel Hill, Chapel Hill, North Carolina, USA

Correspondence to
Nicolas Bovio, Department of Occupational and Environmental Health, Center for Primary Care and Public Health (unisanté), University of Lausanne, Lausanne, Switzerland; nicolas.bovio@unisante.ch

Received 9 December 2019
Revised 17 March 2020
Accepted 5 April 2020
Published Online First 5 May 2020

ABSTRACT

Objectives To assess lung cancer mortality across occupations and economic activities/industries in Switzerland using three statistical estimates.

Methods All Swiss residents aged 18–65 during the 1990 or 2000 censuses were followed through 2014 to ascertain information on date and cause of death. For every occupation and economic activity/industry, causal mortality ratios (CMR) and standardised mortality ratios (SMR) were computed using national cause-specific mortality rates. We also calculated relative SMR (rSMR) and conducted analyses stratified by socioeconomic variables, job skill level and calendar periods.

Results The study sample comprised 5 834 618 participants (111 162 348 person-years). SMR and CMR led to similar results, while rSMR were generally higher. We found 18 occupations in men, 10 occupations in women and 3 industries in each sex with an excess of lung cancer mortality. Among men, rubber and plastic products machine operators, and workers in mining and quarrying, and construction industries were at high risk. Among women, motor vehicle drivers and workers in trade, repair of motor vehicles and of domestic articles and manufacture of goods industries showed the highest risks. In both sexes, hotel and restaurant workers presented an excess of lung cancer mortality.

Conclusion Most of the activities and occupations in which we observed excess lung cancer mortality have previously been observed to involve occupational exposure to lung carcinogens. These findings suggest that the number of occupational lung cancer is likely underestimated by the official Swiss statistics. Further research should address this question and the exposure–effect relationships in the most at-risk occupational groups.

Key messages

What is already known about this subject?

- Lung cancer is the most common cause of cancer death worldwide.
- The population attributable fraction of lung cancer due to occupational exposures is estimated at 19.3% in men and 2.6% in women.
- In Switzerland, there are no relevant data on the burden of occupational lung cancer.

What are the new findings?

- The occupational activities at highest risk of lung cancer mortality in Switzerland are construction, mining and quarrying industries, and rubber and plastic products machine operations for men, and trade, repair of motor vehicles, manufacture of goods industries and motor vehicle driving for women.
- Using causal mortality ratios and relative standardised mortality ratios, in addition to standardised mortality ratios, enables more consistent estimates of occupational lung cancer mortality.
- Our estimation of the number of occupation-related lung cancer differs from the official statistics on the lung cancer recognised as occupational disease in Switzerland.

How might this impact on policy or clinical practice in the foreseeable future?

- These findings question the effectiveness of the current Swiss system for reporting and recognising lung cancer cases as occupational disease.
- The occupational groups at high risk of lung cancer mortality, identified in this study, should be targeted for further investigation and tailored prevention.

INTRODUCTION

Lung cancer was the leading cause of cancer in 2016, accounting for 2.0 million incident cases and 1.7 million deaths worldwide.[1] In Switzerland, 12 946 men and 8314 women were diagnosed with lung cancer between 2011 and 2015, representing, respectively, 11.9% and 8.9% of the overall cancer cases. Over the same period, 21.6% of all cancer deaths among men (n=10 017) and 15.7% among women (n=5'872) were from lung cancer.[2] While smoking is a leading cause of lung cancer, the International Agency for Research on Cancer (IARC) recently estimated that the population attributable fraction (PAF) of lung cancers due to occupational exposures was 19.3% in men and 2.6% in women.[3 4] To date, Switzerland has no public reporting on occupational lung cancer incidence.[5] By applying the PAF estimated by IARC to the number of lung cancer which occurred between 2011 and 2015 in Switzerland, about 2500 and 740 lung cancer cases should be considered occupational among men and women, respectively. However, the Swiss National Accident Insurance Fund (Suva) in

To cite: Bovio N, Richardson DB, Guseva Canu I. *Occup Environ Med* 2020;**77**:540–548.

charge of compensation and prevention of occupational injuries and diseases only recognised around 50 occupational lung cancer cases over this period.[6] Such a difference may suggest either a difference in incidence profile from lung cancer among Swiss workers, due, for example, to highly effective preventive measures and exposure control in Swiss workplaces, or a failure in the Swiss system of declaration and recognition of occupational diseases.[7 8]

Since lung cancer is associated with a poor prognosis and has an estimated 5 year relative survival of only 18%, mortality is as relevant as incidence to study lung cancer risk.[9] Therefore, the goal of this study was to estimate the risk of lung cancer across occupations and economic activities/industries in Switzerland using three complementary indicators.

METHODS

Data sources

The data of the Swiss National Cohort (SNC) were used to examine lung cancer rates in the Swiss adult population. The SNC is a national longitudinal research platform of the entire resident population of Switzerland. The records of the 1990 and 2000 Swiss censuses were linked to mortality, life birth and emigration records until 2015, using a combination of deterministic and probabilistic methods.[10] Censuses were mandatory, with population coverage estimated at 98.6%.[11] National mortality rates were obtained from the Swiss Federal Statistical Office (SFSO).

Study sample

All active or former Swiss workers were considered at risk with respect to occupation-related lung cancer. In Switzerland, the minimum legal age of employment is 15 and the age of majority is 18. The statutory retirement age is 65 for men and 64 for women. Since employment start and end dates were unavailable, our study sample included all adults aged 18–65 years registered either in the 1990 or 2000 census.

Coding of occupation and economic activity/industry

Occupations were coded using the International Standard Classification of Occupations, version 1988 (ISCO-88) by the SFSO. Economic activities/industries were coded based on the Statistical Classification of Economic Activities in the European Communities (NACE) in the 1990 census and on the General Classification of Economic Activities -95, in the 2000 census, a Swiss adaptation of the NACE, first revision, which was itself based on the International Standard Classification of Industries (ISCI), third revision. A more detailed description of coding and transcoding of these variables is available elsewhere.[12]

Follow-up and identification of lung cancer deaths

Mortality follow-up started either on 4 December 1990 (for the 1990 census) or on 4 December 2000 (for the 2000 census). We followed all participants aged 18–65 at the beginning of follow-up up to the earliest date of their 85th birthday, emigration, death or end of the study (31 December 2014). As occupation and economic activity/industry are time-dependent variables, we assigned person-years as follows:

- Participants with a single occupation/industry contributed to this occupation/industry for the entire period of their follow-up.
- Participants who changed occupation/industry between 1990 and 2000 census, contributed to the first occupation/industry between 1990 and 2000, and to the second one after 2000.

Depending on the socioprofessional status (SPS), we also distinguished the unemployed/job-seekers from those with unknown occupation and considered the former as an additional occupational category.

Cases were identified as deaths from lung cancer based on the death certificate. Causes of death were recoded using ICD-8 before 1995 and ICD-10 thereafter. Only deaths with initial causes coded 162 and primary causes coded C33-C34 according to the International Classification of Disease 8th and 10th edition, respectively, were selected.

Statistical analysis

To identify occupations or economic activities/industries with lung cancer mortality statistically different from that of the general Swiss population, we computed standardised mortality ratios (SMR) and causal mortality ratios (CMR) in men and women. Both methods have the same interpretation and compare the observed deaths in the occupational cohort with the one expected in the absence of occupational exposure(s). The main difference lies in the way expected deaths are calculated. In SMR, expected deaths are the result of a product of constant hazard rates of the reference population (in our case the general Swiss population) and the person-times accrued in the exposed occupation cohort. In CMR, expected deaths are also the product of rates of the reference population and person-times, but they are adjusted at an individual level with the survival probability throughout the follow-up.[13] Therefore, CMR are considered less biassed compared with SMR as it does not assume that occupational exposures do not influence the cohort's person time, unlike SMR.[13 14] For both methods, 95% CIs were calculated using the exact Poisson formula.[15] The national cause-specific rates stratified by age and calendar period (both 5-year groups) were applied to the person-years of every occupation and economic activity/industry. In addition, we calculated relative SMR (rSMR), defined as the ratio of the SMR for lung cancer to the SMR for all causes other than lung cancer using Poisson regression. Assuming a comparable bias for all causes, this measure may reduce bias of the true mortality rate ratio and, thus, the healthy worker effect.[14] CMR, SMR and rSMR were computed over the entire study period.

Moreover, SMR were computed for five calendar periods (1990–1994, 1995–1999, 2000–2004, 2005–2009 and 2010–2014) and compared using heterogeneity and trend tests.[15] Lastly, we computed SMR and CMR stratified by work-related variables—nationality, SPS defined in the SNC as an 8-class variable,[16] number of workings hours per week, occupation skill-level,[17] marital status and linguistic region. All analyses were run on STATA V.15 (StataCorp).

RESULTS

Cohort description

In total, 5 834 618 Swiss residents were included in this study (111 162 348 person-years), 49% of whom were women. A total of 558 098 individuals died (9.6%) during the follow-up. Men were twice as likely to die from lung cancer as women with 32 910 and 14 447 deaths, respectively. The mean age at death from lung cancer was 65.6±9.4 years in men and 64.9±10.2 years in women. The mean duration of follow-up was 18.6±6.6 years and 19.5±6.2 years in men and women, respectively (table 1). At study end point, 20% of men and 16% of women were lost to follow-up. Participants lost to follow-up were

Table 1 Characteristics of the study sample and number of deaths due to lung cancer: the Swiss National Cohort (1990–2014)

	Female			Male		
Characteristics	**N (%)**	**No of lung cancer deaths**	**(%)**	**N (%)**	**No of lung cancer deaths**	**(%)**
Total	2 876 625 (100)	14 477	(100)	2 957 993 (100)	32 910	(100)
Person-years (in 100 000)	560.31			551.31		
Nationality (binary)						
Swiss	2 287 618 (80)	13 244	(91)	2 197 892 (74)	27 105	(82)
Non-Swiss	589 007 (20)	1233	(9)	760 101 (26)	5805	(18)
Socioprofessional category						
Top management and independent professions	30 124 (1)	73	(1)	103 434 (3)	593	(2)
Other self-employed	103 812 (4)	505	(3)	262 966 (9)	3108	(9)
Professionals and senior management	87 334 (3)	228	(2)	247 788 (8)	1319	(4)
Supervisors/low level management and skilled labour	829 073 (29)	2497	(17)	1 000 766 (34)	8232	(25)
Unskilled employees and workers	264 046 (9)	1330	(9)	283 168 (10)	3159	(10)
In paid employment, not classified elsewhere	437 975 (15)	1477	(10)	475 647 (16)	3723	(11)
Unemployed/job-seeking	90 812 (3)	300	(2)	77 181 (3)	748	(2)
Not in paid employment	1 032 828 (36)	8066	(56)	506 491 (17)	12 028	(37)
Unknown	621 (0)	1	(0)	552 (0)	0	(0)
1-digit ISCO-88						
0 Armed forces	63 (0)	0	(0)	2367 (0)	17	(0)
1 legislators, senior officials and managers	73 883 (3)	368	(3)	245 778 (8)	1860.	(6)
2 professionals	128 431 (4)	286	(2)	277 934 (9)	1293	(4)
3 technicians and associate professionals	320 958 (11)	752	(5)	316 521 (11)	2421	(7)
4 clerks	278 755 (10)	1148	(8)	129 867 (4)	1393	(4)
5 service workers and shop and market sales workers	278 598 (10)	1114	(8)	140 681 (5)	974	(3)
6 skilled agricultural and fishery workers	23 560 (1)	48	(0)	78 861 (3)	890	(3)
7 craft and related trades workers	42 916 (1)	144	(1)	415 594 (14)	3845	(12)
8 plant and machine operators and assemblers	18 383 (1)	95	(1)	140 088 (5)	1883	(6)
9 elementary occupations	100 573 (3)	559	(4)	116 164 (4)	1957	(6)
Unemployed/job-seeking	90 812 (3)	300	(2)	77 181 (3)	748	(2)
Unknown	1 519 693 (53)	9663	(67)	1 016 957 (34)	15 629	(47)
Skill level (based on ISCO)						
Lowest	100 573 (3)	559	(4)	116 164 (4)	1957	(6)
Second lowest	642 212 (22)	2549	(18)	905 091 (31)	8985	(27)
Second highest	320 958 (11)	752	(5)	316 521 (11)	2421	(7)
Highest	202 314 (7)	654	(5)	523 712 (18)	3153	(10)
Unknown	1 610 568 (56)	9963	(69)	1 096 505 (37)	16 394	(50)
Weekly working hours						
1–5 hours per week	72 085 (3)	247	(2)	12 235 (0)	171	(1)
6–19 hours per week	261 797 (9)	947	(7)	36 613 (1)	420	(1)
20–27 hours per week	234 092 (8)	976	(7)	45 249 (2)	646	(2)
28–35 hours per week	171 602 (6)	644	(4)	54 282 (2)	414	(1)
36–39 hours per week	49 534 (2)	171	(1)	35 729 (1)	190	(1)
40–45 hours per week	709 850 (25)	2119	(15)	1 580 518 (53)	13 105	(40)
46 and more hours per week	110 340 (4)	434	(3)	447 302 (15)	3294	(10)
Unknown	1 267 325 (44)	8939	(62)	746 065 (25)	14 670	(45)
Language region						
German	2 042 499 (71)	9733	(67)	2 120 386 (72)	22 695	(69)
French	694 517 (24)	3931	(27)	699 753 (24)	8274	(25)
Italian	130 461 (5)	766	(5)	127 912 (4)	1806	(5)
Rhaeto Romansh	9148 (0)	47	(0)	9942 (0)	135	(0)
Vital status at end point						
Alive	2 187 271 (76)			2 030 220 (68)		
Lost to follow-up	472 074 (16)			586 955 (20)		
Dead	217 280 (8)			340 818 (12)		
From lung cancer		14 477	(100)		32 910	(100)
Age (years) : mean±SD						

continued

Table 1 continued

Characteristics	Female N (%)	Female No of lung cancer deaths (%)	Male N (%)	Male No of lung cancer deaths (%)
At study entry	37.1±13.1		36.6±12.8	
At study end	56.6±15.3		55.2±14.8	
At death from lung cancer	64.9±10.2		65.6±9.4	
Duration (years) : mean±SD				
Follow-up	19.5±6.2		18.6±6.6	
Between the last occupational information and death from lung cancer	7.5±3.8		6.8±3.8	

ISCO, International Standard Classification of Occupations.

younger at enrolment, with a mean age at baseline of 33.0±11.8 years in men and 32.3±12.0 years in women, compared with 37.5±12.9 years and 38.0±13.1 years, respectively, for the rest of the cohort. Moreover, elementary occupations in both sexes were over-represented with a frequency four times higher for those lost to follow-up, compared with those with a complete follow-up.

Risk of lung cancer by occupational group

Online supplementary table S1 presents CMR and SMR for each occupation (3-digit ISCO-88) with at least 10 observed deaths due to lung cancer in both sexes. Overall, CMR and SMR results were very similar. The absolute difference (Δ) between CMR and SMR never exceeded 0.03, except for unemployed/job-seekers (Δ=0.11), garbage collectors and related labourers (ISCO-88=916) (Δ=0.05) and manufacturing labourers (ISCO-88=932) (Δ=0.05) in men.

In men, 46 occupations out of 95 presented a statistically significant deficit in mortality from lung cancer (figure 1), compared with the general Swiss male population. Physicists, chemists and related professionals (ISCO=211), religious professionals (ISCO=246) and college, university and higher education teaching professionals (ISCO=231) were identified as the most protected occupations. In contrast, rubber-products and plastic-products machine operators (ISCO=823), other machine operators (ISCO=829), unemployed/job-seeking men, garbage collectors and related labourers (ISCO=916) and plant and machine operators and assemblers (ISCO=800) were the five occupational groups with the highest excess of lung cancer mortality. Comparisons of SMR across the five calendar periods by 2-digit ISCO-88 showed a statistically significant decreasing trend in lung cancer mortality in sales and services elementary occupations (ISCO=91), with the highest SMR found over 1990–1994 (SMR=1.34, 95% CI 1.11 to 1.61) (online supplementary table S2).

In women, a statistically significant deficit in lung cancer mortality was observed in 13 out of 55 occupations (figure 2). Crop and animal producers (ISCO=613), primary education teaching associate professionals (ISCO=331) and other teaching associate professionals (ISCO=334) presented the lowest CMR. The five occupations with the highest risk of lung cancer mortality were motor vehicle drivers (ISCO=832), computer associate professionals (ISCO=312), precision workers in metal and related materials (ISCO=731), material-recording and transport clerks (ISCO=413) and unemployed/job seeking women. Corporate managers (ISCO=12) were identified with an increasing trend in lung cancer mortality over the study period with the highest statistically significant SMR found over 1995–1999 (SMR=1.88, 95% CI 1.54 to 2.30); afterwards an important decrease was observed in 2000–2004, followed by a slight increase of lung cancer mortality (online supplementary table S3).

Results on rSMR (2-digit ISCO-88) were generally higher than CMR and SMR in both sexes (table 2). Among men, plant and machine operators, and drivers (ISCO=80–83) were identified with the highest rSMR. Among women, drivers and plant operators (ISCO=83) presented the highest risk (rSMR=2.34, 95% CI 1.62 to 3.39). Relative SMR also brought to light some aspects potentially masked by SMR in women. We identified female managers of small enterprises (ISCO=13), physical and engineering science associate professionals (ISCO=31) and other precision, handicraft, craft printing and related traded workers (ISCO=73) with increased risks of lung cancer mortality of 43%, 50% and 50%, respectively, compared with the general population.

Risk of lung cancer by economic activity/industry

Online supplementary table 4 presents CMR, rSMR and SMR for each economic activity/industry in both sexes. Our results showed that working in hotel and restaurant was associated with a higher risk of death by lung cancer in both sexes (figures 2 and 3). Among men, working in construction industry was identified with an excess of lung cancer mortality, though the highest risk was observed in mining and quarrying industry (CMR=1.68, 95% CI 1.36 to 2.06). A statistically significant trend was also observed in men working in construction, with the highest statistically significant SMR found over the period 1990–1994 (SMR=1.27, 95% CI 1.17 to 1.39) (online supplementary table S2). Among women, industries of trade, repair of motor vehicles and of domestic articles, and manufacture of goods were observed with CMR and SMR significantly higher than one (online supplementary table S4).

Moreover, rSMR identified men working in manufacture of goods, and in transport and communication at higher risk of lung cancer mortality with, respectively, a 14% and 12% increased risk, compared with the general Swiss male population. Female workers in construction (rSMR=1.33, 95% CI 1.11 to 1.58) and in domestic services (rSMR=1.72, 95% CI 1.18 to 2.51) were also found to have significantly increased rSMR.

Risk of lung cancer by work-related variables

The stratified analyses showed that non-Swiss men had a higher risk of mortality from lung cancer compared with the general Swiss population (CMR=1.10, 95% CI 1.07 to 1.13) (online supplementary table S5). Conversely, non-Swiss women presented a deficit of mortality (CMR=0.77, 95% CI 0.73 to 0.82), while Swiss women were identified with an excess

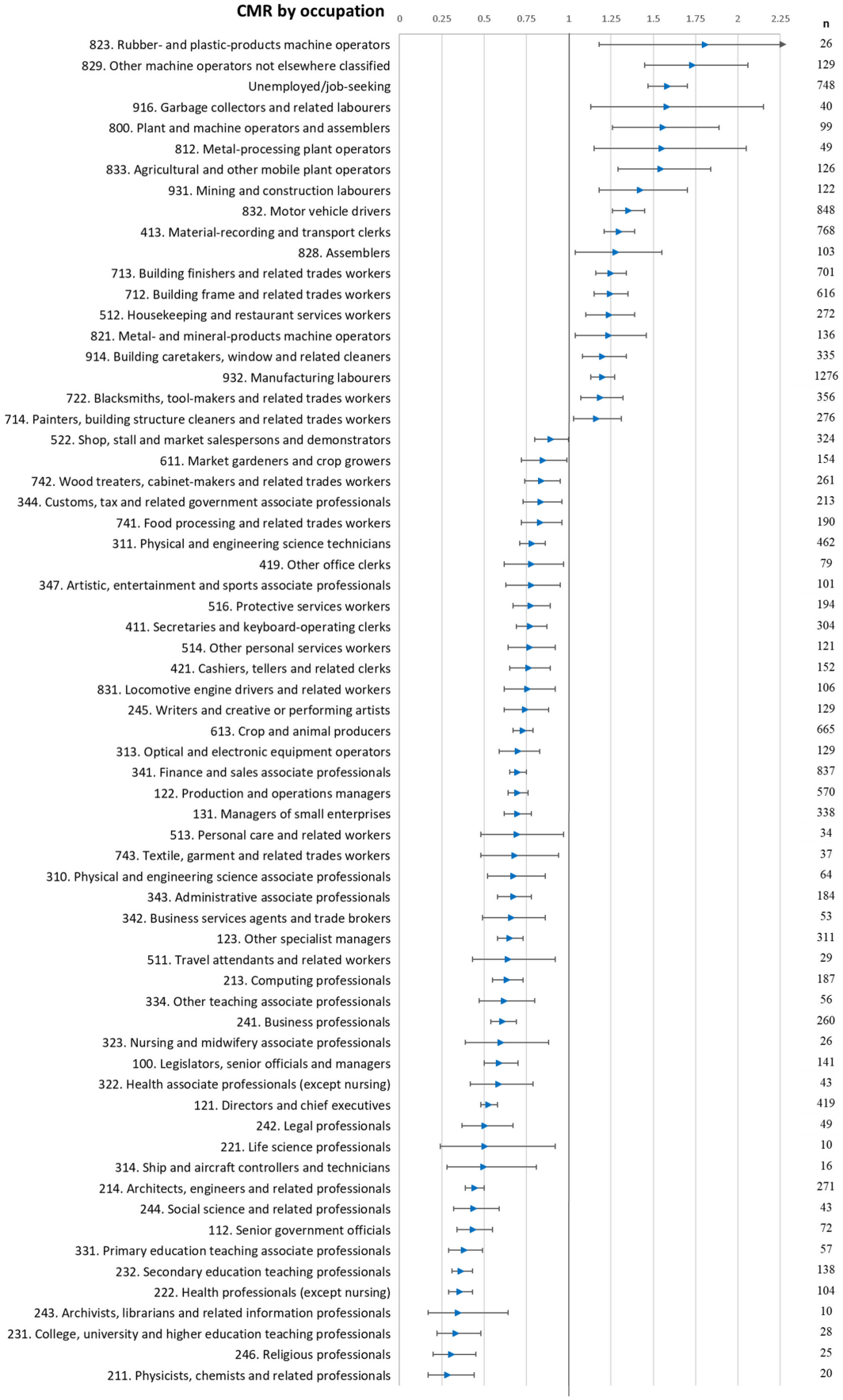

Figure 1 Causal mortality ratios (CMR) for mortality due to lung cancer by occupation (3-digit ISCO-88) among males aged 18–85 in the Swiss National Cohort (1990–2014). Only statistically significant results based on at least 10 deaths are presented. ISCO-88, International Standard Classification of Occupations, version 1988.

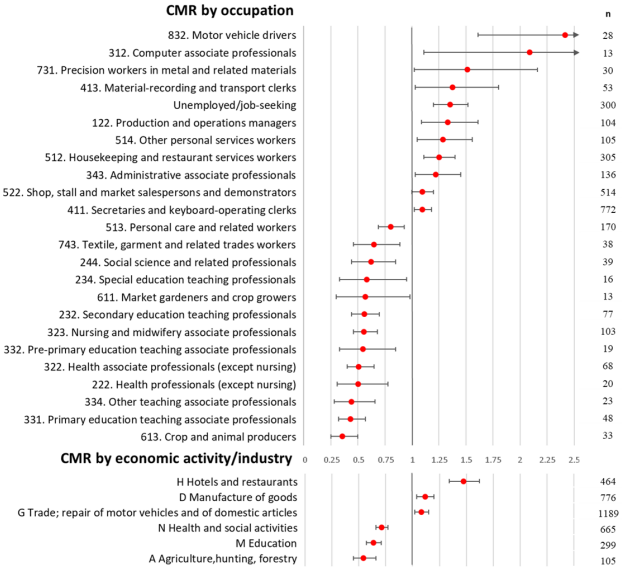

Figure 2 Causal mortality ratios (CMR) for mortality due to lung cancer by occupation (3-digit ISCO-88) and economic activity/industry (ISCI third and NACE first revision) among females aged 18–85 in the Swiss National Cohort (1990–2014). Only statistically significant results based on at least 10 deaths are presented. ISCO-88, International Standard Classification of Occupations, version 1988.

(CMR=1.07, 95% CI 1.06 to 1.09). In men, we observed an increased risk of lung cancer mortality when the occupation's skill level decreased. In women, only occupations with the second lowest skill level presented a 4%-increased risk of lung cancer mortality.

DISCUSSION

Nationwide studies comparing the risk of lung cancer mortality across occupations and economic activities/industries were recently conducted in Korea and Japan. Lee *et al*[18] found that Korean men working in services/sales and blue-collar occupations had the highest lung cancer rates, while in Japan, the highest rates were observed in unemployed men.[19] Occupational inequalities in female were also identified in Japan, with lower risk of lung cancer among women with high socioeconomic status, even after adjusting for smoking.[20] In Switzerland, the last epidemiology study (conducted 20 years ago) only provided odd ratios by occupation and socioeconomic group for males aged 25–65.[5] In our study, we used three risk estimates of lung cancer mortality; the SMR—to enable comparison of the results with other national and international studies; the CMR—to enable a less bias estimation of mortality; and the rSMR—to control for the healthy worker effect often present in occupational cohorts.

Occupational groups at risk

Our results confirmed an invert socioeconomic gradient in lung cancer mortality.[21 22] In both sexes, the risk increased as the skill level decreased. Previous studies showed that this gradient remained after adjusting for smoking and education, although the effect was greater among men than women.[21] Prior findings[23] also showed that unemployed individuals were at higher risk of lung cancer mortality than the general population.

In line with previous reports,[3 24] male and female motor vehicle drivers were identified with an excess of lung cancer mortality. A more detailed analysis by 4-digit ISCO-88 identified female car, taxi and van drivers with the highest mortality excess. Despite a relatively small number of observed deaths (n=10), lung cancer mortality was more than three times higher than in the general population (CMR=3.34, 95% CI 1.60 to 6.14) (online supplementary table S6). This may partly be explained by exposure to diesel exhaust,[25] classified as group 1 human carcinogens by IARC but as group 2A (probable human carcinogens) by Suva.[26 27] We found no studies assessing risk for female workers in metal and related materials. Further investigation would be necessary. In men, the highest excess of lung cancer mortality found in rubber and plastic products machine operators is also consistent with prior studies, although the evidence of aromatic amines carcinogenicity in humans is still limited.[28] In addition, four other occupational groups of operators were identified in the ten most at-risk groups (figure 1). Previous studies revealed that the risk remained in these groups even after adjusting for sex, age, smoking and socioeconomic status, except for motorised farm machinery operators identified with a non-significant deficit of lung cancer mortality.[22 29] Thus, the 54%-increased risk of lung cancer mortality we found in agricultural and other mobile operators (ISCO=833) deserves further analyses. Lastly, the extent to which garbage collectors are exposed to carcinogens is less clear. There is considerable potential for hazardous exposure through waste management.[30]

Economic activities/industries at risk

Each industry/economic activity is likely to have its own combination of potentially carcinogenic exposures, which can be related to the excess of lung cancer mortality identified in this study. For instance, the high prevalence of smoking among men and women working in hotels and restaurants might explained the increased risk of lung cancer mortality compared with the general population.[31 32] In contrast, the deficit of lung cancer mortality observed among workers in agriculture, hunting and forestry might be related to a low smoking frequency in this industry.[33]

The significant excess of lung cancer mortality identified in men working in mining, quarrying and construction is probably due to workplace exposures to carcinogens such as silica dust, asbestos, radon and diesel engine exhaust.[3 22 28] Moreover, the decreasing trend of lung cancer mortality we observed across calendar periods in men working in construction, especially after asbestos prohibition in 1990 in Switzerland is in line with previous findings showing that construction workers at higher risk of asbestos-related lung cancer presented the same risk as the general population a few decades after cessation of exposure.[34] However, male construction workers remained at risk over 2010–2014, which deserves further analysis.

In women, the excess of lung cancer mortality observed in trade, repair of motor vehicles and of domestic articles was in line with prior reports.[22 24] Moreover, a more detailed analysis of the economic activity of manufacture of goods revealed that manufacture of electrical and electronic equipment, manufacture of machinery and equipment, and manufacture of chemicals and chemical products presented statistically significant increased risks of lung cancer mortality of 22%, 31% and 65%, respectively. Exposures to IARC group 1 carcinogens, including strong inorganic acid mists, hexavalent chromium, cobalt, crystalline silica, lead or benzo(a)pyrene and beryllium, were previously identified in these activities and may partially explain this finding.[28]

Potential under-reporting of lung cancer for recognition as occupational disease

Although the Swiss Ordinance of Accident Insurance lists quite exhaustively occupational carcinogenic agents, mesothelioma

Table 2 Standardised mortality ratios* (SMR), causal mortality ratios* (CMR), relative SMR (rSMR) for lung cancer† by occupation‡ in both sexes, aged 18–85: the Swiss National Cohort (1990–2014)

2-digit International Standard Classification of Occupations, version 1988 (ISCO-88)	O SMR	(95% CI)§	CMR	(95% CI)	rSMR	(95% CI)
Male						
01.Soldiers	17 0.77	(0.45 to 1.23)	0.77	(0.45 to 1.24)	1.00	(0.62 to 1.61)
10.Legislators, senior officials and managers	141 0.59	(0.50 to 0.69)	0.59	(0.50 to 0.70)	0.82	(0.70 to 0.97)
11.Legislators and senior officials	78 0.42	(0.33 to 0.52)	0.43	(0.34 to 0.53)	0.84	(0.67 to 1.05)
12.Corporate managers	1303 0.62	(0.58 to 0.65)	0.62	(0.59 to 0.66)	0.93	(0.88 to 0.98)
13.Managers of small enterprises	338 0.69	(0.62 to 0.77)	0.70	(0.62 to 0.78)	1.00	(0.90 to 1.11)
21.Physical, mathematical and engineering science professionals	481 0.48	(0.43 to 0.52)	0.49	(0.45 to 0.54)	0.78	(0.71 to 0.85)
22.Life science and health professionals	114 0.35	(0.29 to 0.42)	0.37	(0.30 to 0.44)	0.67	(0.56 to 0.81)
23.Teaching professionals	181 0.35	(0.31 to 0.41)	0.37	(0.31 to 0.42)	0.71	(0.61 to 0.82)
24.Other professionals	517 0.56	(0.51 to 0.61)	0.57	(0.52 to 0.62)	0.80	(0.73 to 0.87)
31.Physical and engineering science associate professionals	789 0.76	(0.71 to 0.82)	0.77	(0.72 to 0.83)	1.04	(0.97 to 1.12)
32.Life science and health associate professionals	81 0.58	(0.46 to 0.72)	0.59	(0.47 to 0.73)	0.78	(0.63 to 0.97)
33.Teaching associate professionals	113 0.46	(0.38 to 0.55)	0.47	(0.39 to 0.56)	0.79	(0.66 to 0.95)
34.Other associate professionals	1437 0.71	(0.68 to 0.75)	0.72	(0.68 to 0.76)	0.95	(0.90 to 1.00)
41.Office clerks	1214 1.06	(1.01 to 1.13)	1.06	(1.00 to 1.12)	1.14	(1.08 to 1.21)
42.Customer services clerks	171 0.77	(0.66 to 0.89)	0.77	(0.66 to 0.90)	0.99	(0.85 to 1.15)
51.Personal and protective services workers	650 0.90	(0.83 to 0.97)	0.90	(0.83 to 0.97)	1.01	(0.94 to 1.09)
52.Models, salespersons and demonstrators	324 0.89	(0.80 to 1.00)	0.89	(0.80 to 1.00)	1.07	(0.96 to 1.20)
61.Skilled agricultural and fishery workers	890 0.75	(0.70 to 0.80)	0.77	(0.72 to 0.82)	0.96	(0.90 to 1.02)
71.Extraction and building trades workers	1620 1.23	(1.17 to 1.29)	1.23	(1.17 to 1.29)	1.33	(1.27 to 1.40)
72.Metal, machinery and related trades workers	1430 1.04	(0.98 to 1.09)	1.04	(0.99 to 1.09)	1.17	(1.11 to 1.24)
73.Precision, handicraft, craft printing and related trades workers	276 0.90	(0.80 to 1.02)	0.92	(0.81 to 1.03)	1.16	(1.03 to 1.31)
74.Other craft and related trades workers	512 0.81	(0.75 to 0.89)	0.82	(0.75 to 0.90)	0.97	(0.89 to 1.06)
80.Plant and machine operators and assemblers	99 1.58	(1.30 to 1.93)	1.56	(1.26 to 1.89)	1.64	(1.35 to 2.00)
81.Stationary plant and related operators	110 1.17	(0.97 to 1.42)	1.17	(0.96 to 1.41)	1.26	(1.04 to 1.52)
82.Machine operators and assemblers	592 1.23	(1.13 to 1.33)	1.22	(1.12 to 1.32)	1.35	(1.24 to 1.46)
83.Drivers and mobile plant operators	1082 1.27	(1.20 to 1.35)	1.27	(1.20 to 1.35)	1.34	(1.27 to 1.43)
91.Sales and services elementary occupations	494 1.18	(1.08 to 1.29)	1.17	(1.07 to 1.28)	1.25	(1.14 to 1.36)
92.Agricultural,fishery and related labourers	62 1.30	(1.01 to 1.66)	1.27	(0.97 to 1.63)	1.17	(0.92 to 1.51)
93.Labourers in mining, construction, manufacturing and transport	1401 1.27	(1.20 to 1.34)	1.22	(1.15 to 1.28)	0.99	(0.94 to 1.04)
Unemployed/job-seeking	748 1.69	(1.58 to 1.82)	1.58	(1.47 to 1.70)	0.95	(0.88 to 1.02)
Female						
10.Legislators, senior officials and managers	43 0.95	(0.70 to 1.28)	0.95	(0.69 to 1.28)	1.20	(0.89 to 1.61)
11.Legislators and senior officials	12 0.94	(0.49 to 1.64)	0.94	(0.49 to 1.64)	1.11	(0.63 to 1.95)
12.Corporate managers	202 1.29	(1.12 to 1.48)	1.29	(1.12 to 1.48)	1.52	(1.32 to 1.74)
13.Managers of small enterprises	111 1.17	(0.97 to 1.41)	1.16	(0.96 to 1.40)	1.43	(1.19 to 1.73)
21.Physical, mathematical and engineering science professionals	27 1.07	(0.71 to 1.56)	1.08	(0.71 to 1.57)	1.37	(0.94 to 2.00)
22.Life science and health professionals	21 0.49	(0.30 to 0.75)	0.49	(0.31 to 0.76)	0.76	(0.50 to 1.17)
23.Teaching professionals	106 0.57	(0.47 to 0.69)	0.58	(0.48 to 0.70)	0.94	(0.78 to 1.13)
24.Other professionals	132 0.68	(0.58 to 0.81)	0.69	(0.58 to 0.82)	0.93	(0.79 to 1.11)
31.Physical and engineering science associate professionals	97 1.18	(0.96 to 1.43)	1.18	(0.96 to 1.44)	1.50	(1.23 to 1.84)
32.Life science and health associate professionals	171 0.53	(0.46 to 0.62)	0.54	(0.46 to 0.62)	0.75	(0.65 to 0.88)
33.Teaching associate professionals	90 0.45	(0.37 to 0.55)	0.45	(0.36 to 0.56)	0.75	(0.61 to 0.92)
34.Other associate professionals	394 1.02	(0.93 to 1.13)	1.03	(0.93 to 1.13)	1.31	(1.19 to 1.45)
41.Office clerks	969 1.06	(1.00 to 1.13)	1.07	(1.00 to 1.14)	1.35	(1.27 to 1.44)
42.Customer services clerks	177 1.10	(0.95 to 1.28)	1.11	(0.95 to 1.28)	1.33	(1.15 to 1.54)
51.Personal and protective services workers	600 1.06	(0.97 to 1.14)	1.06	(0.98 to 1.15)	1.25	(1.16 to 1.36)
52.Models, salespersons and demonstrators	514 1.09	(1.00 to 1.19)	1.10	(1.00 to 1.20)	1.32	(1.21 to 1.44)
61.Skilled agricultural and fishery workers	48 0.40	(0.30 to 0.53)	0.40	(0.30 to 0.53)	0.56	(0.43 to 0.75)
72.Metal, machinery and related trades workers	29 1.16	(0.78 to 1.66)	1.16	(0.78 to 1.67)	1.46	(1.01 to 2.10)
73.Precision, handicraft, craft printing and related trades workers	54 1.33	(1.02 to 1.73)	1.33	(1.00 to 1.73)	1.50	(1.15 to 1.95)
74.Other craft and related trades workers	54 0.69	(0.53 to 0.90)	0.70	(0.52 to 0.91)	0.93	(0.71 to 1.21)
82.Machine operators and assemblers	62 1.10	(0.86 to 1.41)	1.10	(0.84 to 1.40)	1.21	(0.94 to 1.55)
83.Drivers and mobile plant operators	28 2.15	(1.43 to 3.10)	2.14	(1.42 to 3.09)	2.34	(1.62 to 3.39)
91.Sales and services elementary occupations	293 1.02	(0.91 to 1.15)	1.02	(0.91 to 1.15)	1.25	(1.12 to 1.40)

continued

Table 2 continued

2-digit International Standard Classification of Occupations, version 1988 (ISCO-88)	O SMR	(95% CI)§	CMR	(95% CI)	rSMR	(95% CI)
93.Labourers in mining, construction, manufacturing and transport	264 1.15	(1.02 to 1.30)	1.14	(1.01 to 1.29)	1.05	(0.93 to 1.18)
Unemployed/job-seeking	300 1.38	(1.24 to 1.55)	1.35	(1.20 to 1.52)	0.91	(0.81 to 1.01)

*Based on the mortality rates of Swiss population (15–85 years).
†Only results based on at least 10 deaths from lung cancer for each category are presented.
‡Based on the ISCO (3-digit ISCO 88).
§95% CI.

constitutes the large majority of cancers recognised as occupational by Suva.[6] No study has ever evaluated the extent of under-reporting and resulting underestimation of number occupational diseases, including lung cancer. However, Swiss physicians acknowledge an underreporting of cases, namely because of too stringent conditions enabling Suva to recognise a case as occupational disease. Swiss physicians also ignore or underestimate the Suva recognition rates.[35] Despite a descriptive nature of this study, we showed that the most at-risk occupations are those, where exposure to lung carcinogens were consistently documented. Therefore, the under-reporting of lung cancers to Suva raises a concern, which should be addressed.

Limitations and strengths

One of the main strengths of this study lies in the use of standardised national and international classifications, which allowed us to compare our results with other studies.[12] Moreover, using one of the largest longitudinal datasets worldwide with a 24-year long follow-up at the population level was another strength of this study. We defined occupational settings to approximate the exposure to occupational carcinogens before the outcome of interest occurred, limiting any information bias. Lastly, information on Swiss death certificates was found to be satisfactory with most of malignant neoplasms.[10]

In terms of limitations, we were not able to classify 34% and 53% of occupations in men and women, corresponding to 67% and 47% of all lung cancer deaths, respectively. A prior report comparing participants with known and unknown occupations by main sociodemographic variables did not find any potential for selection bias.[12] This bias might, though, come from the over-representation of elementary occupations in participants lost to follow-up. However, a potential underestimation of the number of lung cancer deaths in this occupational group is unlikely, as participants lost to follow-up were on average too young to die from lung cancer, with a mean age at baseline of 33.0±11.8 years in men and 32.3±12.0 years in women. Having only two time points for defining occupations is another limitation, which raises the concern of exposure misclassification. Indeed, information on the longest-held occupation might better reflect long-term exposure to carcinogens,[36] although information on occupation and industry, when available, was found to be accurate.[37] Lastly, our results should be interpreted with caution as no adjustment for smoking was applied in the analyses, which may have led to an overestimation of lung cancer mortality in occupational or industrial groups with a high smoking prevalence. A job-exposure matrix (JEM) of the lifestyle factors in different occupations was recently developed in Denmark.[38] However, Danish estimates of smoking prevalence differ from those in Switzerland.[39] Therefore, the need of prior validation of this JEM for Switzerland precluded its use in this study.

Given the PAF of lung cancer due to occupational exposures (19.3% in men and 2.6% in women),[3 4] improving data quality on occupation and potential confounders is particularly important to identify more accurately the most at-risk occupational groups.

CONCLUDING REMARKS

This study reports the risk of lung cancer mortality across occupational and industrial groups by sex at a national level. It is descriptive in nature but provides some important insights from both methodological and public health perspectives. It demonstrates that SMR remains a good approximation of mortality in both occupational and general cohorts, though rSMR helped to correct the healthy worker effect, which is usually present in SMR.

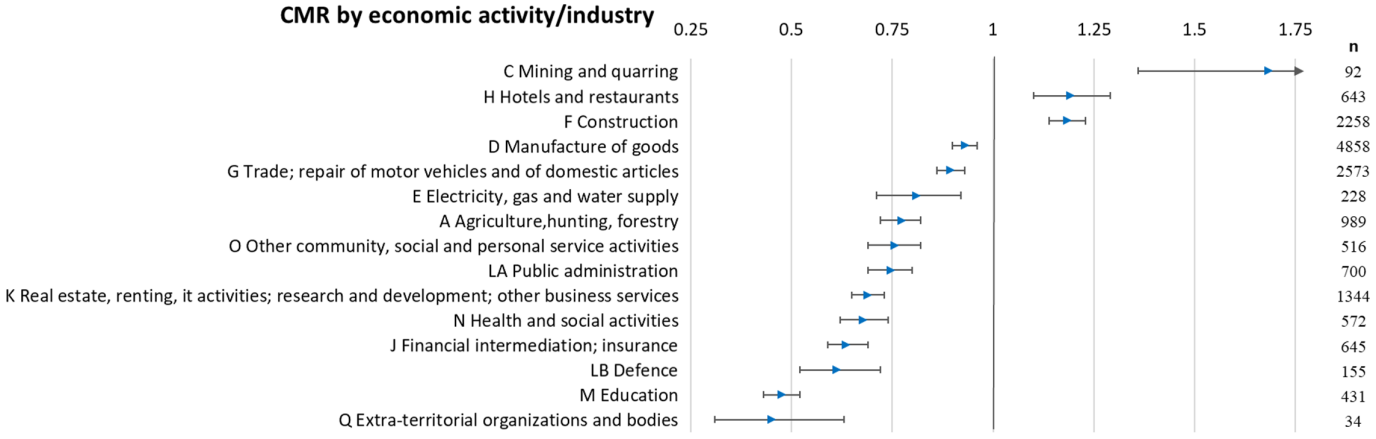

Figure 3 Causal mortality ratios (CMR) for mortality due to lung cancer by economic activity/industry (ISCI third and NACE first revision) among males aged 18–85 in the Swiss National Cohort (1990–2014). Only statistically significant results based on at least 10 deaths are presented.

Our results, based on both SMR and CMR estimates, demonstrate that 18 out of 95 occupations in men, 10 out of 55 occupations in women and three economic activities/industries in each sex present significantly higher risk of lung cancer mortality than the general Swiss population. Occupational exposures to lung carcinogens were consistently documented in most of these activities and occupations. Moreover, our study demonstrated that Swiss workers had no particular profile of mortality from lung cancer by occupational group and sex, compared with other developed countries.[3 21 22 24 25 29] This suggests that part of the excessive lung cancer mortality observed in these groups could be due to occupational carcinogens. However, further analyses are needed to examine the extent to which the excess of mortality observed in most at-risk occupational groups is due to active smoking, secondhand smoking, occupational or environmental exposures. This would allow tailoring effective interventions targeted at the most at-risk groups and the assessment of the efficacy of the current system of reporting and recognising occupational lung cancers.

Acknowledgements We thank the Swiss federal statistical office for providing mortality and census data, and for the support that made the Swiss National Cohort (SNC) and this study possible. The members of the Swiss National Cohort Study Group are Matthias Egger (Chairman of the Executive Board), Adrian Spoerri and Marcel Zwahlen (all Bern), Milo Puhan (Chairman of the Scientific Board), Matthias Bopp (both Zurich), Martin Röösli (Basel), Michel Oris (Geneva) and Murielle Bochud (Lausanne). This work was supported by the Swiss National Science Foundation (grant no 210.0-03-2018). We thank Claudia Berlin from ISPM Bern for her help in data management of federal census data.

Contributors The Swiss National Cohort (SNC)

Funding This work was supported by the Swiss National Science Foundation (grant no 210.0-03-2018).

Competing interests This work was conducted in frame of the SNC nested study contract no 180036.

Patient consent for publication Not required.

Ethics approval The SNC and the present study were approved by the Cantonal Ethics Committees of Bern and Zurich, and have therefore been performed in accordance with the ethical standards laid down in the 1964 Declaration of Helsinki and its later amendments.

Provenance and peer review Not commissioned; externally peer reviewed.

Data availability statement No data are available. We do not own the data. To have acess to data, people should directly contact the person in charge of the Swiss National Cohort.

ORCID iD
Nicolas Bovio http://orcid.org/0000-0002-2924-8670

REFERENCES

1 GBD 2016 Risk Factors Collaborators. Global, regional, and national comparative risk assessment of 84 behavioural, environmental and occupational, and metabolic risks or clusters of risks, 1990-2016: a systematic analysis for the global burden of disease study 2016. *Lancet* 2017;390:1345–422.
2 NICER. Cancer incidence and mortality in Switzerland, 2019. Available: https://www.nicer.org/NicerReportFiles2018/EN/report/atlas.html?&geog=0
3 Jung JKH, Feinstein SG, Palma Lazgare L, *et al*. Examining lung cancer risks across different industries and occupations in Ontario, Canada: the establishment of the occupational disease surveillance system. *Occup Environ Med* 2018;75:545–52.
4 Rushton L, Hutchings SJ, Fortunato L, *et al*. Occupational cancer burden in Great Britain. *Br J Cancer* 2012;107:S3–7.
5 Bouchardy C, Schüler G, Minder C, *et al*. Cancer risk by occupation and socioeconomic group among men--a study by the Association of Swiss Cancer Registries. *Scand J Work Environ Health* 2002;28:1–88.
6 OFSP. *Amiante: aspects cliniques et mesures préventives*. Publique OFdlS, 2015: 2.
7 Guillemin M. *Santé au travail: le déni des politiques publiques*. REISO, Revue d'information sociale, 2018.
8 Guseva Canu I, François M, Graczyk H, *et al*. Healthy worker, healthy citizen: the place of occupational health within public health research in Switzerland. *Int J Public Health* 2020;65:111–20.
9 de Groot PM, Wu CC, Carter BW, *et al*. The epidemiology of lung cancer. *Transl Lung Cancer Res* 2018;7:220–33.
10 Spoerri A, Zwahlen M, Egger M, *et al*. The Swiss national cohort: a unique database for national and international researchers. *Int J Public Health* 2010;55:239–42.
11 SFSO. Methodology report—coverage estimation for the Swiss population census 2000. Swiss federal statistical office, Neuchâtel, PP 1–147, 2004. Available: https://www.bfs.admin.ch/bfsstatic/dam/assets/341896/master [Accessed 27 Aug 2018].
12 Guseva Canu I, Bovio N, Mediouni Z, *et al*. Suicide mortality follow-up of the Swiss national cohort (1990-2014): sex-specific risk estimates by occupational socio-economic group in working-age population. *Soc Psychiatry Psychiatr Epidemiol* 2019;54:1483–95.
13 Richardson DB, Keil AP, Cole SR, *et al*. Observed and expected mortality in cohort studies. *Am J Epidemiol* 2017;185:479–86.
14 Shrestha S, Parks CG, Keil AP, *et al*. Overall and cause-specific mortality in a cohort of farmers and their spouses. *Occup Environ Med* 2019;76:632–43.
15 Breslow NE, Day NE. Statistical methods in cancer research. Volume II--The design and analysis of cohort studies. *IARC Sci Publ* 1987;82:1–406.
16 OFS. *Catégories socioprofessionnelles (CSP) 2010 Opérationnalisation des Csp dans Le Système des variables-clés shape dès 2010*. Neuchâtel, 2016: 19.
17 ILO. *International standard classification of occupations 2008 (ISCO-08): structure, group definitions and correspondence tables*, 2012: 476.
18 Lee H-E, Zaitsu M, Kim E-A, *et al*. Occupational class and cancer survival in Korean men: follow-up study of nation-wide working population. *Int J Environ Res Public Health* 2020;17:303.
19 Eguchi H, Wada K, Prieto-Merino D, *et al*. Lung, gastric and colorectal cancer mortality by occupation and industry among working-aged men in Japan. *Sci Rep* 2017;7:43204.
20 Zaitsu M, Kaneko R, Takeuchi T, *et al*. Occupational inequalities in female cancer incidence in Japan: hospital-based matched case-control study with occupational class. *SSM Popul Health* 2018;5:129–37.
21 Hovanec J, Siemiatycki J, Conway DI, *et al*. Lung cancer and socioeconomic status in a pooled analysis of case-control studies. *PLoS One* 2018;13:e0192999.
22 Pukkala E, Martinsen JI, Lynge E, *et al*. Occupation and cancer - follow-up of 15 million people in five Nordic countries. *Acta Oncol* 2009;48:646–790.
23 Vanthomme K, Van den Borre L, Vandenheede H, *et al*. Site-Specific cancer mortality inequalities by employment and occupational groups: a cohort study among Belgian adults, 2001-2011. *BMJ Open* 2017;7:e015216.
24 EU-OSHA. *Exposure to carcinogens and work-related cancer: a review of assessment methods. executive summary*. Luxembourg: European Agency for Safety and Health at Work (EU-OSHA), 2014.
25 Silverman DT. Diesel exhaust causes lung cancer: now what? *Occup Environ Med* 2017;74:233–4.
26 Shankar A, Dubey A, Saini D, *et al*. Environmental and occupational determinants of lung cancer. *Transl Lung Cancer Res* 2019;8:S31–49.
27 SUVA. Valeurs limites Valeurs actuelles VME/VLE, 2018. Available: https://www.suva.ch/fr-CH/materiel/directives-et-textes-de-lois/grenzwerte-am-arbeitsplatz-mak-werte-applikation/#59317A47178F431595269A7BB5018B2A=%2F%3Flang%3Dfr-CH
28 Brown T, Darnton A, Fortunato L, *et al*. British occupational cancer burden study G. occupational cancer in Britain. respiratory cancer sites: larynx, lung and mesothelioma. *Br J Cancer* 2012;107:S56–70.
29 Corbin M, McLean D, Mannetje Andrea 't, *et al*. Lung cancer and occupation: a new Zealand cancer registry-based case-control study. *Am J Ind Med* 2011;54:89–101.
30 Rushton L. Health hazards and waste management. *Br Med Bull* 2003;68:183–97.
31 López MJ, Nebot M, Juárez O, *et al*. [Estimation of the excess of lung cancer mortality risk associated to environmental tobacco smoke exposure of hospitality workers]. *Med Clin* 2006;126:13–14.
32 Daly B-J, Schmid K, Riediker M. Contribution of fine particulate matter sources to indoor exposure in bars, restaurants, and cafes. *Indoor Air* 2010;20:204–12.
33 Boulanger M, Tual S, Lemarchand C, *et al*. Lung cancer risk and occupational exposures in crop farming: results from the agriculture and cancer (AGRICAN) cohort. *Occup Environ Med* 2018;75:776–85.
34 Järvholm B, Ström E. The risk of lung cancer after cessation of asbestos exposure in construction workers using pleural malignant mesothelioma as a marker of exposure. *J Occup Environ Med* 2014;56:1297–301.
35 Graczyk H, Francois M, Krief P, *et al*. Recognition of occupational diseases in Switzerland: a critical review of the Swiss occupational disease list 2020. submitted.
36 Zaitsu M, Kaneko R, Takeuchi T, *et al*. Occupational class and male cancer incidence: nationwide, multicenter, hospital-based case-control study in Japan. *Cancer Med* 2019;8:795–813.
37 Vienneau D, de Hoogh K, Hauri D, *et al*. Effects of radon and UV exposure on skin cancer mortality in Switzerland. *Environ Health Perspect* 2017;125:067009.
38 Bondo Petersen S, Flachs EM, Prescott EIB, *et al*. Job-exposure matrices addressing lifestyle to be applied in register-based occupational health studies. *Occup Environ Med* 2018;75:890–7.
39 OFS. Consommation de tabac PAR âge, sexe, région linguistique, niveau de formation, 2018. Available: https://www.bfs.admin.ch/bfs/fr/home/statistiques/sante/determinants/tabac.assetdetail.6466022.html