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ORIGINAL ARTICLE

Long-term follow-up for cancer incidence in a cohort of Danish firefighters

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ABSTRACT

Objectives To examine cancer incidence among Danish firefighters using several employment-related exposure subgroups.

Methods A historical cohort of 9061 male Danish firefighters was established from collected personnel and membership records from employers and trade unions. Using the unique Danish personal identification number, information on additional previous employment, cancer and vital status was linked to members of the cohort from the Supplementary Pension Fund Register, the Danish Cancer Registry and the Danish Civil Registration System. SIRs were calculated for specific cancer types using rates for the general population, a sample of the working population and military employees, respectively.

Results Compared with the selected reference groups, the overall observed incidence of cancer among the firefighters was at level with the expected (SIR 1.02, 95% CI 0.96 to 1.09 vs the general population). The SIR for colon cancer was consistently significantly reduced, while the slight excess seen for melanoma of the skin, prostate and testicular cancer compared with the general population was not reproduced using the military as reference.

Conclusions Previous associations with melanoma of the skin, prostate and testicular cancer are supported by our main results. However, the increase in incidence of these cancers is not reproduced using the military as reference. Similarities in cancer profile for the firefighters and the military point to shared risk factors in either lifestyle or work environment.

What this paper adds

- Previous studies on cancer incidence among firefighters have indicated a possible occupational association for especially non-Hodgkin's lymphoma, melanoma, prostate and testicular cancer.
- We examined a cohort of 9061 Danish firefighters using the general population and two alternative occupational groups as reference and found no overall increase in cancer incidence. While a slight excess of melanoma of the skin, prostate and testicular cancer was seen among the firefighters compared with the general population, the incidence of these cancers was not increased using the military as reference.
- The observed similarities in cancer profile for the firefighters and military employees point to shared aetiological factors in either work or way of life. In consequence, focus on factors other than fire smoke should also be emphasised in future research.

INTRODUCTION

Where there is fire there is smoke and depending on the material burning and conditions for combustion, fire smoke contains particles, vapour and gasses in a complex mixture of chemicals offering a hostile and dangerous environment to firefighters working in it. Common components of fire smoke thus include known human carcinogens such as benzene, polycyclic aromatic hydrocarbons (PAH), polychlorinated biphenyls (PCB), asbestos, arsenic, 1,3-butadiene, formaldehyde and cadmium, but the spectrum of toxic substances and metabolites potentially present in especially structural or vehicle fires is vast and often unpredictable.[1] In addition, chemicals from extinguishing agents, exhaust gasses and pollution spills add to the overall exposure load of firefighters affecting the body after inhalation, oral and dermal uptake. Furthermore, firefighters are intermittently subjected to extreme thermal, physical and emotional stress and night work.[1]

Evidence of excess cancer morbidity and mortality among firefighters has been gathered for decades. In 2007, the International Agency for Research on Cancer (IARC) conducted a meta-analysis reviewing 42 existing studies in the field classifying firefighting as being possibly carcinogenic (group 2B).[1] At this point, the main suspicion centred on non-Hodgkin's lymphoma, prostate and testicular cancer as the affected outcomes. However, as subsequent studies of firefighters almost consistently report increased risk of malignant melanoma, this is a cause for concern as well.[2–7]

Weakening the evidence of a possible association, many of the available studies are limited on both measures of exposure and outcome. Thus, lacking detailed individual measurement data, duration of employment normally serves as a proxy for exposure despite uncertainty in the correlation with actual toxic effects.[1] Regarding outcomes, only few countries have access to information from reliable long-term national cancer registries. Hence, data from death certificates have frequently been used yielding only measures of mortality and therefore impeding evaluation of cancer types with high long-term survival.

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The aim of this study is to examine the incidence of specific cancers among Danish firefighters using national registries of high quality, and hereby differentiate risk according to several employment-related exposure parameters. Cancers previously associated with firefighting will be of a priori interest, namely melanoma of the skin, non-Hodgkin's lymphoma, prostate and testicular cancer.

MATERIALS AND METHODS

Establishing the cohort

The Danish fire services operate on two main levels. First, a national level consisting of a governmental emergency agency with regional departments ensuring local training and assistance. Second, a municipal level run either by the municipality itself or contracted out to a private or voluntary fire brigade.

In Denmark, no centralised records exist regarding firefighters. Thus, all both municipal, private and volunteer-based Danish fire departments along with trade unions and authorities were contacted initially to retrieve systematic individual employment information from personnel and membership records. All permanent residents in Denmark alive on or after 2 April 1968 have by law been awarded a unique personal identification number (CPR number) by the Danish Civil Registration System (CRS) containing information on sex and date of birth.[8] In addition to this CPR number, basic career data such as employment types, periods, places and functions were collected for past and present firefighters. Finally, people stating their job title as firefighter in the CRS were included as well.[8]

Further employment history for the identified firefighters was extracted from the Danish Supplementary Pension Fund Register (ATP) using their CPR number. Since 1 April 1964, this register has kept information permanently on all employment on company and industry type level by wage earners aged 16–66 years working at least 9 hours/week.[9] Based on these data, unidentified periods of firefighting employment were added to cohort members and previously established periods were confirmed. Combining all retrieved employment records, all municipal districts in Denmark were represented in the cohort.

Study population

With initial evaluation of the collected data records, 17 134 firefighters were identified. Using name, sex, birthdate and workplace, 1254 firefighters missing a CPR number were tracked in the CRS adding numbers for 980 of them unambiguously.[8]

Firefighter records were subsequently examined and only those adhering to all of the cohort criteria were included in the analyses (valid CPR number, valid employment dates confirmed by sources containing both past and present employees, date of birth no earlier than 2 April 1928, firefighting employment before the age of 60 and 31 December 2004, no diagnoses of cancer prior to entering firefighting employment and a job title/function indicating actual firefighting exposure).

Finally, the number of female firefighters identified was insufficient for meaningful cancer analyses and they were thus excluded from the cohort (n=316). For further details on the process of shaping the cohort, see online supplementary figure 1.

Reference groups

Due to hiring requirements, firefighters may have a better baseline health than the general population. Thus, in order to minimise a potential healthy hire effect, two additional external reference groups were constructed using data from the ATP. First, a sample of all types of employees, selected merely based on sex and birth year, was chosen as an image of the working population. Second, all men ever employed by the Danish military were selected as a group resembling the firefighters regarding both socioeconomic status and physical fitness. Apart from firefighting employment, these additional reference groups were shaped according to the same criteria as the cohort securing a sample of 247 350 employees and 391 735 military men.

Exposure

As no single measure could reflect all aspects of firefighting, several proxies for exposure were assessed in this study. Thus, duration of firefighting employment (<1 year, ≥1 year, ≥10 years, ≥20 years), era of first employment (pre-1970, 1970–1994, post-1994), age at first employment (<25 years, ≥25 to <35 years, ≥35 years), employment type (full time, other) and function (regular, specialised) were divided into multiple exposure subcategories.

In Denmark, the majority of the larger urban areas employ full-time career firefighters, whereas rural zones are covered mainly by part time or volunteer workers. While the roles of especially volunteer firefighters differ between and within countries, the ones included in this study were selected for duty with the same criteria, received the same basic training and education and ultimately performed the same tasks as the part-time workers. In consequence, the volunteer and part-time firefighters were analysed together as one group.

Firefighters with multiple employment types were classified as full time if they had ever been such. Justifying this simplification, almost all (99.7%) full-time workers had spent half or more of their time in this type of employment. In addition, a unit of specialised smoke divers were analysed separately as a potential heavy exposure group based on their extensive fire attendance.

Vital status and cancer

Through linkage of CPR numbers to the CRS, vital status, including date of emigration, disappearance or death, was obtained for all cohort and reference group members.[8]

Similarly, all cancers diagnosed in Denmark since 1943 have been registered systematically with almost complete coverage by the Danish Cancer Registry. Hence, information on specific cancer types and date of diagnosis was retrieved for the cohort and reference groups using their CPR numbers.[10] Follow-up for cancer started on the latest of either date of first employment or 2 April 1968 for the cohort. It ended on date of death, emigration or 31 December 2014, whichever came first. All primary cancers diagnosed within this window of time were included in the analyses using the ICD-10 (International Classification of Diseases) system.[10]

Statistical analysis

Person-years at risk were calculated for each firefighter according to the follow-up period and split into 5-year age and calendar time intervals. Using incidence rates for the entire Danish male population as reference, the expected number of site-specific cancers was then calculated according to the same intervals. Finally, SIRs with corresponding 95% CIs were estimated as the overall number of observed versus expected cases. This procedure was repeated comparing the firefighters with the two external reference groups.

Further, lag time analyses deferring start of follow-up (5, 10, 15 and 20 years) and analyses combining several exposure measures were performed (online supplementary tables S1,

Table 1 Characteristics of the cohort of male Danish firefighters: 1968–2014

Characteristics	Full time	Other*
Cohort		
Firefighters eligible for SIR analysis	4243	4818
Person-years of follow-up	131 773	108 772
Mean years of follow-up (SD)	31 (11.40)	23 (9.45)
Mean attained age† (SD)	59 (12.88)	53 (11.50)
Mean birth year	1954	1961
Vital status†		
Alive	3484	4501
Dead	712	291
Emigrated	47	26
Firefighter employment		
Mean age at first hire (SD)	26 (5.67)	31 (7.88)
Average year of first hire	1979	1991
Year of initial employment		
<1970	1186	176
1970–1994	2196	2325
>1995	861	2317
Employment duration		
<1 year	1102	321
≥1 year	3141	4497
≥10 years	2541	3012
≥20 years	1711	1311
Average employment length in years (SD)	16 (13.57)	14 (10.45)
Job function		
Regular	3766	4818
Specialised	477	0

*Other comprises part-time/volunteer workers.
†31 December 2014.

S4 and S5). Internal analyses were performed using a Poisson regression model adjusting for age and calendar time.

Approximately 94% of the firefighters were included in the cohort from sources with complete employment records from the beginning of the follow-up period in 1968. In order to assess the remaining potential left truncation, a sensitivity analysis restricting the cohort to firefighters born after 31 December 1949 was performed (online supplementary table S2).

As the lag time, internal and sensitivity analyses contributed no substantial additional information, only the main results of the external analyses are presented here.

Statistical analyses were conducted using Stata V.14.2 (StataCorp, College Station, TX, USA).

RESULTS

The final cohort consisted of 9061 male Danish firefighters contributing 240 545 person-years at risk. At the end of follow-up, 7985 were living in Denmark, 1003 were deceased and 73 had emigrated. The mean attained age at the end of follow-up was 59 years for the full-time employees versus 53 years among the part-time/volunteer workers. Table 1 summarises the selected characteristics of the cohort.

In total, 1389 primary cancers were observed among 1211 firefighters during follow-up. Compared with the general population, the overall cancer incidence was almost even (SIR 1.02, 95% CI 0.96 to 1.09). There were, however, notable differences in the incidence of specific cancer types. Table 2 presents the results by reference group.

For melanoma of the skin, an increase was seen compared with both the general population and the sample of employees reaching significance for the latter. The SIR for firefighters employed before the age of 25 was significantly increased using both these reference groups (SIR 1.46, 95% CI 1.07 to 2.02 and SIR 1.55, 95% CI 1.13 to 2.14) while the SIR for specialised firefighters was significantly increased versus all three references. The incidence of non-melanoma skin cancer was overall near expectation.

A slight excess of prostate cancer was observed in comparison to the general population. This excess bordered significance against the sample of employees, while disappearing almost with the military as reference. Regarding the selected exposure measures, no distinct pattern of risk correlation seemed present (table 3). As for age at diagnosis, a significant increase in prostate cancer was seen ≥70 years while younger age groups (<50 years) had less than expected cases.

The SIR for testis cancer was increased compared with the general population (SIR 1.30, 95% CI 0.97 to 1.73). A slight excess was seen in the group aged 50–69 at diagnosis (SIR 1.17, 95% CI 0.40 to 2.73), while the majority of cases occurred before the age of 50 (online supplementary table S3). The overall excess was, however, not reproduced using the additional reference groups. Finally, the distribution of cases regarding histological subtypes did not differ from that of the general population (data not shown). The incidence of non-Hodgkin's lymphoma was at level with all three references (table 2).

The only outcome with significantly increased SIR across all references was cancer of the heart and mediastinum with only three cases. In contrast, the incidence of colon cancer was significantly reduced versus all references (table 2). There were also slightly less than expected cases of lung cancer compared with the general population or the sample of employees.

For the lymphohaematopoietic cancers, the only outcome showing excess was Hodgkin's lymphoma. The SIR for Hodgkin's lymphoma was significantly increased for part-time/volunteer firefighters (SIR 2.29, 95% CI 1.15 to 4.58; general population), firefighters employed after 1994 or for minimum of 1 year increasing with longer employment duration.

Among the remaining sites analysed, pancreatic cancer was the only outcome with more than one significantly increased SIR across the selected exposure subgroups (full-time firefighters, first employed before 1970 and hired before the age of 25).

DISCUSSION

With this first large cohort study of cancer incidence among male Danish firefighters, 51 cancer sites are evaluated through 46 years of follow-up in relation to several exposure measures. Overall cancer morbidity is almost at level with that of the general population and the two additional reference groups. However, the pattern of excess, regarding specific cancer types generated by previous studies in this field, is in part confirmed.

For melanoma of the skin, the observed modest increase is consistent with findings from the meta-analysis by LeMasters *et al* and numerous subsequent studies.[2–7 11] Ultraviolet (UV) radiation is the predominant risk factor involved in carcinogenesis of the skin and receiving excessive amounts is often work or lifestyle related. While the cumulative life dose of UV light primarily affects the risk of non-melanoma skin cancer, the incidence of melanoma seems closely related to early, intermittent and intense exposures. When working outdoors though, firefighters are typically completely covered by protective gear and clothing limiting their occupational exposure to sunlight.

Table 2 Cancer incidence among 9061 male Danish firefighters by reference group: 1968–2014

		The general population		Sample of employees		The military	
Cancer site (ICD-10)	**Obs**	**SIR**	**95% CI**	**SIR**	**95% CI**	**SIR**	**95% CI**
All cancers (minus other skin)	1071	1.02	0.96 to 1.09	1.07	1.01 to 1.14	1.01	0.95 to 1.07
Lip (C00)	4	1.04	0.39 to 2.78	1.13	0.42 to 3.01	1.60	0.60 to 4.28
Tongue (C01–02)	12	1.52	0.86 to 2.68	1.62	0.92 to 2.85	1.46	0.83 to 2.57
Mouth (C03–06, C462)	7	0.60	0.28 to 1.25	0.57	0.27 to 1.19	0.61	0.29 to 1.27
Salivary glands (C07–08)	4	1.79	0.67 to 4.77	1.90	0.71 to 5.07	1.59	0.60 to 4.24
Pharynx (C09–14)	20	0.91	0.59 to 1.41	0.94	0.60 to 1.45	0.87	0.56 to 1.35
Oesophagus (C15)	21	0.99	0.65 to 1.53	1.05	0.68 to 1.61	1.18	0.77 to 1.81
Stomach (C16)	27	1.09	0.75 to 1.59	1.12	0.77 to 1.63	1.26	0.87 to 1.84
Colon (C18–19)	57	0.73	0.57 to 0.95	0.77	0.59 to 0.99	0.70	0.54 to 0.90
Rectum (C20)	64	1.22	0.95 to 1.55	1.24	0.97 to 1.58	1.20	0.94 to 1.53
Liver (C22)	14	0.97	0.58 to 1.64	0.98	0.58 to 1.65	1.17	0.69 to 1.98
Gall bladder (C23–24)	5	0.99	0.41 to 2.37	1.04	0.43 to 2.50	1.02	0.42 to 2.44
Pancreas (C25)	34	1.20	0.86 to 1.68	1.27	0.91 to 1.78	1.28	0.92 to 1.80
Anus (C21, C26)	4	1.31	0.49 to 3.49	1.13	0.42 to 3.01	1.12	0.42 to 2.99
Nasal cavity (C30–31)	4	1.38	0.52 to 3.67	1.27	0.48 to 3.39	1.42	0.53 to 3.79
Larynx (C32)	16	0.92	0.56 to 1.50	0.92	0.57 to 1.51	1.01	0.62 to 1.66
Lung (C33–34, C39)	132	0.91	0.76 to 1.07	0.95	0.80 to 1.13	1.06	0.90 to 1.26
Heart and mediastinum (C380–383, C388)	3	4.27	1.38 to 13.23	3.61	1.17 to 11.20	4.30	1.39 to 13.32
Bones (C40–41)	3	1.25	0.40 to 3.89	1.17	0.38 to 3.64	1.14	0.37 to 3.55
Melanoma of skin (C43)	70	1.24	0.98 to 1.57	1.28	1.01 to 1.61	1.05	0.83 to 1.33
Other skin (C44, C460)	318	1.00	0.90 to 1.12	1.01	0.90 to 1.12	0.86	0.77 to 0.96
Mesothelium (C450–459)	4	0.65	0.24 to 1.73	0.68	0.26 to 1.82	0.71	0.27 to 1.89
Connective tissue	7	0.84	0.40 to 1.76	0.97	0.46 to 2.04	0.77	0.37 to 1.61
Prostate (C61)	202	1.10	0.95 to 1.26	1.15	1.00 to 1.32	1.02	0.88 to 1.17
Testis (C62)	47	1.30	0.97 to 1.73	1.04	0.78 to 1.39	0.98	0.73 to 1.30
Other genitals (C60, C63)	3	0.78	0.25 to 2.41	0.82	0.26 to 2.54	0.70	0.23 to 2.18
Kidney (C64)	32	1.04	0.74 to 1.47	1.02	0.72 to 1.44	1.04	0.74 to 1.48
Renal pelvis (C65–66)	10	1.46	0.79 to 2.72	1.59	0.85 to 2.95	1.35	0.73 to 2.51
Urinary bladder (C67, D090, D303, D414)	88	1.09	0.89 to 1.35	1.11	0.90 to 1.37	1.05	0.86 to 1.30
Eye (C69)	3	0.88	0.28 to 2.74	0.82	0.27 to 2.55	0.90	0.29 to 2.78
Meninges (C70, D32, D42)	9	1.22	0.64 to 2.35	1.07	0.56 to 2.05	1.23	0.64 to 2.37
Brain (C71, C751–753, D330–332, D430–432, D352–354, D443–445)	33	0.94	0.67 to 1.33	0.87	0.62 to 1.23	0.90	0.64 to 1.26
Other parts of CNS (C72, D333–339, D433–D439)	12	1.39	0.79 to 2.45	1.47	0.83 to 2.58	1.31	0.74 to 2.30
Thyroid (C73)	6	1.21	0.54 to 2.69	1.18	0.53 to 2.63	1.05	0.47 to 2.35
Hodgkin's lymphoma (C81)	13	1.64	0.95 to 2.82	1.35	0.78 to 2.32	1.42	0.82 to 2.44
Non-Hodgkin's lymphoma (C82–85, C883–889)	37	0.96	0.69 to 1.32	0.97	0.70 to 1.33	0.97	0.70 to 1.34
Myeloma (C90, C880–882)	8	0.62	0.31 to 1.24	0.66	0.33 to 1.32	0.65	0.33 to 1.31
Lymphatic leukaemia (C91)	15	0.91	0.55 to 1.51	0.97	0.59 to 1.61	0.88	0.53 to 1.47
Myeloid leukaemia (C92)	9	0.76	0.40 to 1.46	0.73	0.38 to 1.40	0.83	0.43 to 1.60
Ill-defined/unspecified (C76–80)	27	0.90	0.62 to 1.32	0.95	0.65 to 1.38	0.96	0.66 to 1.40
Remaining not shown	5	0.41	0.13 to 0.97	0.42	0.14 to 0.97	0.41	0.13 to 0.95

CNS, central nervous system; ICD, International Classification of Diseases.

Among the chemicals encountered occupationally by firefighters, a causal relation to melanoma of the skin has been shown for PCBs and is suspected for other relevant exposures potentially entering the body through dermal uptake such as PAHs and dioxins.[12 13] Supporting a potential occupational association, the incidence of melanoma is significantly increased among the specialised firefighters in our cohort. However, the differences observed between the regular firefighters and this elite unit may also be explained by lifestyle and in particular tanning fashions.

We also observe a slight excess in the incidence of prostate cancer, though neither overall nor subgroup results reach significance. Our results show fewer than expected cases among firefighters under 50 years of age and a significant increase in later ages countering the tendency of an increased incidence in younger age groups (30–49 years) seen in recent studies.[5 14]

In Denmark, full-time firefighters work mainly 24-hour shifts while part-time and volunteer personnel have more varied shift structures. Night shift work has been linked to increased risk of prostate cancer by previous studies and interestingly, comparing firefighters with other potential night workers such as our military reference shows virtually no difference in incidence.[15] However, our military reference generally seems to resemble the firefighters closely regarding cancer incidence and apart from having similar occupational conditions, they may share lifestyle-related confounders.

Table 3 Cancer incidence among male Danish firefighters by exposure subgroup compared with the general population: 1968–2014

	Employment type				Era of first employment					
	Full time (n=4243)		Other† (n=4818)		<1970 (n=1362)		1970–1994 (n=4521)		≥1995 (n=3178)	
Cancer site*	Obs	SIR (95% CI)	Obs	SIR (95% CI)	Obs	SIR (95% CI)	Obs	SIR (95% CI)	Obs	SIR (95% CI)
All cancers (minus other skin)	680	1.06 (0.99 to 1.15)	391	0.96 (0.87 to 1.06)	521	1.12 (1.02 to 1.22)	455	0.93 (0.85 to 1.02)	95	1.04 (0.84 to 1.27)
Colon	39	0.79 (0.58 to 1.08)	18	0.64 (0.40 to 1.01)	31	0.78 (0.55 to 1.11)	24	0.73 (0.49 to 1.09)	2	0.40 (0.10 to 1.59)
Rectum	38	1.16 (0.84 to 1.60)	26	1.31 (0.89 to 1.92)	37	1.47 (1.06 to 2.02)	24	1.01 (0.68 to 1.51)	3	0.80 (0.26 to 2.49)
Pancreas	27	1.54 (1.05 to 2.25)	7	0.65 (0.31 to 1.37)	22	1.63 (1.08 to 2.48)	10	0.78 (0.42 to 1.45)	2	1.02 (0.26 to 4.08)
Lung	82	0.87 (0.70 to 1.08)	50	0.97 (0.73 to 1.27)	77	0.99 (0.79 to 1.24)	48	0.80 (0.60 to 1.06)	7	0.88 (0.42 to 1.85)
Melanoma of the skin	40	1.28 (0.94 to 1.74)	30	1.19 (0.83 to 1.70)	25	1.42 (0.96 to 2.11)	32	1.07 (0.76 to 1.51)	13	1.43 (0.83 to 2.47)
Other skin	180	0.96 (0.83 to 1.11)	138	1.07 (0.90 to 1.26)	126	0.97 (0.81 to 1.15)	159	1.04 (0.89 to 1.21)	33	0.98 (0.70 to 1.38)
Prostate	130	1.12 (0.95 to 1.33)	72	1.05 (0.83 to 1.32)	108	1.16 (0.96 to 1.40)	85	1.05 (0.85 to 1.30)	9	0.90 (0.47 to 1.73)
Testis	23	1.23 (0.82 to 1.86)	24	1.36 (0.91 to 2.04)	8	1.55 (0.77 to 3.09)	28	1.32 (0.91 to 1.91)	11	1.12 (0.62 to 2.02)
Urinary bladder	59	1.14 (0.89 to 1.48)	29	1.01 (0.70 to 1.45)	51	1.21 (0.92 to 1.59)	35	1.05 (0.75 to 1.46)	2	0.41 (0.10 to 1.66)
Non-Hodgkin's lymphoma	23	1.02 (0.68 to 1.53)	14	0.87 (0.52 to 1.47)	13	0.90 (0.52 to 1.55)	18	0.89 (0.56 to 1.42)	6	1.46 (0.65 to 3.24)

	Job function				Age at first employment					
	Regular (n=8584)		Specialised (n=477)		<25 years (n=4016)		25–34 years (n=3426)		≥35 years (n=1619)	
Cancer site	Obs	SIR (95% CI)	Obs	SIR (95% CI)	Obs	SIR (95% CI)	Obs	SIR (95% CI)	Obs	SIR (95% CI)
All cancers (minus other skin)	994	1.02 (0.96 to 1.08)	77	1.12 (0.88 to 1.39)	572	1.12 (1.03 to 1.22)	286	0.91 (0.81 to 1.03)	213	0.95 (0.83 to 1.09)
Colon	53	0.73 (0.56 to 0.96)	4	0.78 (0.29 to 2.08)	33	0.85 (0.60 to 1.19)	13	0.59 (0.34 to 1.02)	11	0.65 (0.36 to 1.18)
Rectum	58	1.18 (0.91 to 1.53)	6	1.72 (0.77 to 3.84)	29	1.13 (0.79 to 1.63)	19	1.25 (0.80 to 1.96)	16	1.36 (0.83 to 2.22)
Pancreas	31	1.17 (0.83 to 1.67)	3	1.60 (0.52 to 4.97)	23	1.68 (1.12 to 2.53)	3	0.36 (0.12 to 1.13)	8	1.27 (0.63 to 2.53)
Lung	125	0.92 (0.77 to 1.09)	7	0.73 (0.35 to 1.54)	70	0.95 (0.75 to 1.20)	31	0.78 (0.55 to 1.10)	31	0.97 (0.68 to 1.38)
Melanoma of the skin	61	1.15 (0.90 to 1.48)	9	2.44 (1.27 to 4.70)	38	1.47 (1.07 to 2.02)	15	0.77 (0.47 to 1.28)	17	1.52 (0.95 to 2.45)
Other skin	287	0.97 (0.86 to 1.09)	31	1.49 (1.04 to 2.11)	132	0.89 (0.75 to 1.05)	117	1.18 (0.98 to 1.41)	69	0.99 (0.78 to 1.26)
Prostate	188	1.09 (0.95 to 1.26)	14	1.15 (0.68 to 1.94)	100	1.12 (0.92 to 1.36)	56	1.08 (0.83 to 1.41)	46	1.06 (0.80 to 1.42)
Testis	43	1.27 (0.94 to 1.71)	4	1.65 (0.62 to 4.39)	25	1.33 (0.90 to 1.97)	17	1.21 (0.75 to 1.94)	5	1.48 (0.62 to 3.56)
Urinary bladder	83	1.10 (0.89 to 1.37)	5	0.95 (0.39 to 2.28)	54	1.32 (1.01 to 1.73)	17	0.76 (0.47 to 1.22)	17	0.98 (0.61 to 1.58)
Non-Hodgkin's lymphoma	33	0.91 (0.65 to 1.29)	4	1.53 (0.57 to 4.08)	15	0.83 (0.50 to 1.37)	15	1.21 (0.73 to 2.00)	7	0.86 (0.41 to 1.80)

	Employment duration							
	<1 year (n=1423)		≥1 year (n=7638)		≥10 years (n=5553)		≥20 years (n=3022)	
Cancer site	Obs	SIR (95% CI)	Obs	SIR (95% CI)	Obs	SIR (95% CI)	Obs	SIR (95% CI)
All cancers (minus other skin)	318	1.14 (1.02 to 1.27)	753	0.98 (0.91 to 1.06)	615	0.94 (0.87 to 1.02)	447	0.91 (0.83 to 1.00)
Colon	16	0.70 (0.43 to 1.14)	41	0.75 (0.55 to 1.02)	39	0.82 (0.60 to 1.12)	31	0.84 (0.59 to 1.20)
Rectum	16	1.08 (0.66 to 1.77)	48	1.27 (0.96 to 1.68)	38	1.16 (0.85 to 1.60)	33	1.32 (0.94 to 1.85)
Pancreas	14	1.79 (1.05 to 3.01)	20	0.98 (0.63 to 1.52)	13	0.74 (0.43 to 1.27)	10	0.74 (0.40 to 1.37)
Lung	50	1.13 (0.85 to 1.49)	82	0.81 (0.65 to 1.00)	65	0.73 (0.57 to 0.93)	49	0.70 (0.53 to 0.93)
Melanoma of the skin	13	1.07 (0.62 to 1.85)	57	1.28 (0.99 to 1.66)	43	1.19 (0.88 to 1.60)	24	0.96 (0.64 to 1.43)
Other skin	66	0.82 (0.65 to 1.05)	252	1.06 (0.94 to 1.20)	219	1.09 (0.96 to 1.25)	159	1.08 (0.92 to 1.26)
Prostate	59	1.12 (0.87 to 1.45)	143	1.09 (0.92 to 1.28)	125	1.09 (0.91 to 1.29)	101	1.12 (0.92 to 1.36)
Testis	10	1.72 (0.92 to 3.19)	37	1.22 (0.88 to 1.68)	25	1.07 (0.73 to 1.59)	14	0.99 (0.58 to 1.67)
Urinary bladder	31	1.28 (0.90 to 1.82)	57	1.01 (0.78 to 1.32)	51	1.04 (0.79 to 1.37)	37	0.97 (0.70 to 1.34)
Non-Hodgkin's lymphoma	8	0.86 (0.43 to 1.73)	29	0.98 (0.68 to 1.42)	23	0.93 (0.62 to 1.40)	16	0.88 (0.54 to 1.43)

*Results for overall cancer and the 10 most frequent cancer sites shown.
†Other comprises part-time/volunteer workers.

For testis cancer, the pattern of accordance with the military reference continues with a SIR of 0.98. The corresponding SIR versus the general population is 1.30 (95% CI 0.97 to 1.73). In spite of a significant relative risk of 1.47 (95% CI 1.20 to 1.80) in the meta-analysis by IARC, recent studies have shown no consistency in results regarding this outcome.[1–7 14 16–18] Though testicular cancer worldwide is a relatively rare disease, Denmark has one of the highest national incidence rates. Confirmed aetiological factors are related mainly to early life events, while possible associations with exposures from lifestyle, environment or occupation remain hypothetical.[19] In our cohort, the highest risk of testicular cancer is seen among the short-term firefighters (<1 year of employment) and in the youngest age group (<50 years), and the histological distribution is similar to that of the general population limiting support for the hypothesised association with firefighting.

The incidence of non-Hodgkin's lymphoma in our cohort is near expectation. In the meta-analysis by IARC building on 7 studies and 312 cases, this outcome is significantly increased.[1] However, only few of the subsequent large studies support this finding.[2 16] As the contrasting excess of Hodgkin's lymphomas observed in our cohort is significant only among the presumably less exposed part-time/volunteer workers, this may not be work related.

Previous studies on a small cohort of Danish firefighters have shown significant increases in both lung cancer incidence and death.[5 20] Despite possible exposure to inhalable combustion products, the incidence of lung cancer is not increased in our cohort. However, assessing the impact of firefighting on this particular outcome is difficult without knowledge of smoking habits for both cohort and reference groups. The overall incidence of tobacco-related cancers (mouth, tongue, pharynx, larynx, nasal cavity, lung, oesophagus, pancreas, stomach, colon, rectum, liver, kidney, renal pelvis, urinary bladder, myeloid leukaemia) in our cohort is at level with that of the general population though (SIR 0.98, 95% CI 0.90 to 1.07).

The significant reduction in colon cancer observed in our study is generally not seen in previous studies.[11] Notably, rectum cancer shares many risk factors connected to this outcome and no reduction is seen here (table 2). Though the incidence of pancreatic cancer is increased for several exposure subgroups, the increase seems confined to short-term firefighters limiting suspicion of an occupational association.

Finally, the significant increase in cancer of the heart and mediastinum is likely a random finding. Thus, the three observed cases each represent different and rare cancers with the only common denominator being the anatomical location in the chest.

As for limitations in our study, potential confounders related to non-firefighting jobs or lifestyle such as smoking, alcohol consumption, diet and sun exposure may affect the incidence of certain cancers. Despite the long follow-up period, the cohort is relatively young leaving the number of detected cancers low and infrequent types difficult to evaluate. Further, cancer among female firefighters cannot be assessed in this study, as the number of women in this profession, at least in Denmark, remains negligible. Lastly, the selected surrogate measures may not reflect actual exposure as well as the number, type and duration of runs or fires fought, which have been tested in recent studies.[3 21] As fires are dictated by circumstance in an uncontrolled and unpredictable manner, fire attendance varies greatly between firefighters limiting the use of employment parameters as proxies for exposure to smoke.[1] In defence of our approach, firefighters typically spend little time at fires[1] and other sources of occupational hazards (night work, exhaust gasses from traffic) may correlate better with employment measures.

Keeping the limited number of firefighters in Denmark in mind, the established cohort is relatively large covering a wide span of firefighting history with long follow-up. In addition, occupational information is confirmed by multiple sources validating the chosen measures of exposure. Another important strength is the use of different reference groups addressing the presence of a potential healthy worker effect in the cohort.

Finally, the old and virtually complete national health registries offer accurate and valid information on both cancer and vital status. Reliable calculation of cancer incidence is thus possible even in early eras of firefighting.

CONCLUSION

The overall incidence of cancer is not increased among the firefighters in our cohort, but the previously seen increase in the incidence of melanoma of the skin, prostate and testicular cancer is supported by our main results. However, the slight excess observed for all three cancer sites is reduced notably using military employees as reference. The observed similarities in cancer profile for these two occupational groups point to shared aetiological factors in either work or way of life. In consequence, focus on factors other than fire smoke should also be emphasised in future research.

Continued follow-up of the cohort is recommended and planned in order to provide further clarity on the association between firefighting and cancer morbidity.

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Contributors KKUP collected the data, performed programming and analyses, participated in interpretation of results and wrote the manuscript. JEP performed programming of data, participated in analyses and interpretation of results, and revised the manuscript critically. JPB and NEE designed the study, supervised the interpretation of results and revised the manuscript critically. JH was a major contributor in designing the study and supervised all subsequent data collection, programming and analyses, participated in interpretation of results and supervised writing of the manuscript. JH was responsible for guaranteeing the overall content. All authors read and approved the final manuscript.

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