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Comparison of cancer incidence and mortality in the Norwegian Fire Departments Cohort, 1960–2018

Niki Marjerrison ,[1,2] Jarle Jakobsen ,[1,2] Paul A Demers,[3] Tom K Grimsrud,[1] Johnni Hansen,[4] Jan Ivar Martinsen,[1] Karl-Christian Nordby,[5] Marit B Veierød,[2] Kristina Kjærheim[1]

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[1]Department of Research, Cancer Registry of Norway, Oslo, Norway
[2]Department of Biostatistics, Institute of Basic Medical Sciences, Oslo Centre for Biostatistics and Epidemiology, University of Oslo, Oslo, Norway
[3]Occupational Cancer Research Centre, Ontario Health, Toronto, Ontario, Canada
[4]Danish Cancer Society Research Center, Danish Cancer Society, Copenhagen, Denmark
[5]Department of Occupational Medicine and Epidemiology, National Institute of Occupational Health, Oslo, Norway

Correspondence to
Niki Marjerrison, Department of Research, Cancer Registry of Norway, Oslo, Norway; niki.marjerrison@kreftregisteret.no

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ABSTRACT

Objectives Elevated risk of cancer at several sites has been reported among firefighters, although with mixed findings. The purpose of this study was to calculate standardised incidence ratios (SIRs) and standardised mortality ratios (SMRs) for cancer and compare them to assess whether use of the different measures could be a source of inconsistencies in findings.

Methods The Norwegian Fire Departments Cohort, comprising 4295 male employees who worked at 15 fire departments across Norway, was linked to health outcome registries for the period 1960–2018. SIRs and SMRs were derived using national reference rates.

Results Overall, we observed elevated incidence of colon cancer (SIR, 95% CI 1.27, 1.01 to 1.58), mesothelioma (2.59, 1.12 to 5.11), prostate cancer (1.18, 1.03 to 1.34) and all sites combined (1.15, 1.08 to 1.23). Smaller, non-significant elevations were found for mortality of colon cancer (SMR, 95% CI 1.20, 0.84 to 1.67) and mesothelioma (1.66, 0.34 to 4.86), while SMR for prostate cancer was at unity. Potential errors were observed in some of the mortality data, notably for mesothelioma cases. Among those who died of cancer, 3.7% (n=14) did not have a prior diagnosis of malignancy at the same site group.

Conclusions Assessment of incidence or mortality did not greatly influence the interpretation of results. The most prominent differences in SIR and SMR appeared to be due to inconsistencies between sites of cancer diagnosis and cause of death. The difference in SIR and SMR for prostate cancer suggested a detection bias from differential screening practices.

WHAT IS ALREADY KNOWN ON THIS TOPIC

⇒ Firefighters are exposed to numerous carcinogens through their work and elevated risk of cancer at several sites have been reported among firefighters. However, previous heterogeneous findings have made interpretations regarding associations with occupational exposures difficult.

WHAT THIS STUDY ADDS

⇒ In this study, we calculated and compared the standardised incidence ratios and standardised mortality ratios for cancer sites among male employees in the Norwegian Fire Departments Cohort, to assess whether use of the different measures could be a source of inconsistencies in findings. We found that assessment of incidence or mortality did not greatly influence the interpretation of results. The most prominent differences in results appeared to be related to inconsistencies between site of morphologically confirmed cancer diagnosis and cause of death, revealing a possible limitation in mortality data, but mortality data may also have demonstrated a possible detection bias related to differential patterns of screening for prostate cancer.

HOW THIS STUDY MIGHT AFFECT RESEARCH, PRACTICE AND/OR POLICY

⇒ Where high-quality incidence data are available, cancer incidence probably better informs occupational cancer risk at most sites. However, while mortality data face possible limitations, assessment of cancer mortality can also provide valuable insight into potential biases of incidence rates. As firefighters' occupational exposures are complex and findings on cancer risk can be difficult to interpret, assessment of both cancer incidence and mortality may be beneficial in understanding their cancer risk.

INTRODUCTION

Firefighters are exposed to numerous known and potential carcinogens through their work. In 2007, the International Agency for Research on Cancer (IARC) classified work as a firefighter as possibly carcinogenic.[1] The most consistent associations identified were between firefighting and prostate cancer, based on eight mortality and eight incidence studies; testicular cancer, based on one mortality and five incidence studies; and non-Hodgkin's lymphoma, based on two mortality and five incidence studies.[1]

Recent meta-analyses of studies on cancer risk among firefighters have pointed at elevated incidence of colon,[2 3] prostate,[3 4] testis,[3] bladder[2 3] and thyroid[3] cancer as well as mesothelioma[2 3] and cutaneous melanoma.[3] These meta-analyses have also reported elevated mortality for rectum[2 3] and bladder[2] cancer and non-Hodgkin's lymphoma.[3]

However, a high level of heterogeneity has been observed between individual studies.[2 3] Differences may be a result of many factors, such as temporal and geographical variability in exposures from

firefighting or other sources. Cancer incidence is generally preferred in occupational cancer studies to identify risk factors and assess the impact of preventive measures. Cancer mortality may be used where incidence data are lacking and can also be informative in the identification of risk factors, especially for cancers with a dismal prognosis. Furthermore, cancer mortality can be important in informing on effects of screening and treatment.

Recent studies on cancer risk among firefighters have more frequently assessed cancer incidence than mortality; among the studies included in the largest meta-analysis on cancer risk among firefighters, 86% (n=12) of studies published after 2010 assessed cancer incidence, while prior to 2000, 71% (n=17) assessed cancer mortality.[3] For some cohorts, both incidence and mortality have been analysed,[5–12] though follow-up periods and classification of cancers/deaths have differed, and comparisons of standardised incidence ratios (SIRs) and standardised mortality ratios (SMRs) have not been made since 1992 by Demers *et al*.[7]

In a previous study, we examined cancer incidence in a subgroup of formerly or presently active firefighters in the Norwegian Fire Departments Cohort from an aetiological perspective, focusing on sites with known associations with occupational exposures encountered during firefighting.[13] The purpose of the present study was to calculate SIRs and SMRs for all cancer sites among men in the cohort. Furthermore, we compare the SIRs and SMRs to assess whether use of the different measures could be a source of inconsistencies in study findings.

METHODS

The Norwegian Fire Departments Cohort

The Norwegian Fire Departments Cohort was established between 2017 and 2019, described previously.[13] In brief, 21 fire departments were invited to participate, 14 accepted, and 1 additional department self-selected. Departments were asked to register all employees who worked between 1950 and present with personal identification information and the title, start and end date of all positions held during their employment. As of 2019, these 15 participating fire departments provided firefighting services for nearly 50% of the Norwegian population.[14]

Of the 4627 persons in the Norwegian Fire Departments Cohort, those who died before 1960 (n=32) and those who were employed for the first time after 31 December 2018 (n=11) were excluded from the present study based on the follow-up period (1 January 1960–31 December 2018). Women (n=289) were excluded from the present analyses because of low numbers. Thus, 4295 men were eligible for analyses.

Two sets of analyses were conducted. The first set included all those eligible from the Norwegian Fire Departments Cohort (n=4295). Thereafter, we assessed a subgroup with past or present positions entailing active firefighting (n=3881). Those excluded from the second part of analyses comprised chimney sweeps, fire inspectors and office personnel.

Follow-up

A person entered follow-up on the latter of 1 January 1960 or start of first employment and was followed until the earliest of date of death, emigration or 31 December 2018 for outcomes in national registries. The cohort was linked to registries using the unique personal identification number given to all Norwegian citizens alive in 1960 or born later. Date of emigration was obtained from the National Population Register. Date and diagnosis of cancer were obtained from the Cancer Registry of Norway (CRN) for multiple primary malignancies. There has been mandatory reporting of all cancer cases in Norway since the start of the CRN in 1952, and it has a high degree of completeness and morphological verification.[15] Cancer cases were provided according to the 10th revision of the International Classification of Diseases (ICD-10) for the codes C00–C97; cases that were coded in ICD V.7–9 were updated to the corresponding ICD-10 code by the CRN and provided as such. Underlying cause and date of death were obtained from the Cause of Death Registry. The Cause of Death Registry is based on data from death certificates and has a high degree of coverage.[16] Mortality data were provided in ICD V.7–10, and we updated earlier versions to ICD-10 for the codes C00-C97 using the IARC Cancer Dictionary.[17]

Statistical analysis

SIRs and SMRs were calculated as the ratio of observed and expected number of cancer cases or deaths, respectively, with rates for the general Norwegian male population as the reference. From the cohort, person-years in 5-year age and 1-year period strata were multiplied with the respective reference rates to obtain the number of expected site-specific or overall cancer cases and deaths.

We analysed cancer incidence and mortality stratified by period of follow-up (≤1984, 1985–1994, ≥1995) and by age at diagnosis (≤49, 50–69, ≥70 years) to assess possible period-related and age-related differences in incidence and mortality in the cohort.

For all SIRs and SMRs, the exact 95% CIs were calculated assuming a Poisson distribution of the observed number of cases.

We conducted sensitivity analyses for all SIRs and SMRs with observation restricted to age less than 85 years, because of the potential for increased uncertainty in cause of death with older age as well as with observation restricted to those who began employment in 1950 or later, to adjust for survivor bias among those entering the cohort at an early period.

We also investigated cancer diagnoses among those identified as having died from cancer as an indication of the quality of the registration of cause of death.

All analyses were conducted using Stata V.17 (Stata Corp, College Station, Texas).

Ethics

This project was approved by the Regional Committee for Medical and Health Research Ethics (reference number: 5646).

RESULTS

During 117 458 person-years of follow-up of the 4295 men, there were 916 incident cancer cases and 376 cancer deaths. Year of birth ranged from 1884 to 1996 (median: 1956) and start of employment from 1913 to 2018 (median: 1981) (table 1). Mean age at employment was 27.6 years, and mean age attained at the end of follow-up was 58.7 years. Demographic characteristics of the 3881 (78.7%) men who had ever held positions entailing active firefighting were similar to that observed for the full cohort.[13]

We observed elevated incidence for all sites combined (SIR 1.15, 95% CI 1.08 to 1.23); SMR from cancer was 1.08 (95% CI 0.98 to 1.20) (table 2). Significantly elevated incidence was observed for colon cancer (SIR 1.27, 95% CI 1.01 to 1.58), mesothelioma (SIR 2.59, 95% CI 1.12 to 5.11) and prostate cancer (SIR 1.18, 95% CI 1.03 to 1.34). The corresponding SMR for colon cancer was of a similar size (SMR 1.20, 95% CI 0.84 to 1.67) but was of a smaller size for mesothelioma (SMR

Table 1 Characteristics of male employees in the Norwegian Fire Departments Cohort, follow-up from 1 January 1960 to 31 December 2018

	Full cohort	
	n	%
Eligible for analysis	4295	
Person-years at risk	117 458	
Mean years of follow-up (SD)	27.3 (16.2)	
Status on 31 December 2018		
Emigrated	31	0.7
Dead	1218	28.4
Alive	3046	70.9
Year of birth		
<1950	1696	39.5
1950–1969	1252	29.1
≥1970	1347	31.4
Age at first employment		
<30	3162	73.6
30–49	1061	24.7
≥50	72	1.7
Year of first employment		
<1950	707	16.4
1950–1969	643	15.0
1970–1989	1211	28.2
≥1990	1734	40.4
Age at end of follow-up		
<50	1482	34.5
50–69	1552	36.1
70–84	995	23.2
≥85	266	6.2

1.66, 95% CI 0.34 to 4.86) and was at unity for prostate cancer (SMR 1.01, 95% CI 0.76 to 1.31). For urinary tract cancer, non-significantly elevated incidence (SIR 1.22, 95% CI 0.96 to 1.54) and mortality (SMR 1.13, 95% CI 0.64 to 1.83) were found, based on 73 cases and 16 deaths. There were more testicular cancer cases than expected with 18 cases (SIR 1.35, 95% CI 0.80 to 2.14) alongside zero deaths.

For oesophageal cancer, both SMR (1.94, 95% CI 1.08 to 3.20) and SIR (1.55, 95% CI 0.85 to 2.60) were elevated, based on 15 deaths and 14 diagnoses. On investigation of cases with deaths or diagnoses of oesophageal cancer, we found two cases of stomach cancer with death attributed to oesophageal cancer, and one case of oesophageal cancer with death attributed to stomach cancer.

For gallbladder and bile duct cancer, SMR was elevated (2.79, 95% CI 1.02 to 6.08) while incidence was elevated at a lower level (SIR 1.31, 95% CI 0.42 to 3.05), based on six deaths and five diagnoses. We found two of these deaths occurred in cases with diagnoses only for liver or stomach cancer.

If causes of death were recoded in accordance with morphologically confirmed incidence data reflecting the best evidence of diagnoses and the SMRs subsequently recalculated, SMR for oesophageal cancer would be lowered to 1.81 (95% CI 0.99 to 3.04), SMR for stomach cancer elevated to 1.26 (95% CI 0.85 to 1.80) and SMR for gallbladder and bile duct cancer lowered to 2.33 (95% CI 0.76 to 5.43).

Eight incident cases of mesothelioma were followed by only three deaths. Another four deaths in cases with mesothelioma diagnoses were seen within approximately 2 years after diagnoses, registered using ICD-10 as death from cancer of the peritoneum, asbestosis, leukaemia or unknown/unattended. When recalculated after recoding two deaths originally attributed to cancer of the peritoneum and asbestosis to mesothelioma, SMR increased to 2.77 (95% CI 0.90 to 6.47).

The stratified analyses, presented in tables 3 and 4, were based on the reclassified deaths for cancer of the oesophagus, stomach, gallbladder and bile ducts and mesothelioma.

Stratification by period of follow-up demonstrated SIRs for all sites combined slightly decreasing from 1.20 (95% CI 1.01 to 1.40) in the earliest follow-up period to 1.13 (95% CI 1.05 to 1.23) in the more recent period, while SMRs decreased more prominently from 1.26 (95% CI 1.01 to 1.54) in the earliest period to unity (SMR 1.00, 95% CI 0.87 to 1.15) in the most recent period (table 3).

Standardised estimates for incidence and mortality were similarly elevated across the first two periods for colon and the combined group of liver, gallbladder and bile duct cancer (table 3). The SIR and SMR estimates for laryngeal cancer both suggested elevated risks in the two follow-up periods after 1984, although SMRs were less precise. There were more cases of prostate cancer than expected in both periods of follow-up following 1985 with a statistically significantly elevated SIR in 1995–2018, while the SMRs for prostate cancer were less stable.

Stratification by age at diagnosis demonstrated SIRs for all sites combined increasing from unity with age under 50 years (SIR 0.99, 95% CI 0.78 to 1.25) to 1.25 with age over 70 years (95% CI 1.14 to 1.37) (table 4). SMRs also increased across age strata, from 0.77 (95% CI 0.44 to 1.25) with younger age to 1.19 (95% CI 1.04 to 1.36) with oldest.

Both SIR and SMR were prominently elevated for liver, gallbladder and bile duct cancer and laryngeal cancer with age over 70 years (table 4). With age over 70 years, we also observed elevated incidence of kidney and urinary tract cancer and more deaths than expected of these cancers, based on 18 cases and 6 deaths of kidney cancer, and 45 cases and 13 deaths of urinary tract cancer. More cases than expected of prostate cancer were seen across all age groups with a statistically significantly elevated SIR for age 50–69 years, while mortality ratios were below unity except for the age group over 70 years.

Analysis of cancer diagnoses among those with cause of death attributed to a cancer (n=376) demonstrated that 294 (78.2%) had an exact match according to the two-digit ICD-10 code. Among those remaining, 61 (16.2%) had a diagnosis and cause of death that were within the same group of cancer diagnoses (as defined in table 2). Fourteen (3.7%) did not have a prior diagnosis of malignancy at the same site or site group, six (1.6%) had cause of death coded as ill-defined or unspecified following a site-specific cancer diagnosis and one (0.3%) had a cancer site-specific cause of death following an ill-defined or unspecified cancer diagnosis.

Censoring at age 85 did not essentially change the results (results not shown). With analysis restricted to those who began employment in 1950 or later, colon cancer incidence was no longer elevated (SIR 0.87, 95% CI 0.61 to 1.20); otherwise, this restriction did not essentially change any results (results not shown). SIRs and SMRs for the subgroup of 3881 men who had ever held positions entailing active firefighting were similar to those observed for the full cohort (online supplemental tables 1–3).

Table 2 Observed number of cases/deaths and standardised incidence/mortality ratios (SIRs/SMRs) with 95% CIs in men in the Norwegian Fire Departments Cohort (n=4295), follow-up from 1 January 1960 to 31 December 2018

		Incidence			Mortality		
Cancer site	ICD-10	Obs.	SIR	95% CI	Obs.	SMR	95% CI
All cancers	C00-C97	916	1.15	1.08 to 1.23	376	1.08	0.98 to 1.20
Lip	C00	<5	0.51	0.11 to 1.50	0	0.00	0.00 to 12.3
Oral cavity	C02-C06	<5	0.67	0.18 to 1.72	0	0.00	0.00 to 2.81
Pharynx	C09-C14, C01	11	1.49	0.74 to 2.67	<5	0.97	0.26 to 2.49
Oesophagus	C15	14	1.55	0.85 to 2.60	15	1.94	1.08 to 3.20
Oesophagus, corrected*					14	1.81	0.99 to 3.04
Stomach	C16	41	1.34	0.96 to 1.82	28	1.18	0.78 to 1.70
Stomach, corrected*					30	1.26	0.85 to 1.80
Colon	C18	82	1.27	1.01 to 1.58	35	1.20	0.84 to 1.67
Rectum, rectosigmoid	C19-C21	42	1.01	0.73 to 1.36	21	1.25	0.78 to 1.92
Liver	C22	10	1.65	0.79 to 3.04	9	1.64	0.75 to 3.12
Gallbladder, bile ducts	C23-C24	5	1.31	0.42 to 3.05	6	2.79	1.02 to 6.08
Gallbladder, bile ducts*					5	2.33	0.76 to 5.43
Liver, gallbladder, bile ducts*	C22-C24	15	1.52	0.85 to 2.50	14	1.84	1.00 to 3.08
Pancreas	C25	25	1.17	0.76 to 1.73	21	1.06	0.66 to 1.62
Larynx	C32	13	1.77	0.94 to 3.03	5	2.22	0.72 to 5.17
Lung	C33-C34	91	1.02	0.82 to 1.25	67	0.92	0.71 to 1.17
Cutaneous melanoma	C43	50	1.28	0.95 to 1.68	13	1.43	0.76 to 2.45
Non-melanoma skin†	C44	37	0.96	0.68 to 1.33	<5	0.88	0.02 to 4.92
Mesothelioma	C45	8	2.59	1.12 to 5.11	<5	1.66	0.34 to 4.86
Mesothelioma, corrected*					5	2.77	0.90 to 6.47
Prostate	C61	231	1.18	1.03 to 1.34	55	1.01	0.76 to 1.31
Testis	C62	18	1.35	0.80 to 2.14	0	0.00	0.00 to 2.83
Kidney‡	C64	32	1.31	0.89 to 1.84	12	1.07	0.55 to 1.87
Urinary tract§	C65-C68	73	1.22	0.96 to 1.54	16	1.13	0.64 to 1.83
Central nervous system	C70-C72	30	1.30	0.88 to 1.86	14	1.31	0.72 to 2.20
Thyroid	C73	6	1.33	0.49 to 2.90	<5	2.22	0.27 to 8.03
Hodgkin lymphoma	C81	<5	0.49	0.06 to 1.76	<5	0.71	0.02 to 3.97
Non-Hodgkin lymphoma	C82-C86, C96	27	1.12	0.74 to 1.63	9	0.89	0.41 to 1.69
Multiple myeloma	C90	10	0.82	0.39 to 1.50	8	1.03	0.44 to 2.03
Leukaemia	C91-C95	15	0.83	0.46 to 1.36	12	1.11	0.57 to 1.94
Ill-defined or unspecified	C76, C80	10	0.72	0.34 to 1.32	15	0.89	0.50 to 1.47
Other specified¶		26	0.90	0.59 to 1.31	5	0.50	0.16 to 1.17

*Observed number of deaths corrected to be in line with morphologically confirmed diagnoses, as described in the text (Results, paragraph 3–6).
†Excluding basal cell carcinoma.
‡Excluding renal pelvis.
§Including bladder and renal pelvis.
¶The 'other specified' group includes the following codes: C07-C08, C17, C26-C31, C37-C38, C40-C41, C46-C50, C56-C57, C60, C63, C69, C74-C75, C88, C97.
ICD, International Classification of Diseases; Obs, observed; SIR, standardised incidence ratio; SMR, standardised mortality ratio.

DISCUSSION

This study evaluated cancer incidence and mortality in the Norwegian Fire Departments Cohort, comprising male employees active at 15 fire departments across Norway between 1913 and 2018 and alive between 1960 and 2018. Through a follow-up period of 58 years, incidence was elevated for colon cancer, mesothelioma, prostate cancer and all sites combined compared with the general population. Elevated mortality was found for cancer of the oesophagus and the gallbladder and bile ducts, though based on mortality data that were inconsistent with incidence data, and potential errors were observed in some of the mortality data, notably for mesothelioma cases.

[13] The size of the cohort limited the power to detect small elevations in rare cancers, such as the subgroups of lymphohaematopoietic cancers. Nonetheless, the historical character and the long follow-up period contributed a high number of person-years for analysis. High-quality, reliable incidence data allowed us to detect elevations in cancers that are less fatal with a long latency period and a potential occupational aetiology, such as bladder cancer.[18 19] The longer latency period of bladder cancer, the predominant urinary tract malignancy, has previously made identification of associations with occupational exposures difficult.[18]

We observed 73 cases alongside 16 deaths of urinary tract cancers. Largely in line with our findings, recent meta-analyses have reported elevated bladder cancer incidence[2 3] and mortality,[2] with elevations in incidence of 12%[3] and 18%.[2] The moderate elevations may also provide an explanation for inconsistent findings in incidence studies, as individual studies with less power may not detect an elevated risk. Findings from previous Nordic incidence studies have varied somewhat, with more bladder cancer cases than expected observed in Nordic,[20] Swedish[21] and Danish[8] studies, and fewer cases than expected in a study of 1080 firefighters in Stockholm.[22]

Table 3 Observed number of cases or deaths and standardised incidence ratios (SIRs) or standardised mortality ratios (SMRs) with 95% CIs for selected cancer sites in men in the Norwegian Fire Departments Cohort, stratified by period of follow-up (n=4295)

		Period of follow-up								
		≤1984 (35 977 pyr)			1985–1994 (21 017 pyr)			≥1995 (60 464 pyr)		
Cancer site	ICD-10	Obs.	Ratio	95% CI	Obs.	Ratio	95% CI	Obs.	Ratio	95% CI
All cancers, SIR	C00-C97	151	1.20	1.01 to 1.40	151	1.18	1.00 to 1.39	614	1.13	1.05 to 1.23
All cancers, SMR	C00-C97	92	1.26	1.01 to 1.54	77	1.14	0.90 to 1.42	207	1.00	0.87 to 1.15
Oesophagus, SIR	C15	<5	1.97	0.41 to 5.76	<5	1.49	0.18 to 5.37	9	1.46	0.67 to 2.76
Oesophagus*, SMR	C15	<5	2.15	0.44 to 6.27	<5	1.62	0.20 to 5.86	9	1.76	0.81 to 3.35
Stomach, SIR	C16	16	1.35	0.77 to 2.20	10	1.52	0.73 to 2.80	15	1.23	0.69 to 2.02
Stomach, SMR	C16	13	1.34	0.71 to 2.29	9	1.74	0.79 to 3.29	8	0.90	0.39 to 1.78
Colon, SIR	C18	17	1.96	1.14 to 3.15	16	1.50	0.86 to 2.43	49	1.09	0.80 to 1.44
Colon, SMR	C18	11	2.35	1.17 to 4.21	9	1.66	0.76 to 3.15	15	0.79	0.44 to 1.30
Rectum, rectosigmoid, SIR	C19-C21	5	0.72	0.24 to 1.69	6	0.80	0.29 to 1.73	31	1.14	0.78 to 1.62
Rectum, rectosigmoid, SMR	C19-C21	<5	0.82	0.17 to 2.38	<5	0.53	0.06 to 1.90	16	1.73	0.99 to 2.80
Liver, gallbladder, bile ducts, SIR	C22-C24	6	3.97	1.46 to 8.64	<5	2.04	0.42 to 5.96	6	0.87	0.32 to 1.89
Liver, gallbladder, bile ducts*, SMR	C22-C24	5	3.46	1.12 to 8.08	<5	2.65	0.55 to 7.75	6	1.19	0.44 to 2.59
Larynx, SIR	C32	<5	0.54	0.01 to 3.03	5	3.31	1.08 to 7.73	7	1.75	0.70 to 3.61
Larynx, SMR	C32	<5	1.71	0.04 to 9.52	<5	2.20	0.06 to 12.3	<5	2.46	0.51 to 7.20
Lung, SIR	C33-C34	19	1.15	0.69 to 1.79	22	1.33	0.83 to 2.01	50	0.89	0.66 to 1.17
Lung, SMR	C33-C34	15	1.07	0.60 to 1.76	19	1.31	0.79 to 2.04	33	0.75	0.51 to 1.05
Cutaneous melanoma, SIR	C43	5	1.15	0.37 to 2.69	11	1.95	0.97 to 3.48	34	1.16	0.81 to 1.63
Cutaneous melanoma, SMR	C43	<5	1.30	0.16 to 4.69	<5	2.63	0.72 to 6.74	7	1.17	0.47 to 2.40
Non-melanoma skin†, SIR	C44	<5	1.05	0.22 to 3.08	<5	0.56	0.12 to 1.64	31	1.03	0.70 to 1.46
Non-melanoma skin†, SMR	C44	0	0.00	0.00 to 14.9	0	0.00	0.00 to 16.8	<5	1.33	0.03 to 7.39
Mesothelioma, SIR	C45	<5	3.88	0.10 to 21.6	0	0.00	0.00 to 5.71	7	3.04	1.22 to 6.26
Mesothelioma*, SMR	C45	<5	–		0	–		<5	2.22	0.60 to 5.68
Prostate, SIR	C61	15	0.81	0.45 to 1.33	34	1.32	0.91 to 1.84	182	1.20	1.03 to 1.39
Prostate, SMR	C61	7	0.97	0.39 to 1.99	7	0.65	0.26 to 1.33	41	1.13	0.81 to 1.53
Testis, SIR	C62	<5	1.53	0.42 to 3.92	0	0.00	0.00 to 1.27	14	1.68	0.92 to 2.82
Testis, SMR	C62	0	0.00	0.00 to 4.83	0	0.00	0.00 to 23.5	0	0.00	0.00 to 9.63
Kidney‡, SIR	C64	<5	0.98	0.27 to 2.52	9	2.51	1.15 to 4.77	19	1.13	0.68 to 1.76
Kidney‡**, SMR	C64	<5	0.39	0.01 to 2.17	5	2.32	0.75 to 5.41	6	0.93	0.34 to 2.02
Urinary tract§, SIR	C65-C68	15	1.50	0.84 to 2.48	16	1.46	0.83 to 2.37	42	1.08	0.78 to 1.46
Urinary tract§, SMR	C65-C68	<5	1.10	0.23 to 3.21	5	1.83	0.59 to 4.27	8	0.92	0.40 to 1.81
Thyroid, SIR	C73	<5	1.12	0.03 to 6.26	0	0.00	0.00 to 4.71	5	1.68	0.55 to 3.93
Thyroid, SMR	C73	<5	4.21	0.11 to 23.5	0	0.00	0.00 to 17.0	<5	2.06	0.05 to 11.5
Hodgkin lymphoma, SIR	C81	0	0.00	0.00 to 2.21	0	0.00	0.00 to 4.97	<5	0.93	0.11 to 3.35
Hodgkin lymphoma, SMR	C81	<5	1.17	0.03 to 6.51	0	0.00	0.00 to 14.6	0	0.00	0.00 to 8.70
non-Hodgkin's lymphoma, SIR	C82-C86, C96	<5	0.95	0.20 to 2.77	7	1.86	0.75 to 3.84	17	0.99	0.58 to 1.59
non-Hodgkin's lymphoma, SMR	C82-C86, C96	<5	0.54	0.01 to 3.04	<5	0.94	0.11 to 3.40	6	0.98	0.36 to 2.12
Multiple myeloma, SIR	C90	<5	1.28	0.26 to 3.73	<5	0.96	0.12 to 3.45	5	0.64	0.21 to 1.49
Multiple myeloma, SMR	C90	<5	1.25	0.15 to 4.51	<5	1.90	0.39 to 5.56	<5	0.65	0.13 to 1.91
Leukaemia, SIR	C91-C95	<5	1.09	0.30 to 2.78	<5	0.35	0.01 to 1.96	10	0.86	0.41 to 1.58
Leukaemia, SMR	C91-C95	<5	1.33	0.36 to 3.40	<5	0.52	0.01 to 2.91	7	1.19	0.48 to 2.45

Cells lacking SMR had 0 expected deaths.
Follow-up from 1 January 1960 to 31 December 2018.
*Observed number of deaths corrected to be in line with morphologically confirmed diagnoses, as described in the text (Results, paragraph 3–6).
†Excluding basal cell carcinoma.
‡Excluding renal pelvis.
§Including bladder and renal pelvis.
ICD, International Classification of Diseases; Obs., observed; pyr, person-years.

A limitation in the mortality data was identified in the form of possible misclassifications. While population-based cancer registries are largely based on data from clinical and pathology reports,[23] cause of death registries is based on death certificates that are rarely validated against clinical or pathological information.[16 24] In Norway, the Cause of Death Registry has a high degree of coverage, but few validation studies on the quality and accuracy of its data have been conducted.[16 25] Furthermore, underlying cause of death cannot always be determined, and it can be challenging to identify a single underlying cause of death when comorbidity, or contributing causes of death, may also be important.[16]

In 1981, Percy *et al*[26] examined variability and biases in cancer mortality data and discussed how they may negatively impact

Table 4 Observed number of cases or deaths and standardised incidence ratios (SIRs) or standardised mortality ratios (SMRs) with 95% CIs for selected cancer sites in men in the Norwegian Fire Departments Cohort stratified by age at diagnosis (n=4295)

		Age at diagnosis								
		≤49 years (65 816 pyr)			50–69 years (40 232 pyr)			≥70 years (11 410 pyr)		
Cancer site	ICD-10	Obs.	Ratio	95% CI	Obs.	Ratio	95% CI	Obs.	Ratio	95% CI
All cancers, SIR	C00-C97	72	0.99	0.78 to 1.25	404	1.09	0.98 to 1.20	440	1.25	1.14 to 1.37
All cancers, SMR	C00-C97	16	0.77	0.44 to 1.25	137	0.99	0.83 to 1.17	223	1.19	1.04 to 1.36
Oesophagus, SIR	C15	0	0.00	0.00 to 5.74	7	1.42	0.57 to 2.93	7	1.94	0.78 to 3.99
Oesophagus*, SMR	C15	0	0.00	0.00 to 9.25	7	1.74	0.70 to 3.59	7	2.06	0.83 to 4.25
Stomach, SIR	C16	<5	1.24	0.26 to 3.63	22	1.51	0.95 to 2.28	16	1.18	0.67 to 1.91
Stomach*, SMR	C16	<5	1.79	0.37 to 5.24	14	1.29	0.70 to 2.16	13	1.16	0.62 to 1.98
Colon, SIR	C18	<5	0.74	0.15 to 2.16	30	1.11	0.75 to 1.59	49	1.47	1.09 to 1.94
Colon, SMR	C18	<5	0.70	0.02 to 3.89	17	1.60	0.93 to 2.57	17	0.99	0.58 to 1.59
Rectum, rectosigmoid, SIR	C19-C21	<5	1.12	0.23 to 3.28	19	0.91	0.55 to 1.42	20	1.11	0.68 to 1.71
Rectum, rectosigmoid, SMR	C19-C21	0	0.00	0.00 to 3.69	6	0.85	0.31 to 1.86	15	1.68	0.94 to 2.78
Liver, gallbladder, bile ducts, SIR	C22-C24	<5	1.34	0.03 to 7.46	5	1.05	0.34 to 2.46	9	2.05	0.94 to 3.89
Liver, gallbladder, bile ducts*, SMR	C22-C24	<5	1.81	0.05 to 10.1	<5	1.17	0.32 to 2.99	9	2.47	1.13 to 4.69
Larynx, SIR	C32	0	0.00	0.00 to 5.69	<5	0.68	0.14 to 2.00	10	4.10	1.97 to 7.55
Larynx, SMR	C32	0	0.00	0.00 to 32.7	<5	0.92	0.02 to 5.13	<5	3.71	1.01 to 9.50
Lung, SIR	C33-C34	<5	0.93	0.25 to 2.38	35	0.76	0.53 to 1.06	52	1.34	1.00 to 1.75
Lung, SMR	C33-C34	<5	0.68	0.08 to 2.45	24	0.67	0.43 to 1.00	41	1.20	0.86 to 1.63
Cutaneous melanoma, SIR	C43	10	1.11	0.53 to 2.05	24	1.32	0.84 to 1.96	16	1.33	0.76 to 2.17
Cutaneous melanoma, SMR	C43	0	0.00	0.00 to 1.80	10	2.43	1.17 to 4.47	<5	0.91	0.19 to 2.67
Non-melanoma skin†, SIR	C44	<5	1.22	0.15 to 4.42	11	1.04	0.52 to 1.86	24	0.92	0.59 to 1.37
Non-melanoma skin†, SMR	C44	0	0.00	0.00 to 95.0	0	0.00	0.00 to 9.69	<5	1.26	0.03 to 7.03
Mesothelioma, SIR	C45	0	0.00	0.00 to 28.4	<5	2.86	0.78 to 7.33	<5	2.53	0.69 to 6.48
Mesothelioma*, SMR	C45	0	0.00	0.00 to 148	<5	4.36	0.90 to 12.7	<5	1.83	0.22 to 6.60
Prostate, SIR	C61	<5	2.42	0.66 to 6.20	120	1.25	1.03 to 1.49	107	1.09	0.89 to 1.32
Prostate, SMR	C61	0	0.00	0.00 to 20.6	8	0.76	0.33 to 1.49	47	1.07	0.79 to 1.43
Testis, SIR	C62	16	1.44	0.82 to 2.34	<5	1.02	0.12 to 3.68	0	0.00	0.00 to 11.7
Testis, SMR	C62	0	0.00	0.00 to 4.48	0	0.00	0.00 to 11.3	0	0.00	0.00 to 23.9
Kidney‡, SIR	C64	<5	0.71	0.09 to 2.58	12	0.90	0.46 to 1.57	18	2.17	1.29 to 3.43
Kidney‡, SMR	C64	<5	2.79	0.34 to 10.1	<5	0.77	0.21 to 1.96	6	1.14	0.42 to 2.48
Urinary tract§, SIR	C65-C68	<5	0.97	0.20 to 2.83	25	0.96	0.62 to 1.42	45	1.47	1.07 to 1.96
Urinary tract§, SMR	C65-C68	0	0.00	0.00 to 11.2	<5	0.73	0.15 to 2.12	13	1.33	0.71 to 2.27
Thyroid, SIR	C73	<5	0.69	0.02 to 3.84	<5	1.91	0.52 to 4.88	<5	1.05	0.03 to 5.86
Thyroid, SMR	C73	0	0.00	0.00 to 44.8	<5	2.60	0.07 to 14.5	<5	2.23	0.06 to 12.4
Hodgkin lymphoma, SIR	C81	0	0.00	0.00 to 1.39	<5	1.37	0.17 to 4.96	0	0.00	0.00 to 5.98
Hodgkin lymphoma, SMR	C81	0	0.00	0.00 to 5.93	<5	1.75	0.04 to 9.75	0	0.00	0.00 to 9.11
non-Hodgkin's lymphoma, SIR	C82-C86, C96	6	1.48	0.54 to 3.22	14	1.21	0.66 to 2.04	7	0.83	0.33 to 1.70
Non-Hodgkin lymphoma, SMR	C82-C86, C96	0	0.00	0.00 to 2.71	5	1.24	0.40 to 2.90	<5	0.80	0.22 to 2.06
Multiple myeloma, SIR	C90	0	0.00	0.00 to 3.51	5	0.86	0.28 to 2.00	5	0.90	0.29 to 2.10
Multiple myeloma, SMR	C90	0	0.00	0.00 to 10.4	<5	0.65	0.08 to 2.35	6	1.36	0.50 to 2.96
Leukaemia, SIR	C91-C95	<5	0.39	0.01 to 2.18	8	0.97	0.42 to 1.91	6	0.81	0.30 to 1.77
Leukaemia, SMR	C91-C95	0	0.00	0.00 to 2.43	6	1.51	0.55 to 3.28	6	1.07	0.39 to 2.33

Follow-up from 1 January 1960 to 31 December 2018.
*Observed number of deaths corrected to be in line with morphologically confirmed diagnoses, as described in the text (Results, paragraph 3–6).
†Excluding basal cell carcinoma.
‡Excluding renal pelvis.
§Including bladder and renal pelvis.
ICD, International Classification of Diseases; Obs., observed; pyr, person-years.

the value of mortality data in epidemiologic studies. Cancer sites such as lung, prostate and bladder cancer, for which there is a high detection and confirmation rate, were considered sites where mortality rates could be considered reliable.[26] Improved diagnostics, treatment and survival may have changed this picture somewhat, but even in the present study, lung cancer deaths appeared well registered, as would be expected with a cancer site where incidence and mortality rates still follow each other closely.[19]

We observed only three deaths in eight incident cases of mesothelioma, which is known as an aggressive and incurable malignancy.[27] On reassessment of deaths recorded in accordance with morphologically confirmed incidence data, SMR increased and both incidence and mortality from mesothelioma were elevated

over two-fold. As corrections cannot similarly be made for reference rates, these findings should be interpreted with caution. Nonetheless, in line with our SIR and recoded SMR, Daniels *et al*[5] also reported incidence and mortality from mesothelioma elevated over two-fold among US firefighters. Most mesothelioma cases are attributable to inhalation of asbestos fibres,[27] and risk of mesothelioma has long been a concern for firefighters. The first studies to observe elevated risk for mesothelioma were not until 2014,[5 20] likely related to the long latency and rarity of the disease as well as the lack of specific code for mesothelioma prior to ICD-10. In the present study, two deaths coded using ICD-10 among those with mesothelioma diagnoses were also missed in the initial mortality analysis, demonstrating the importance of considering alternative asbestos-related and mesothelioma-related codes in studies of mesothelioma cancer risk.

Detection bias due to differential screening practices may also influence firefighters' estimated cancer risk. In such situations, mortality rates, representing the most aggressive tumours, can offer a more unbiased estimate of the true risk.[28]

In Norway, general screening for prostate cancer using the prostate-specific antigen test is not recommended,[19] but introduction of the test around 1990 was associated with a rapid increase in incidence.[29] Findings on prostate cancer in firefighters are among the more consistent, with meta-analyses reporting elevated incidence and mortality at unity.[3 4 30] There is limited evidence in humans of associations between increased prostate cancer risk and occupational exposure to polycyclic aromatic hydrocarbons and night-shift work.[31 32] However, some have also suggested that the elevated incidence observed may be related to the regular health check-ups that firefighters undergo through their work.[2–4] A pattern of elevated prostate cancer SIR and a lower and less noteworthy SMR was readily recognised in our results for the years from 1985 on, and for ages below 70 years. In a recent census-based study, Jakobsen *et al*[33] reported younger age at prostate cancer diagnosis and better prognostic factors among Norwegian firefighters, suggesting that the elevated incidence observed may be related to diagnostic intensity.

As firefighters are required to be in relatively good health for their work, a healthy worker effect (HWE) may bias studies of occupational risks downwards. Nonetheless, the HWE has been reported to be less pronounced for studies on cancer risk,[34 35] and it is thought to diminish in studies with longer follow-up periods[34] and with increased time since first employment.[36] Some previous SIR[8 37 38] and SMR studies[9 39] on firefighters have used external occupational groups as the reference, which has been suggested as a method to reduce possible bias from the HWE.[34] Otherwise, few previous studies on cancer risk among firefighters have closely considered the HWE.

The HWE appears to have the most potential to bias findings for cancer sites where smoking is a predominant risk factor.[40 41] Our finding of lung cancer incidence and mortality close to the expected levels, despite an obvious risk of inhalation of carcinogens during firefighting, may be partly explained by presumed lower smoking rates among Norwegian firefighters compared with the general population. Our findings of elevated laryngeal cancer risk (1985–1995 and age ≥70 years) and some findings on urinary tract cancer could be in line with occupational exposure to carcinogens. Pukkala *et al*[20] observed elevated incidence of lung adenocarcinoma among Nordic firefighters, also with the most prominently elevated risk with age over 70 years. However, other Scandinavian studies have reported both lung and laryngeal cancer incidence near unity,[8 21 22] and Bigert *et al*[42] did not find evidence of excess lung cancer risk related to occupational exposure as a firefighter even after adjustment for smoking. Unfortunately, we did not have data on lifestyle factors for our cohort.

Many studies on cancer risk among firefighters have discussed limitations following the lack of data on exposures, which likely differ temporally and regionally and may contribute to inconsistent findings on cancer risk. However, the potential implications of assessment of cancer incidence versus mortality have not been examined since 1992, when Demers *et al*[7] demonstrated the advantages of assessing cancer incidence and mortality alongside each other.

While assessment of incidence or mortality did not greatly influence the interpretation of results in the present study, our results again demonstrate how assessment and comparison of both cancer measures can be valuable. Where high-quality incidence data are available, cancer incidence probably better informs occupational cancer risk at most sites. The most prominent differences between SIR and SMR appeared to be related to cases with inconsistencies between site of cancer diagnosis and cause of death. Nonetheless, despite some limitations in mortality data, assessment of cancer mortality can provide additional insight into potential biases of incidence rates, such as that related to possible differential patterns of screening that may have contributed to an elevated SIR for prostate cancer in this occupational group. As firefighters' occupational exposures are complex and findings on cancer risk can be difficult to interpret, the insight provided by assessment of both cancer incidence and mortality can be particularly beneficial in understanding their cancer risks.

Twitter Marit B Veierød @MaritBVeierod

Contributors NM carried out statistical analyses and drafted the paper. TKG and KK conceived the study and planned the design and data collection. NM and JJ managed the data. MBV and JIM provided guidance for the statistical analyses. All authors participated in the interpretation and presentation of results and have read and approved the final manuscript. Guarantor: KK.

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Ethics approval This study was approved by the Regional Committee for Medical and Health Research Ethics (reference number: 5646). This study was exempted from the requirement to obtain consent on the grounds that it was practically and financially unfeasible to send letters to those registered in the cohort for participation. Data collection was done retrospectively, and complete overview over workers in the cohort is important to avoid biases and consequent errors in results, and misinterpretation of risk.

Provenance and peer review Not commissioned; externally peer reviewed.

Data availability statement Data may be obtained from a third party and are not publicly available. The data that support the findings of this study are available from the CRN (cohort data and cancer data) and the National Population Register (death and emigration data) but restrictions apply to the availability of these data, which were used under license for the current study, and so are not publicly available. Requests for data sharing/case pooling for projects with necessary approvals and legal basis according to the EU General Data Protection Regulation (GDPR) may be directed to principal investigator Dr Krisitna Kjærheim; email: kristina.kjaerheim@kreftregisteret.no.

ORCID iDs
Niki Marjerrison http://orcid.org/0000-0002-3618-8522
Jarle Jakobsen http://orcid.org/0000-0002-7687-077X

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