Occupational Medicine 2016;**66:**241–246
Advance Access publication 8 December 2015 doi:10.1093/occmed/kqv197

Cause-specific mortality in Finnish ferrochromium and stainless steel production workers

M. Huvinen[1] **and E. Pukkala**[2,3]

[1]Outokumpu Oyj, PO Box 140, FI-02201 Espoo, Finland, [2]Finnish Cancer Registry, Institute for Statistical and Epidemiological Cancer Research, Unioninkatu 22, FI-00130 Helsinki, Finland, [3]School of Health Sciences, University of Tampere, FI-33014 Tampere, Finland.

Correspondence to: M. Huvinen, Outokumpu Oyj, PO Box 140, FI-02201 Espoo, Finland. Tel: +358 9 4212450; e-mail: markku.huvinen@outokumpu.com

Background	Although stainless steel has been produced for more than a hundred years, exposure-related mortality data for production workers are limited.
Aims	To describe cause-specific mortality in Finnish ferrochromium and stainless steel workers.
Methods	We studied Finnish stainless steel production chain workers employed between 1967 and 2004, from chromite mining to cold rolling of stainless steel, divided into sub-cohorts by production units with specific exposure patterns. We obtained causes of death for the years 1971–2012 from Statistics Finland. We calculated standardized mortality ratios (SMRs) as ratios of observed and expected numbers of deaths based on population mortality rates of the same region.
Results	Among 8088 workers studied, overall mortality was significantly decreased (SMR 0.77; 95% confidence interval [CI] 0.70–0.84), largely due to low mortality from diseases of the circulatory system (SMR 0.71; 95% CI 0.61–0.81). In chromite mine, stainless steel melting shop and metallurgical laboratory workers, the SMR for circulatory disease was below 0.4 (SMR 0.33; 95% CI 0.07–0.95, SMR 0.22; 95% CI 0.05–0.65 and SMR 0.16; 95% CI 0.00–0.90, respectively). Mortality from accidents (SMR 0.84; 95% CI 0.67–1.04) and suicides (SMR 0.72; 95% CI 0.56–0.91) was also lower than in the reference population.
Conclusions	Working in the Finnish ferrochromium and stainless steel industry appears not to be associated with increased mortality.
Key words	Cause-specific mortality; ferrochromium; Finland; hexavalent chromium; molybdenum; nickel; occupational exposure; stainless steel; trivalent chromium.

Introduction

The Finnish ferrochromium and stainless steel production chain is unique. All units are in the same geographic area and owned by the same company (the only producer of stainless steel in Finland). Various metallurgical species of chromium are encountered in workplace air at different stages of production, from chromite ore mining to cold rolling of stainless steel.

Most workers who joined the company in the 1960s, 70s and 80s belonged to the first generation of professionals in mining and metallurgical production. The annual turnover rate of workers was about 2–4% so it is possible to follow the same sub-cohorts working in the same departments over time.

No adverse long-term respiratory health effects have been observed in previous studies of Finnish ferrochromium and stainless steel production [1,2]. Overall cancer incidence was not elevated and lung cancer risk was decreased by about 20% [3]. Earlier studies of ferrochromium and stainless steel industry workers [4–8] have not found significantly elevated mortality but these studies were relatively small. In a Swedish study [8], there was a significant increase in mortality caused by accidents and violence in short-term workers.

In ferrochromium and stainless steel production, fine and ultrafine particles may be generated in the smelting and melting processes and emitted from diesel-powered vehicles. Long-term exposure to fine particulate air pollution is associated with cardiovascular mortality

probably due to pulmonary and systemic inflammation and accelerated atherosclerosis [9–11].

According to earlier exposure studies at Outokumpu Tornio Works (the Finnish stainless steel production company), the median personal workplace air concentration of Cr^{6+} in the ferrochromium smelter was below the detection limit of the method (0.5 μg/m^3, maximum 2.4 μg/m^3) [12]. In an analysis using a field emission scanning electron microscope, the aerosols from the ferrochromium smelter were observed to contain agglomerates of particles with a diameter of <1 μm. Chromium seemed to be dissolved in a silica matrix. The particles encountered in the stainless steel melting shop were predominantly metal alloys. No pure chromium or nickel particles were observed [13]. In an analysis using scanning electron microscopy (SEM), energy-dispersive X-ray spectroscopy (EDS) and X-ray diffraction, the composition of the metal particles generated from the melting process and released to the ambient air was observed to resemble stainless steel [14]. In a continuous outdoor air quality monitoring programme within the industrial area of Outokumpu Tornio Works, the mean concentration of chromium in the respirable particles (PM_{10}) was 181 ng/m^3. The respective figure for nickel was 77 ng/m^3 [15].

The aim of this study was to assess cause-specific mortality in Finnish ferrochromium and stainless steel workers employed since the beginning of production in 1967, with special reference to circulatory and respiratory diseases.

Methods

We studied everyone employed at the Kemi mine and Tornio production units of Outokumpu Group (called Tornio Works) between 1967 and 2004, who had not died or emigrated before 1971. We identified the cohort from the company's employment records. All Finnish residents have had unique personal identity codes (PICs) since 1967, which enable reliable automatic record linkage. Through an extensive search of population registers, we traced correct PICs, possible emigration date and vital status for all but nine (0.1%) of the workers, leaving a cohort of 8088 (Table 1).

We obtained causes of death for 1971–2012 from Statistics Finland. The longitudinal cause of death register of Statistics Finland has 53 causes of death categories. It started in 1971, and the latest year available for our study was 2012. Determination of cause of death is based on medical or forensic evidence, which provides grounds for death certification. Forensic determination may be necessary if death is not due to illness, if it is accidental or violent or is caused by a treatment procedure or occupational disease.

We obtained causes of death from first employment or 1 January 1971, whichever was later, to emigration, death or 31 December 2012, whichever was first. We further divided the data by time elapsed since first employment and analysed them by production department (Table 1), from the date when a person had worked for 5 years in a department.

We counted observed deaths and person-years at risk, by 5-year age groups, separately for males and females, and for seven 6-year calendar periods between 1971 and 2012. We calculated expected numbers of deaths and specific causes of death by multiplying person-years in each stratum by the corresponding average mortality and cause-specific mortality in the population of the area of the Regional

Table 1. Number of persons (*n*) at Tornio Works, and person-years at follow-up during 1971–2012, by work department, age and gender

	Men		Women		Total	
	n	Person-years	*n*	Person-years	*n*	Person-years
Total	6293	158 642	1795	41 118	8088	199 760
Age[a]						
<30	5305	42 471	1516	14 065	6821	56 537
30–44	878	67 439	228	16 183	1106	83 622
45–59	106	37 901	51	8261	157	46 162
60–74	4	10 035	–	2216	4	12 250
75+	–	796	–	393	–	1188
Department (at least 5 years of employment)						
Chromite mine	116	2914	6	200	122	3114
Ferrochromium plant	274	6917	5	124	279	7041
Stainless steel melting shop	404	7088	7	126	411	7214
Hot rolling mill	132	2091	6	76	138	2166
Cold rolling mill	849	15 689	89	1838	938	17 527
Maintenance and services	557	14 416	169	3823	726	18 238
Metallurgical laboratory	111	2579	54	1175	165	3754
Office	172	3808	202	4893	374	8702

[a]Age in *n* columns defined in the beginning of follow-up.

State Administrative Agency for Northern Finland. As Tornio Works is at the northernmost end of the Baltic Sea on the Swedish border, we assumed that selected reference rates represented typical mortality levels in that region.

To calculate standardized mortality ratios (SMRs) for broader age ranges, we added up age-specific observed numbers of deaths and divided by the sum of expected numbers of respective age categories. To calculate 95% confidence intervals (CIs) for the SMRs, we assumed that the number of observed deaths followed a Poisson distribution.

This study received ethical approval from the National Institute for Health and Welfare (THL/1010/5.05.00/2012).

Results

We followed up 6293 men (158 642 person-years) and 1795 women (41 118 person-years) in the cohort (Table 1). Mean individual follow-up was 24.7 years. We observed 451 deaths caused by diseases. The expected number was 586.4 and the SMR was 0.77 (95% CI 0.70–0.84) (Table 2). Overall mortality, mortality from diseases of the circulatory system, and in particular from ischaemic heart disease, was significantly decreased (Table 2). The SMR for all malignant neoplasms combined was 0.88 (95% CI 0.73–1.03) and for lung cancer 0.80 (95% CI 0.55–1.12) (Table 2). In those who had worked in the same department for >5 years, the SMR for lung cancer was 0.60 (95% CI 0.33–1.01) (Table 3). In department-specific analyses, there were significant decreases in circulatory disease mortality in chromite mine workers, in the stainless steel melting shop, in the metallurgical laboratory and in the offices (Table 3). The SMR for accidents was 0.84 (95% CI 0.67–1.0) and for suicides 0.72 (95% CI 0.56–0.91) (Table 4).

There were no significant differences between the SMRs according to age, period or sex. For example, the SMR for all diseases among male and female employees combined was 0.53 (95% CI 0.39–0.70) in the 30–44 age group, 0.77 (95% CI 0.65–0.88) aged 45–59, 0.89 (95% CI 0.76–1.02) aged 60–74 and 0.74 (95 % CI 0.56–0.96) aged ≥75. The SMR among male employees was 0.79 (95% CI 0.71–0.86) for all diseases, 0.64 (95% CI 0.53–0.77) for ischaemic heart diseases and 0.69 (95% CI 0.52–0.91) for suicides. The respective ratios for female employees were 0.63 (95% CI 0.45–0.84), 0.68 (95% CI 0.31–1.29) and 0.74 (95% CI 0.15–2.15).

Discussion

We found significant decreases in overall mortality, and in particular in mortality from circulatory diseases, accidents and suicides.

Table 2. Observed (Obs) and expected (Exp) numbers of deaths and SMRs with 95% CIs among workers at Tornio Works during 1971–2012, by disease

Causes of death	Obs	Exp	SMR	95% CI
All diseases	451	586.4	0.77	0.70–0.84***
Malignant neoplasms	133	152.0	0.88	0.73–1.03
Malignant neoplasm of stomach	7	10.0	0.70	0.28–1.44
Malignant neoplasm of colon	5	7.7	0.65	0.21–1.52
Primary malignant neoplasm of liver	3	5.3	0.57	0.12–1.66
Malignant neoplasm of pancreas	12	12.5	0.96	0.50–1.67
Malignant neoplasm of larynx, trachea and lung	33	41.2	0.80	0.55–1.12
Malignant neoplasm of breast	1	5.2	0.19	0.00–1.08
Malignant neoplasm of prostate	10	7.9	1.27	0.61–2.33
Malignant neoplasm of lymphoid/haematopoietic tissue	20	15.0	1.33	0.81–2.05
Other malignant neoplasms	24	23.2	1.03	0.66–1.53
Endocrine, nutritional and metabolic diseases	5	11.5	0.44	0.14–1.01
Diabetes mellitus	5	9.7	0.52	0.17–1.20
Dementia, Alzheimer's disease	10	12.5	0.80	0.38–1.46
Other diseases of the nervous system	7	14.1	0.50	0.20–1.02
Diseases of the circulatory system	188	264.3	0.71	0.61–0.81***
Ischaemic heart disease	111	171.4	0.65	0.53–0.77***
Other heart diseases	19	31.1	0.61	0.37–0.95*
Cerebrovascular diseases	42	41.7	1.01	0.73–1.36
Other diseases of the circulatory system	16	20.0	0.80	0.46–1.30
Diseases of the respiratory system	20	28.1	0.71	0.43–1.09
Pneumonia	4	10.2	0.39	0.11–1.00
Bronchitis, emphysema	12	13.0	0.92	0.48–1.61
Other diseases excluding dementia and alcohol-related diseases	3	5.6	0.54	0.11–1.56
Alcohol-related diseases and accidental poisoning by alcohol	62	70.9	0.87	0.67–1.12

Included are diseases and causes of death with Exp >5.
*$P < 0.05$; ***$P < 0.001$.

Table 3. Observed (Obs) and expected (Exp) number of deaths (all diseases, circulatory diseases, respiratory diseases and lung cancer) and SMRs with 95% CIs during 1971–2012 among workers at Tornio Works with employment more than 5 years, by department

Department	All diseases				Circulatory diseases				Respiratory diseases				Lung cancer			
	Obs	Exp	SMR	95% CI	Obs	Exp	SMR	95% CI	Obs	Exp	SMR	95% CI	Obs	Exp	SMR	95% CI
Chromite mine	12	19.3	0.62	0.32–1.08	3	9.1	0.33	0.07–0.95*	–	1.0	0.00	0.00–3.65	1	1.6	0.61	0.02–3.41
Ferrochromium plant	30	44.4	0.68	0.46–0.96*	15	21.4	0.70	0.39–1.15	2	2.5	0.80	0.10–2.90	3	3.8	0.80	0.16–2.33
Stainless steel melting shop	18	29.5	0.61	0.36–0.96*	3	13.4	0.22	0.05–0.65**	3	1.4	2.19	0.45–6.39	2	2.3	0.85	0.10–3.08
Hot rolling mill	3	6.2	0.48	0.10–1.40	1	2.6	0.38	0.01–2.12	–	0.2	0.00	0.00–16.3	1	0.4	2.35	0.06–13.1
Cold rolling mill	42	61.2	0.69	0.49–0.92*	20	26.6	0.75	0.46–1.15	1	2.7	0.37	0.01–2.04	2	4.5	0.44	0.05–1.60
Maintenance and services	100	128.6	0.78	0.63–0.93**	49	61.3	0.80	0.59–1.05	8	7.2	1.12	0.48–2.19	6	9.9	0.61	0.22–1.32
Metallurgical laboratory	7	14.3	0.49	0.20–1.00	1	6.1	0.16	0.00–0.90*	–	0.6	0.00	0.00–5.75	1	1.0	0.97	0.02–5.40
Office	14	36.7	0.38	0.21–0.63***	7	15.7	0.45	0.18–0.91*	–	1.9	0.00	0.00–1.94	–	2.8	0.00	0.00–1.34
Any department	208	305.0	0.68	0.59–0.77***	86	140.3	0.61	0.49–0.75***	13	15.6	0.83	0.44–1.42	14	23.2	0.60	0.33–1.01

*$P < 0.05$; **$P < 0.01$; ***$P < 0.001$.

Table 4. Observed (Obs) and expected (Exp) numbers of accidental and violent deaths and SMRs with 95% CIs among workers at Tornio Works during 1971–2012, by type of accident

Type of accident or violence	Obs	Exp	SMR	95% CI
All accidents, excluding accidental poisoning by alcohol	83	98.7	0.84	0.67–1.04
Traffic accidents	20	22.0	0.91	0.56–1.40
Water transport accidents	6	8.4	0.72	0.26–1.56
Accidental falls	22	17.7	1.24	0.78–1.87
Drowning	4	8.1	0.49	0.13–1.25
Accidental poisoning (non-alcohol)	13	18.9	0.69	0.37–1.17
Other accidents and late effects of accidental injuries	13	20.8	0.63	0.33–1.07
Suicides	69	95.6	0.72	0.56–0.91**
Assault	4	9.0	0.44	0.12–1.13
Event of undetermined intent	10	8.0	1.25	0.60–2.30
Total	166	211.6	0.78	0.67–0.90***

Included are diseases and causes of death with Exp >5.
**$P < 0.01$; ***$P < 0.001$.

Strengths of our study include the use of non-selected national registers with good data accuracy and coverage, long follow-up time and complete information on causes of death [16]. However, information on cofactors was not systematically available.

We used the mortality rates of the population of Northern Finland as the main reference because mortality rates vary geographically. Mortality also varies according to socio-economic position. The majority of the workers in the departments at Tornio Works belong to the category of skilled blue-collar workers who in the general population have an average or slightly elevated overall mortality [17]. If we had been able to adjust our SMRs for social class, the overall SMR and most of the cause-specific SMRs would have been even lower.

A Norwegian study of ferrochromium workers found an SMR of 0.81 [7] but a Swedish study of 1876 men working in ferrochromium production and followed from 1951 to 1975 found an SMR of 0.99 [8]. In three studies in the French stainless steel industry, the total SMRs were 0.82 (95% CI 0.69–0.97), 1.04 (95% CI 0.95–1.14) and 0.91 (95% CI 0.84–0.98) [4–6]. The Swedish study reported an SMR for circulatory diseases of 1.04 (95% CI 0.90–1.20) [8]. In the French studies, the SMRs for circulatory diseases were 1.04 (95% CI 0.73–1.44), 0.87 (95% CI 0.70–1.06) and 0.90 (95% CI 0.77–1.04) [4–6]. The Swedish study found an SMR for respiratory diseases of 0.76 (95% CI 0.76–1.23) [8]. In the French stainless steel industry cohorts, the SMRs were 0.15 (95% CI 0.00–0.86), 0.88 (95% CI 0.51–1.40) and 0.89 (0.57–1.09) [4–6]. In the Swedish study, the SMR for deaths due to accidents, poisoning, suicides and violence was 1.3 (95% CI 1.0–1.8) [8]. In the French stainless steel industry studies, the SMRs for accidents and violence were close to 1.0 [4,5].

Our results for cancer mortality reflect the observations for cancer incidence of the same cohort published and discussed before [3]. Since the numbers of

cancer deaths are smaller than numbers of incident cancers and the accuracy of incidence information, from the Finnish Cancer Registry, is higher than can be obtained from death-certificate-based mortality statistics, we do not discuss the cancer-specific SMRs here.

Smoking is the most important confounder and has not been controlled for in most studies. It may lead to a bias in a different direction, depending on whether smoking in the cohort is lower or higher than in the reference population. Smoking habits of a representative sample of the employees of the Tornio Works were documented in connection with two identical cross-sectional respiratory health studies in 1993 and 1998 [2]. The prevalence of smoking in male employees in 1993 varied from 28% in the ferrochromium smelter and stainless steel melting shop to 58% in the chromite mine and in 1998 from 27% in the ferrochromium smelter and the stainless steel melting shop to 43% in the cold rolling mill. The prevalence of smoking in men in the province of Lapland in Northern Finland in 1990–2005 varied from 20% in the highest educational class to 42% in the lowest one [18]. Hence, the confounding due to smoking in our study appears to be small and the smoking figures rather point towards a negative confounding.

SMRs observed in studies from different ferrochromium industry cohorts may vary due to differences in industrial processes and exposure levels. For instance, the ferrochromium electric arc furnaces in Norway were either open or semi-closed furnaces, while the Finnish furnaces are fully closed ones with reducing conditions within the furnace. The production technology has been developed continuously and best available technology utilized. The driving forces have been not only occupational hygiene and safety, but also productivity, energy efficiency and environmental impact, all of which have benefitted from active development. This technological feature explains why the exposure levels to Cr^{6+} were substantially higher in the Norwegian cohorts (variation 13–8000 μg/m^3) than in the Finnish one (median below 0.5 μg/m^3 and maximum 2.4 μg/m^3).

It is common for mortality to be low for some years after first employment (healthy worker effect) but in this cohort the SMRs remained low throughout follow-up. The health of all employees at Tornio Works was monitored regularly by the company's own on-site occupational health unit, which besides preventive services also provided treatment of common acute and chronic diseases and illnesses. This, in addition to selection of employees with relatively healthy lifestyle, may have contributed to decreased disease mortality among workers in the cohort.

General safety awareness at Tornio Works has been raised by frequently organized safety campaigns. Occupational safety has been a top priority in the company's operations for decades.

Key points

- Mortality from respiratory and circulatory diseases in Finnish ferrochromium and stainless steel industry workers was not increased as might have been expected on the basis of earlier publications.
- We found no increase in mortality from other diseases or accidents and violence.
- The occupational exposures or working conditions in the Finnish ferrochromium and stainless steel industry appear not to be associated with increased mortality from any cause of death.

Funding

This research received no specific grant from any funding agency in the public, commercial or not-for-profit sectors.

Acknowledgements

We thank Aki Kanervo, Armi Terho and Riitta Ervasti for their great input in collecting the study cohort.

Conflicts of interest

M.H. has been employed by the Outokumpu group since 1975.

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