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ORIGINAL ARTICLE

Cancer incidence among firefighters: 45 years of follow-up in five Nordic countries

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Novelty & Impact

This study describes the cancer incidence pattern among over 16 000 firefighters with more than 2500 cancer cases. There was a small excess in the overall cancer incidence, but quite high and statistically significant excesses, for example, for prostate cancer in younger ages; and for multiple myeloma, adenocarcinoma of the lung, and mesothelioma in older ages.
Observations from this large cohort with long and complete follow-up strengthen the International Agency for Research on Cancer classification that occupational exposure related to firefighting is possibly associated with cancer risk.

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ABSTRACT

Objectives Firefighters are potentially exposed to a wide range of known and suspected carcinogens through their work. The objectives of this study were to examine the patterns of cancer among Nordic firefighters, and to compare them with the results from previous studies.
Methods Data for this study were drawn from a linkage between the census data for 15 million people from the five Nordic countries and their cancer registries for the period 1961–2005. SIR analyses were conducted with the cancer incidence rates for the entire national study populations used as reference rates.
Results A total of 16 422 male firefighters were included in the final cohort. A moderate excess risk was seen for all cancer sites combined, (SIR=1.06, 95% CI 1.02 to 1.11). There were statistically significant excesses in the age category of 30–49 years in prostate cancer (SIR=2.59, 95% CI 1.34 to 4.52) and skin melanoma (SIR=1.62, 95% CI 1.14 to 2.23), while there was almost no excess in the older ages. By contrast, an increased risk, mainly in ages of 70 years and higher, was observed for non-melanoma skin cancer (SIR=1.40, 95% CI 1.10 to 1.76), multiple myeloma (SIR=1.69, 95% CI 1.08 to 2.51), adenocarcinoma of the lung (SIR=1.90, 95% CI 1.34 to 2.62), and mesothelioma (SIR=2.59, 95% CI 1.24 to 4.77). By contrast with earlier studies, the incidence of testicular cancer was decreased (SIR=0.51, 95% CI 0.23 to 0.98).
Conclusions Some of these associations have been observed previously, and potential exposure to polycyclic aromatic hydrocarbons, asbestos and shift work involving disruption of circadian rhythms may partly explain these results.

What this paper adds

- This first study on cancer risk among Nordic firefighters indicates a small excess in the overall cancer incidence.
- There are more prostate cancer cases diagnosed in ages <50 years than in the men in the general population.
- Risk of myeloma, adenocarcinoma of the lung and mesothelioma are increased in older ages.
- By contrast with earlier studies, the incidence of testicular cancer was decreased.

INTRODUCTION

Firefighters are potentially exposed to a wide range of known and suspected carcinogens through their work. The constituents of fire smoke vary according to combusted materials and other factors, but benzene, formaldehyde, polycyclic aromatic hydrocarbons and fine particulates are common.[1] Exposures can be quite high, although usually for short periods of time. Firefighters may also be exposed to asbestos, which may be released when older structures burn, and historically, asbestos was a component of some protective equipment, such as gloves.[1 2] Last, firefighters may be exposed to diesel exhaust, recently classified as a human lung carcinogen, from firefighting vehicles.[3 4] Additionally, most firefighters work rotating or extended shifts to provide 24 h fire protection, which may involve disruption of circadian rhythms.[1]

Many cohort studies have been conducted, but the results have been inconsistent, and the risk of cancer among firefighters has been a controversial topic, especially in North America where workers' compensation has been a contentious issue. Recently, two large, comprehensive reviews of cancer in firefighters have been completed. The first was a meta-analysis of 32 studies conducted by LeMasters *et al*[5] which evaluated the risk for 21 cancers. Based on the strength of the association, consistency and study type, the authors classified multiple myeloma, non-Hodgkin lymphoma, prostate cancer and testicular cancer as probably being associated with firefighting. Additionally, cancer of the skin, brain, rectum, buccal cavity and pharynx, stomach and colon, as well as malignant melanoma and leukaemia were classified as possibly related to firefighting.

The second comprehensive review was conducted by an International Agency for Research on Cancer (IARC) monograph working group (2010) as part of its evaluation of firefighting. The group reviewed the results of 42 studies, including the results of two large epidemiology studies that had been published after the review by LeMasters *et al*.[5] Based on internal meta-analyses, consistency of the studies and limited dose-response information using duration of employment, the working group concluded that the strongest evidence was for testicular cancer, prostate cancer and non-Hodgkin lymphoma. However, the working group, as a whole, classified firefighting exposure as being only possibly associated with cancer (IARC Category 2B).[1]

Linked

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Although many studies on firefighters have been conducted, the great majority were limited to cancer information from death certificates. The use of death certificates limits the ability to study the cancer sites with high survival rates as well as those based on histology. Additionally, many of the previous studies were not sufficient in size to examine the risk of rare cancers. Last, few studies of firefighters have been conducted outside of North America. The Nordic countries, with their national cancer registries and ability to conduct record linkage, would seem to be ideal places to study firefighters. The Nordic firefighter unions have recently—after having had several cases of, for example, young-age prostate cancers in one single fire department—showed special interest in knowing about cancer risk in their occupation, which makes this topic especially pertinent at this time.

Two small cohort studies have previously been conducted in the Nordic countries. Hansen in 1990 observed an excess risk lung cancer mortality among Danish firefighters, but had limited power to examine the risk of other specific cancers.[6] Tornling and colleagues in 1994 identified possible dose-response relationships with the number of fires fought, for stomach and brain cancer, in a retrospective cohort study of Stockholm firefighters.[7] It was among the best studies conducted to date in terms of exposure information, but was limited in size.

Recently, the Nordic Occupational Cancer (NOCCA) project (http://astra.cancer.fi/NOCCA) linked the census data on occupations from the five Nordic countries and their cancer registries for the period from 1961 to 2005.[8] In this paper, we use data collected for the NOCCA study and present the results for cancer incidence among Nordic firefighters. The objectives of these analyses were to demonstrate the patterns of cancer among Nordic firefighters and compare them with the results from previous studies.

MATERIALS AND METHODS

The details of study materials, coding systems and analysis methods have been described earlier.[8] Briefly, the study base consists of approximately 14.9 million persons participating in any computerised population census in the five Nordic countries: Denmark (1970 census), Finland (1970, 1980 and 1990 censuses), Iceland (1981 census), Norway (1960, 1970 and 1980 censuses) and Sweden (1960, 1970, 1980 and 1990 censuses). The study cohort included male firefighters aged 30–64 years still alive and in the country on January 1st of the year following the census. Female firefighters were excluded because there were too few for analysis.

Census questionnaires included questions related to the persons' economic activity, occupation and industry. All census questionnaires were centrally coded and computerised in the national statistical offices. In Finland, Norway and Sweden, occupation was coded according to national adaptations of the International Standard Classification of Occupations (ISCO) from 1958,[9] and in Iceland according to ISCO 1968.[10] In Denmark, occupation was coded according to a national nomenclature with a distinction between self-employed persons, family workers, salaried employees, skilled workers and unskilled workers. All countries had a specific occupational code for professional firefighters, and a person was classified as a firefighter if he had been working as that for more than half the regular working hours during the census year. Office workers and other non-firefighter personnel of fire departments were not classified as firefighters.

A person entered the cohort on January 1st of the year after the first available census where he participated. Person-years were then counted until the date of emigration, death or to 31 December of the following years: in Denmark and Norway 2003, in Iceland 2004 and in Finland and Sweden 2005. The source of the data on dates of death and emigration in all countries was the Central Population Register. Data on tumours were derived from record linkage with the cancer registries from each of the five Nordic countries. National cancer registration started with cancer diagnosed in 1943 in Denmark, in 1953 in Finland and Norway, in 1955 in Iceland and in 1958 in Sweden. During the follow-up period of the NOCCA study, all cancer registries received information on cancer cases from general and specialist practitioners, hospital departments and from pathology autopsy notifications. All countries except Denmark received notifications from pathology departments. Sweden was the only country not receiving copies of the death certificates. The completeness and accuracy of the Nordic cancer registries are very high in international comparison, and much work has been done to reach comparability in cancer classifications between the Nordic countries over the more than five decades of cancer registration.[11]

The cancer cases have been grouped into 49 main categories and 27 diagnostic subgroups based on the national topography and morphology coding systems (Appendix tables 5–6 at http://astra.cancer.fi/NOCCA). The incident cancer cases included in the present study involve all invasive cancers and also benign brain tumours. The non-melanoma skin cancers were excluded from the 'All cancers' category, as basal cell carcinomas of the skin could not be separated from the rest of the 'Non-melanoma skin cancers' (primarily squamous cell carcinomas) in the Danish data. In the present study, only the first incident cancer within a given diagnostic group was included in the Danish and Icelandic data. This practice induced slight incomparability between the incidence rates in Denmark and Iceland and the other Nordic countries, but it had virtually no effect on relative risk estimates.

The SIR in a given country was calculated as the ratio of the observed and the expected number of cancer cases, using the cancer incidence rates for the entire national male study populations as reference rates. For each country, the observed number of cancer cases and person-years were stratified into eight 5-year attained age categories (30–34; 35–39; …; 85+ years) and into 5-year calendar periods (1971–1975; 1976–1980; …; 2001–2005). The expected number of cancer cases was based on number of person-years in each stratum (country, age and calendar period) and the respective reference rates. Aggregate risk measures for all Nordic countries combined were calculated as the ratio of the total number of observed cases to the total number of expected cases of the five countries. For each SIR, the exact 95% CI was defined assuming a Poisson distribution of the observed number of cases.

Results stratified by country, time period and age group are shown for all cancer sites combined for the sites observed to have an excess overall, and for the sites of a priory interest identified from the reviews by the IARC[1] and LeMasters *et al*[5] (prostate cancer, testicular cancer and non-Hodgkin lymphoma).

RESULTS

A total of 16 422 male firefighters with 412 991 person-years were included in the cohort. The cohort included 8144 men from Sweden, 4740 from Finland, 2579 from Norway, 760 from Denmark and 199 from Iceland.

Altogether, 2653 cancer cases were observed; 1182 from Sweden, 675 from Norway, 496 from Finland, 275 from

Table 1 Cancer incidence among 16 422 male Nordic firefighters, follow-up 1961–2005

Cancer site (ICD-10)	Observed	SIR	95% CI
All cancers	2536	1.06	1.02 to 1.11
Lip (C00)	17	0.80	0.46 to 1.28
Tongue (C01–02)	11	1.04	0.52 to 1.87
Salivary glands (C07–08)	10	1.69	0.81 to 3.11
Oral cavity (C03–06)	11	0.80	0.40 to 1.43
Pharynx (C09–14)	19	1.00	0.60 to 1.57
Oesophagus (C15)	31	0.98	0.66 to 1.39
Stomach (C16)	128	1.09	0.91 to 1.30
Small intestine (C17)	13	1.15	0.61 to 1.97
Colon (C18)	198	1.14	0.99 to 1.31
Rectum, rectosigma (C19–21)	119	0.99	0.82 to 1.19
Primary liver (C22)	25	0.91	0.59 to 1.34
Gallbladder (C23–24)	18	1.45	0.86 to 2.29
Pancreas (C25)	87	1.17	0.94 to 1.45
Larynx (C32)	31	1.06	0.72 to 1.50
Lung (C33–34)	310	0.97	0.87 to 1.09
Adenocarcinoma	80	1.29	1.02 to 1.60
Squamous cell carcinoma	90	0.88	0.71 to 1.08
Small cell carcinoma	34	0.83	0.58 to 1.16
Skin melanoma (C43)	109	1.25	1.03 to 1.51
Mesothelioma (C45)	17	1.55	0.90 to 2.48
Soft tissue (C48–49)	18	1.16	0.69 to 1.84
Penis (C60)	12	1.53	0.79 to 2.67
Prostate (C61)	660	1.13	1.05 to 1.22
Testicular (C62)	9	0.51	0.23 to 0.98
Kidney (C64–65)	84	0.94	0.75 to 1.17
Bladder (C66–68)	194	1.11	0.96 to 1.28
Brain (C70–71)	64	0.86	0.66 to 1.10
Glioma	33	0.92	0.64 to 1.30
Thyroid (C73)	17	1.28	0.75 to 2.05
Non-Hodgkin lymphoma (C82–85,C96)	82	1.04	0.83 to 1.29
Multiple myeloma (C90)	41	1.13	0.81 to 1.53
Leukaemia (C91–95)	56	0.94	0.71 to 1.22
Acute myeloid	21	1.27	0.79 to 1.94
Not included above			
Non-melanoma skin cancer* (C44)	117	1.33	1.10 to 1.59

*Excludes Denmark.

Denmark and 25 from Iceland. Out of them, 117 were non-melanoma skin cancers that were excluded from 'all cancers', leaving altogether 2536 cancers in that category with 2392 expected cases (SIR=1.06, 95% CI 1.02 to 1.11).

Table 1 presents the summary results for the major cancer sites (those with 10 or more cases) and testicular cancer, because of its a priori interest. The observed number of cancers was slightly more than expected due to excesses in Denmark and Norway (table 2). Cancers of prostate, colon and bladder contributed most to this excess. The 95% CIs of the country-specific SIRs overlapped (table 2). The numbers of cancer cases among firefighters in each Nordic country were so small that we would have been able to identify only very large differences in cancer risk between the countries.

Small, statistically significant excesses were observed for three cancer sites; prostate (SIR=1.13, 95% CI 1.05 to 1.22), skin melanoma (SIR=1.25, 95% CI 1.03 to 1.51) and non-melanoma skin cancer (SIR=1.33, 95% CI 1.10 to 1.59). The excess of prostate cancer was observed in Finland, Norway and Sweden, while excesses of skin melanoma were observed in all

Table 2 Cancer incidence among 16 422 male Nordic firefighters, follow-up 1961–2005, by country

	Denmark			Finland			Iceland			Norway			Sweden		
Cancer site	Obs.	SIR	95% CI	Obs.	SIR	95% CI	Obs.	SIR	95% CI	Obs.	SIR	95% CI	Obs.	SIR	95% CI
All cancers	275	1.25	1.11 to 1.41	484	0.97	0.89 to 1.06	24	0.96	0.61 to 1.42	644	1.20	1.11 to 1.30	1109	1.00	0.95 to 1.07
Lung	56	1.37	1.03 to 1.77	71	0.76	0.60 to 0.97	3	0.91	0.19 to 2.66	87	1.18	0.95 to 1.46	93	0.87	0.70 to 1.06
Adenocarcinoma	16	1.90	1.09 to 3.08	15	1.03	0.58 to 1.71	[0.95]	0	0.00 to 3.88	22	1.55	0.97 to 2.34	27	1.13	0.74 to 1.64
Skin melanoma	5	1.08	0.35 to 2.53	20	1.16	0.71 to 1.79	1	1.83	0.05 to 10.21	32	1.61	1.10 to 2.28	51	1.14	0.85 to 1.50
Non-melanoma skin				12	0.94	0.49 to 1.65	1	1.42	0.04 to 7.93	31	1.32	0.90 to 1.87	73	1.43	1.12 to 1.79
Mesothelioma	1	0.92	0.02 to 5.13	4	1.55	0.42 to 3.98	[0.08]	0	0.00 to 44.45	6	2.78	1.02 to 6.06	6	1.18	0.43 to 2.58
Prostate	27	1.03	0.68 to 1.50	143	1.21	1.02 to 1.43	6	0.90	0.33 to 1.95	137	1.16	0.97 to 1.37	347	1.11	1.00 to 1.24
Non-Hodgkin lymphoma	6	1.23	0.45 to 2.67	20	0.99	0.60 to 1.52	1	1.18	0.03 to 6.56	14	1.07	0.58 to 1.79	41	1.04	0.74 to 1.41
Multiple myeloma	3	1.08	0.22 to 3.16	6	0.96	0.35 to 2.10	[0.38]	0	0.00 to 9.80	9	0.96	0.44 to 1.82	23	1.32	0.83 to 1.97

The numbers in brackets give the expected numbers of cases when Obs=0.

five countries. The excess of skin melanoma was primarily driven by excess in Norway, and that for non-melanoma skin cancer by excesses in Norway and Sweden (table 2).

No overall excess of lung cancer was observed in the Nordic countries combined, although a statistically significant excess was observed in the Danish data (table 2). However, further analysis of lung cancer in the full cohort by histology revealed an excess of adenocarcinoma (SIR=1.29, 95% CI 1.02 to 1.60) and a deficit of squamous and small-cell carcinoma (table 1).

The only cancer site with an upper confidence limit lower than 1.0 was testicular cancer (SIR=0.51, 95% CI 0.23 to 0.98), based on nine observed and 17.6 expected cases. Eight of the testicular cancer cases were in the age category of 30–49 years (SIR in that age range is 0.65, 95% CI 0.28 to 1.29), leaving only one observed case vs 5.4 cases expected in the older ages (SIR 0.19, 95% CI 0.01 to 1.03).

The overall relative risk of cancer increased with age (table 3). Among firefighters over the age of 70 years, the SIRs for lung cancer, its subcategory adenocarcinoma, mesothelioma, non-melanoma skin cancer and multiple myeloma were highest and all significantly elevated. By contrast, the SIRs for prostate cancer and skin melanoma were most elevated in the youngest age category (30–49 years). No other associations with an age group at risk were observed.

The SIR of skin melanoma was highest during earlier time periods, while the risk for non-melanoma skin cancer was elevated during later time periods (table 4).

No mesothelioma cases were observed prior to 1976. Outside of the cancer sites listed in the table, there was a significantly excess risk of penile cancer in the period 1961–1975 (SIR=4.50, 95% CI 1.23 to 11.5, based on 4 observed cases), and of bladder cancer in the period 1976–1990 (SIR=1.37, 95% CI 1.09 to 1.71, based on 80 observed cases).

DISCUSSION

This is the first large study of cancer incidence among firefighters in the Nordic countries. The overall cancer incidence was close to that of the general population, but statistically significant excesses were observed for several cancers.

The pattern of excess cancer incidence observed in this study is at least partly consistent with patterns observed in previous studies (table 5). Although small, the excesses of malignant melanoma, non-melanoma skin cancer and prostate cancer have been observed in many other studies.[1] Additionally, the small, non-significant excesses of stomach cancer, colon cancer and multiple myeloma seen in our study were also identified in the meta-analyses of LeMasters *et al*.[5] By contrast with the IARC[1] and LeMasters *et al*[5] comprehensive reviews, our study observed significantly fewer testicular cancers than predicted. A similar finding of reduced testicular cancer incidence (SIR 0.74, 95% CI 0.41 to 1.22) from the simultaneous study of almost 30 000 US career firefighters employed since 1950 and followed through 2009,[12] makes it less likely that our observation would be due to chance only. The aetiology of testicular cancer is unknown, and hence, we cannot give any explanation on this finding.

This study provides only little support for the meta-analysis result for non-Hodgkin lymphoma,[5] since the SIR for this cancer was above 1.0 only among firefighters over the age of 70 years. Care should be taken when comparing observations derived from different studies, because the calendar periods of exposure and follow-up, age distribution of the years at follow-up and even the levels of reference rates used in comparison greatly affect the relative risk estimates.

Although the overall excesses were modest, there were quite high relative risks either in the youngest or oldest age categories of follow-up. The more than twofold excess of prostate cancer in ages below 50 years observed in this study is of particular interest because of recent concerns regarding shift work involving the disruption of circadian rhythms.[1] Although breast cancer has been the main focus of study for shift work, all four studies of acceptable quality on prostate cancer among night workers show an almost twofold increased risk.[13–16] Additionally, studies of flight crews have also identified greater than expected numbers of prostate cancers.[1 17] It is not possible, based on existing studies, to qualify whether some type of shift is worse than others in terms of adding a risk of prostate cancer. We do not have statistics of shift types of firefighters in various Nordic countries in the past, but it is likely that they vary between countries and even within countries. In Denmark and Finland, it has been common to have 12 h and 24 h shifts. It is, however, important to keep in mind that the majority of firefighters normally sleep during the night, except if fires occur. We do not know about the quality of firefighters' sleep, but they probably sleep less than ordinary day workers (which in itself is suggested as contributing to prostate cancer) and have lower quality of sleep.

One review has also suggested there may be evidence for an association between prostate cancer and polycyclic aromatic hydrocarbons and diesel exhaust.[18] The excess observed among relatively young men is intriguing and should be examined in other cohorts. Daniels *et al*[12] report in their paper that excess of prostate cancer was limited to ages of 45–59 years (SIR=1.44, 1.27 to 1.63), but they kindly calculated the SIR for

Table 3 Cancer incidence among 16 422 male Nordic firefighters, by age at follow-up

	30–49 years			50–69 years			70+ years		
Cancer site	Obs.	SIR	95% CI	Obs.	SIR	95% CI	Obs.	SIR	95% CI
All cancers	208	0.95	0.83 to 1.09	1257	1.03	0.97 to 1.09	1071	1.14	1.07 to 1.21
Lung	15	0.76	0.43 to 1.25	154	0.82	0.69 to 0.96	141	1.28	1.08 to 1.52
Adenocarcinoma	2	0.40	0.05 to 1.46	41	1.09	0.78 to 1.48	37	1.90	1.34 to 2.62
Skin melanoma	37	1.62	1.14 to 2.23	54	1.22	0.92 to 1.60	18	0.90	0.53 to 1.42
Non-melanoma skin	4	0.80	0.22 to 2.04	38	1.28	0.91 to 1.76	75	1.40	1.10 to 1.76
Mesothelioma	1	1.02	0.03 to 5.69	6	0.98	0.36 to 2.13	10	2.59	1.24 to 4.77
Prostate	12	2.59	1.34 to 4.52	309	1.16	1.04 to 1.30	339	1.09	0.98 to 1.21
Non-Hodgkin lymphoma	11	0.82	0.41 to 1.46	38	0.95	0.67 to 1.31	33	1.30	0.89 to 1.83
Multiple myeloma	0*	0.00	0.00 to 1.16	17	0.90	0.53 to 1.45	24	1.69	1.08 to 2.51

*Expected number of cases=3.2.

Table 4 Cancer incidence among 16 422 male Nordic firefighters, by period of follow-up

Cancer site	1961–1975 Obs.	SIR	95% CI	1976–1990 Obs.	SIR	95% CI	1991–2005 Obs.	SIR	95% CI
All cancers	196	1.00	0.86 to 1.15	838	1.11	1.03 to 1.19	1502	1.05	1.00 to 1.11
Lung	27	0.92	0.60 to 1.33	109	0.90	0.74 to 1.09	174	1.04	0.89 to 1.21
Adenocarcinoma	4	1.19	0.32 to 3.05	26	1.27	0.83 to 1.87	50	1.31	0.97 to 1.72
Skin melanoma	12	1.94	1.00 to 3.39	37	1.39	0.98 to 1.92	60	1.11	0.84 to 1.42
Non-melanoma skin	2	0.55	0.07 to 1.98	27	1.28	0.84 to 1.86	88	1.39	1.11 to 1.71
Mesothelioma	0*	0.00	0.00 to 10.5	5	1.56	0.51 to 3.64	12	1.62	0.84 to 2.83
Prostate	20	0.97	0.59 to 1.49	145	1.10	0.93 to 1.29	495	1.15	1.05 to 1.26
Non-Hodgkin lymphoma	1	0.23	0.01 to 1.29	26	1.12	0.73 to 1.64	55	1.08	0.81 to 1.40
Multiple myeloma	4	1.17	0.32 to 2.99	11	0.87	0.44 to 1.57	26	1.28	0.84 to 1.88

*Expected number of cases=0.35.

the same age category that was used in our study, that is, 30–49 years. Their SIR rate for prostate cancer in this age range is 2.04 (95% CI 1.43 to 2.82), which is similar to the rate seen in our cohort (SIR 2.59, 95% CI 1.34 to 4.52). This finding is new. One explanation of the excess incidence might be that the firefighters would be targeted for prostate-specific antigen (PSA) testing in ages below 50 years more often than other men in the same ages.

No documentation is available on this point, but occupational health experts we have consulted do not expect this to be the case. The SIR of prostate cancer in ages 30–49 years did not change after the frequency of PSA testing started to rapidly increase in the 1990s which further increases the possibility that the finding might not be due to surveillance bias.

This study observed a small excess of malignant melanoma of the skin and non-melanoma skin cancer. These results are consistent with a number of previous studies of firefighters.[5] Skin cancer has been associated with a number of polycyclic aromatic hydrocarbon-related exposures, such as soot, coal tar pitch volatiles and unrefined mineral oils.[19] The combustion of any organic materials, as may be encountered by firefighters, are likely to contain polycyclic aromatic hydrocarbons. Associations between occupational exposures and malignant melanoma are not well established. In our stratified analyses, malignant melanoma and non-melanoma skin cancer show opposite relationships with age (skin melanoma elevated in younger firefighters, non-melanoma skin cancer in older groups) and time period (skin melanoma elevated in the earliest time period, non-melanoma skin cancer in a later time period).

The large US firefighter cohort study[12] could only give rates for skin melanoma. In their cohort, the SIR was low in the age category of 30–59 years (SIR 0.44, 95% CI 0.22 to 0.79) and close to 1.0 in the older age categories. We, in turn, observed an excess of skin melanoma in the age range of 30–59 years (SIR 1.62, 95% CI 1.14 to 2.23) and SIRs close to 1.0 in the older age categories. Registration of skin cancers in the USA may be less complete than for other types of cancer. Furthermore, in the case of skin melanoma (with large geographic variations in incidence), the problem of having the firefighter cohort mainly from California but reference incidence rates from the entire Surveillance, Epidemiology, and End Results (SEER) population might cause bias, and the US results should be interpreted with caution. In the Nordic countries, an elevated risk of skin melanoma has been observed among persons of quite high socioeconomic position, such as airline pilots, for whom tanned skin has been a symbol of a healthy appearance.[17] The sun exposure of the firefighters is not known, but it could potentially play a role.

Table 5 Comparison of relative risk estimates of current and earlier studies on cancer incidence among firefighters

Cancer site	Current study SIR (95% CI)	Daniels *et al*[12] SIR (95% CI)	LeMasters *et al*[5] mRR (95% CI)	IARC[1] SIR (95% CI)
All sites	1.06 (1.02 to 1.11)	1.09 (1.06 to 1.12)	1.05 (1.00 to 1.09)	
Buccal cavity and pharynx	0.92 (0.62 to 1.31)*	1.32 (1.08 to 1.58)*	1.23 (0.96 to 1.55)	
Stomach	1.10 (0.91 to 1.30)	1.15 (0.93 to 1.40)	1.22 (1.04 to 1.44)	
Colon	1.14 (0.99 to 1.31)	1.21 (1.09 to 1.34)	1.21 (1.03 to 1.41)	
Rectum	0.99 (0.82 to 1.19)	1.11 (0.94 to 1.30)	1.29 (1.10 to 1.51)	
Skin melanoma	1.25 (1.03 to 1.51)	0.87 (0.73 to 1.03)	1.32 (1.10 to 1.57)	
Non-melanoma skin	1.33 (1.10 to 1.59)		1.39 (1.10 to 1.73)	
Mesothelioma	1.55 (0.90 to 2.48)	2.29 (1.60 to 3.19)		
Prostate	1.13 (1.05 to 1.22)	1.03 (0.98 to 1.09)	1.28 (1.15 to 1.43)	1.30 (1.12 to 1.51)
Testicular	0.51 (0.23 to 0.98)	0.74 (0.41 to 1.22)	2.02 (1.30 to 3.13)	1.47 (1.20 to 1.80)
Brain	0.86 (0.66 to 1.10)	1.02 (0.76 to 1.34)	1.32 (1.12 to 1.54)	
Non-Hodgkin lymphoma	1.04 (0.83 to 1.29)	0.99 (0.84 to 1.15)	1.51 (1.31 to 1.73)	1.21 (1.08 to 1.36)
Multiple myeloma	1.13 (0.81 to 1.53)	0.72 (0.50 to 0.99)	1.53 (1.21 to 1.94)	
Leukaemia	0.91 (0.71 to 1.22)	0.94 (0.77 to 1.15)	1.14 (0.98 to 1.31)	

*Combined SIR for buccal cavity and pharynx.
IARC, International Agency for Research on Cancer; mRR: meta risk ratio (summary risk estimate across all types of incidence and mortality studies[5]).

This is the first study to identify an excess of mesothelioma among firefighters. Consistent with its long latency, a significant excess was observed in older firefighters. This may indicate a continuing hazard faced by firefighters encountering asbestos remaining in building materials. Asbestos exposure has long been identified as a potential concern among firefighters, but previous studies may not have had sufficient weight or enough long follow-up to identify a small, but important excess of this cancer. One of the reasons for the lack of previous reports on mesothelioma is simply that nearly all previous studies examined mortality using the underlying cause of death as coded according to ICD versions prior to ICD-10. A specific mesothelioma code was not available until the 1990s with the publication of ICD-10. The SIR for mesothelioma was highest in Norway (table 2), but the differences between the country-specific rates are not statistically significant. We do not have any information suggesting that asbestos exposure in Norway would be higher than in the other countries. The SIRs in the US data by Daniels *et al*[12] for the age category of 70+ was 2.44 (95% CI 1.55 to 3.67), which is almost identical with the respective rate in our Nordic cohort (SIR=2.59, 95% CI 1.24 to 4.77). Daniels also observed an excess risk of mesothelioma in the age category of 50–69 years (SIR 2.22, 95% CI 1.14 to 3.87) while we did not. Such a difference may well be related to different patterns and time periods of asbestos use in the buildings in California and the Nordic countries.

Although the lung would seem a likely target organ for firefighters exposed to combustion products and diesel exhaust, excesses of respiratory cancer have only rarely been observed. One exception is the earlier Danish study,[6] which observed an excess of lung cancer among older firefighters. Our study also observed an excess of lung cancer, which was only among Danish firefighters and mainly due to the high relative risk of adenocarcinoma of the lung among older firefighters. The other two large cohort studies of firefighters to examine incident cancer did not report analyses by histologic type.[12 20]

Our study was based on a large cohort with a long follow-up period. Due to the high coverage, precision and validity of the linked files, the cancer risk estimates can be considered reliable. Because the present study was based on incident cancer cases and exact person-years, there was no bias caused by occupational variation in cancer survival and in mortality from competing causes of death.

The occupational affiliation at one point in time may not always correspond to the lifelong occupational history of a person. Comparison of results based on only one cross-sectional information on occupation with results from studies with complete occupational histories indicates that the diluting effect due to misclassification is small especially in specialised occupations.[8] The average age for firefighters to finish their education in Finland in 2005–2013 was 24.7 years. The occupational stability is high, and up to the age of 55 years, more than 80% of the men pass the physical test and stay in the operational firefighter work.

This study on firefighters, however, has several specific limitations that should be considered. Information on duration of employment and other characteristics of exposure was not available. Assessing firefighters' exposure is a difficult challenge for any study. Only two studies have gone beyond simple duration and created metrics based on the numbers of fires fought.[7 21] However, even the number of fires may not always be a good surrogate for actual exposure.[22] As with all other retrospective studies of firefighters, our ability to control for confounding was very limited. Thus, characteristics of firefighters, such as lifestyle factors that differ with the general population, could confound our results. For example, if the study population had higher levels of non-occupational sun exposure, it could increase their risk of skin cancer.

The firefighters probably represent a selected population group in terms of general health conditions. Firefighters are mainly employed by the municipalities and may be required to undergo a health check before recruitment, and an extensive health check is required for participation in firefighter team leader courses. We know some of the characteristics of Finnish firefighters from surveys on the health habits of the Finnish adult population during 1978–1991 collected for the Finnish Job Exposure Matrix.[23] The prevalence of smoking among firefighters was 29%, which is lower than in the general male population (33%). Weekly alcohol consumption was 112 g (population: 84 g), and body mass index (BMI) 26.1 (25.4). These data suggest that firefighters follow a quite similar way of life than the reference population, and therefore our cancer risk estimates should not be strongly confounded by lifestyle factors. In a recent study on cancer risk of male world class athletes,[24] the BMI of the athletes was not considered to indicate overweight in the same way as among average persons and was not included in the analyses, because the BMI for athletes is elevated due to muscular build instead of body fat.[25]

This study has several important strengths compared to previous studies. In terms of numbers of cases, this is larger than any cohort study of firefighters published before 2014. Thus, this study had the capability to identify small excesses, even for relatively rare cancers. Additionally, this study had access to high-quality cancer registry data from across the Nordic countries. The cancer incidence data allowed for better identification of non-fatal cancers and those identified on the basis of histology (such as mesothelioma), as well as allowing the examination of histologic subtypes of cancer.[26]

In summary, this study suggests that firefighters may be at increased risk of prostate cancer, malignant melanoma, non-melanoma skin cancer, multiple myeloma, mesothelioma and lung adenocarcinoma. Some of these associations have been observed previously, and potential exposure to polycyclic aromatic hydrocarbons, asbestos and shift work involving disruption of circadian rhythms may explain some of these associations. However, further studies of firefighters with better indices of exposure and, ideally, more individual-level information on other risk factors for cancer are needed to more firmly explore the aetiology of these cancers among firefighters.

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