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Risk of Cancer Among Firefighters: A Quantitative Review of Selected Malignancies

Sami Youakim, MD, MSc, FRCP(C)

ABSTRACT. Using the fixed-effect model, the author quantitatively estimated the risks of cancers of the colon, bladder, kidneys, and brain as well as non-Hodgkin's lymphoma and leukemia among firefighters. The risk of these six cancers was not markedly elevated when cohort mortality studies were considered. When all mortality studies were considered, however, there was a mild increase in risk for kidney cancer and non-Hodgkin's lymphoma, with a summary relative risk (sumRR) of 1.22 (95% confidence interval [CI] = 1.02–1.43) and 1.40 (95% CI = 1.20–1.60), respectively. A subcohort analysis based on duration of employment revealed that firefighters with 30 or more years of employment had a significantly increased mortality risk for colon cancer, sumRR of 1.51 (95% CI = 1.05–2.11); kidney cancer, sumRR of 6.25 (95% CI = 1.70–16.00); brain cancer, sumRR of 2.53 (95% CI = 1.27–7.07); and leukemia, sumRR of 2.87 (95% CI = 1.43–5.14). After firefighters had 40 or more years of employment, their risk of mortality was significantly increased for colon cancer, sumRR of 4.71 (95% CI = 2.03–9.27); kidney cancer, sumRR of 36.12 (95% CI = 4.03–120.42); and bladder cancer, sumRR of 5.7 (95% CI = 1.56–14.63). The risk for non-Hodgkin's lymphoma was elevated but not significantly so among firefighters with 20 or more years of employment, with sumRR of 1.72 (95% CI = 0.90–3.31). Kidney cancer risk was significantly elevated as early as the second decade of employment.

KEYWORDS: bladder, brain, cancer, colon, firefighters, kidney, leukemia, lymphoma, non-Hodgkin's

Firefighters are exposed to a large number of known or suspected carcinogens during their firefighting activity, including benzene, benzidine, 1,3-butadiene, dioxins, dibenzofurans, polycyclic aromatic hydrocarbons, asbestos, formaldehyde, and acrylonitrile.[1–6] In Canada, several provincial governments have recently passed legislation recognizing a number of cancers as occupational diseases among firefighters, each of them conditional on a person's minimal period of full-time employment as a firefighter. These cancers include primary cancers of the brain (duration of employment ≥ 10 years), kidneys (≥ 20 years), bladder (≥ 15 years), and colon (≥ 20 years), as well as leukemia (≥ 5 years) and non-Hodgkin's lymphoma (≥ 20 years). These legislative changes are a direct outcome of a solicited internal qualitative review[7] as well as political lobbying of interested parties. Not everyone is in complete agreement with these changes, including many in the community of occupational medicine. In this study, I quantitatively evaluate the risk of these 6 cancers and the associated minimal employment requirements.

METHODS

I performed a comprehensive computer-assisted search of MEDLINE, NIOSHTIC 2, and EMBASE databases for the years 1966 to 2005. I used a combination of the following keywords in my search strategy: firemen or firefighter(s) or fire rescue; cancer or tumor or malignancy (or malignancies); colon or colorectal cancer; lymphoma; non-Hodgkin's lymphoma; leukemia; renal or bladder or kidney; brain. In addition, I reviewed the reference lists of all appropriate articles for pertinent studies that may have been missed in the database search.

Sami Youakim *is with the Division of Occupational Medicine at the University of British Columbia, Vancouver, Canada.*

I selected only those studies that provided results for the specific tumors of interest. I excluded outcome measures for very broad cancer groupings, such as hematopoietic, digestive, colorectal, and genito-urinary cancers. These broad categories are too heterogeneous and include histopathologically and etiologically distinct tumor types.

When several studies provided risk measurements for the same cohorts or case-control series, I included only those with the broadest scope.

I calculated summary relative risk (sumRR) estimates by using the fixed-effect model.[8] I used a Poisson distribution to calculate the 95% confidence intervals (CIs) for the risk estimates.[9,10] I calculated 2 sets of sumRR for each specific tumor; 1 combined only cohort studies and the second combined all studies.

Accurate quantitative estimates of firefighter exposure to carcinogens are logistically very difficult to obtain. Researchers commonly use duration of employment in cohort studies as a surrogate estimate of cumulative exposure to carcinogens. I performed a subcohort analysis to determine if there were higher risk subgroups based on employment duration and to estimate the minimal tenure associated with the increased risk of specific cancers. The time increments that I used in the subcohort analysis were as follows: < 10 years, 10–19 years, 20–29 years, $\geq$ 10 years, $\geq$ 20 years, and $\geq$ 30 years. I combined studies that provided relative risk estimates for these time intervals of duration of employment by using the fixed-effect model in a similar fashion as used for complete cohort data. If there is an association between the risk of a specific cancer and cumulative exposure as estimated by duration of employment as a firefighter, one would expect an increasing trend in the combined relative risk estimates from least to longest duration of employment subgroups. This would be a type of dose–response relationship evaluation.

RESULTS

There were 16 studies in which researchers focused on the risks of the 6 specific cancers of interest among firefighters that used a mortality outcome (see Table 1)[11–26] and 10 studies that were based on disease morbidity or occurrence (see Table 2).[27–34] The studied populations were from 5 countries, including Australia, Canada, New Zealand, Sweden, and the United States.

There were a total of 13 cohort studies of predominantly male, urban, full-time firefighters. Authors of all the cohort studies used similar methods of gathering information and identifying the population at risk. The ascertainment of vital status of firefighters was high in all studies, surpassing 90%. The relative risk estimate of the cohort studies consisted of a standardized mortality ratio (SMR) and a standardized incidence ratio (SIR).

There were 3 case-control studies that directly collected detailed job histories[29–31] and the risk estimates were odds ratios (ORs). The remainder of the studies was a mixture of prevalence- or survey-type studies. The authors of these studies determined occupational status from pension records, death certificates, cancer registries, or hospital records. Their relative risk estimate consisted of proportional mortality ratio (PMR), standardized mortality odds ratio (SMOR), mortality odds ratio (MOR), standardized morbidity OR, and SIR.

I excluded 1 cohort study[20] and 1 case-control study[29] from the analysis because their populations or cases were included in subsequent larger studies.[14,30] I excluded 1 other study[34] from the sumRR estimates because it did not provide the number of observed or expected cases.

I calculated sumRR estimates for all mortality studies combined (see Table 1) and for all morbidity studies combined (see Table 2). I also calculated the corresponding sumRR estimates only for cohort studies for mortality (see Table 1) and morbidity (see Table 2). The overall mortality among firefighters was slightly lower than expected, with a sumRR of 0.84 (95% CI = 0.82–0.86). The overall cancer mortality was close to expected, with a sumRR for cohort studies only of 0.96 (95% CI = 0.93–1.00), whereas the risk estimate based on all mortality studies was slightly but significantly increased, with a sumRR of 1.04 (95% CI = 1.02–1.07; see Table 1). The overall cancer incidence was not higher than expected given the outcomes of combined cohort studies, with a sumRR of 1.02 (95% CI = 0.93–1.11; see Table 2).

None of the 6 specific cancers demonstrated a significantly elevated mortality risk on the basis of combined cohort studies, and only 2 demonstrated a moderate increased risk when all studies were combined; these were kidney cancer, with a sumRR of 1.22 (95% CI = 1.02–1.43), and non-Hodgkin's lymphoma, with a sumRR of 1.40 (95% CI = 1.20–1.60).

On the basis of all studies combined, the risk of cancer incidence or occurrence revealed a moderate statistically significant increased risk for bladder cancer, with a sumRR of 1.36 (95% CI = 1.01–1.80; see Table 2). On the basis of cohort studies only, none of the 6 cancers demonstrated a statistically significant increase in morbidity. In fact, the incidence of kidney cancer was significantly lower than expected, with a sumRR of 0.48 (95% CI = 0.19–0.98).

The risks of the 6 cancers according to a subcohort analysis of duration of employment are given in Table 3. The sumRR for the incidence of 5 cancers (ie, brain, colon, bladder, non-Hodgkin's lymphoma, and leukemia) are not significantly increased regardless of the duration of employment. None of the cohort studies provide this risk estimate for kidney cancer, so the sumRRs for occurrence based on the duration of employment for this cancer are not available. Statistically significant increases in mortality based on duration of employment are noted for 5 of the 6 cancers. For non-Hodgkin's lymphoma, there is no apparent statistically significant increase in risk that is related to duration of employment.

Table 1.—Cancer Risk Estimates, Based on Mortality

Study	All causes	All cancers	Brain	Colon	Bladder	Kidney	NHL	Leukemia
Cohort								
			O/E SMR					
Toronto, Canada (11)	777/820.3	199/190.1	14/7.0	11/18.2	7/5.5	2/4.6	3/1.5[d]	8/5.4[e]
	0.95	1.05	2.01*	0.6	1.28	0.43	2.04	1.47
Philadelphia (12)	2220/2312.5	500/455	8/13	64/42.4	17/13.6	12/11.2	20/14.2	15/18.1
	0.96*	1.10	0.61	1.51*	1.25	1.07	1.41	0.83
San Francisco (13)	1186/1317.8	236/248.4	5/6.2	24/24.2[f]	5/8.8	4/5.9	4/4.5[g]	6/9.8[h]
	0.90*	0.95	0.81	0.99	0.57	0.68	0.89	0.61
Seattle, Tacoma, Portland (14)	1169/1443.2	291/306.3	18/8.7	24/28.2	2/8.7	2/7.4	7/4.9[g]	15/11.8
	0.81*	0.95	2.07*	0.85	0.23*	0.27*	1.42	1.27
Florida (15)	1411/2475.4	403/474.1	13/20	38/33.3	14/7.8		3/4.6[d]	14/16.7
	0.57*	0.85*	0.66	1.14	1.79		0.65	0.84
Buffalo (16)	470/494.2	102/94.0	6/2.6	16/8.7	9/3.2	3/2.3		
	0.95	1.09	2.36	1.83*	2.86*	1.3		
New Zealand (17)	117/201	42/51.9	2/3.0	6/5.0	2/0.7			
	0.58*	0.81	0.68	1.19	2.73			
Stockholm, Sweden (18)	316/387.9	93/91.3	5/1.8	6/7.1		4/3.7		
	0.82*	1.02	2.79	0.85		1.1		
Edmonton, Calgary, Canada (19)	370/384.7	92/72.7	3/2.1		4/1.3	7/1.7		
	0.96	1.27*	1.47		3.16	4.14*		
Seattle (20)[a]	386/498.8	92/95.7	3/3.1					7/4.0[h]
	0.76*	0.96	0.95					1.73
Boston (21)[b]	2470/2720.9	367/427.3	8/7.8					
	0.91*	0.86*	1.03					
Pension or death								
			O/E PMR					
New Jersey (22)[b,c]	263/263.0	67/66.9						4/2.3
	1.00	1.00						1.77
27 states (23)		1636/1487.3	38/36.9		37/37.4	53/36.8	66/50	61/51.3
		1.1*	1.03		0.99	1.44*	1.32*	1.19
Honolulu (24)		54/45.4	3/0.8	5/5.5				
		1.19	3.78*	0.91				
			O/E SMOR					
24 states (25)							12/2.1	
							5.6*	
			O/E MOR					
24 states (26)		1817/1651.8	41/41	149/149	48/40	49/37.7	76/54.3	60/54.6
		1.1*	1	1	1.2	1.3	1.4*	1.1
SumRR								
All studies	0.84	1.04	1.09	1.07	1.14	1.22	1.40	1.08
95% CI	0.82–0.86	1.02–1.07	0.92–1.25	0.95–1.18	0.96–1.33	1.02–1.43	1.20–1.60	0.92–1.23
Cohort studies only	0.84	0.96	1.14	1.13	1.21	0.92	1.25	0.94
95% CI	0.82–0.85	0.93–1.00	0.90–1.41	0.97–1.29	0.92–1.56	0.64–1.29	0.88–1.72	0.71–1.21

Note. Numbers in parentheses refer to reference numbers (see the Reference section). O = observed; E = expected; SMR = standardized mortality rate; PMR = proportional mortality ratio; SMOR = standardized mortality odds ratio; MOR = mortality odds ratio; sumRR = summary relative risk; CI = confidence interval; NHL = non-Hodgkin's lymphoma. Pension or death studies refer to studies in which occupation is derived from pension records or death certificates.

[a]This study was not included in the sumRR (see text for explanation).

[b]Comparison group state males.

[c]White male firefighters.

[d]Lymphosarcoma.

[e]Combined myeloid and lymphoid.

[f]Malignancies of the intestine, except rectum.

[g]Lymphosarcoma and reticulosarcoma.

[h]Leukemia and aleukemia.

*$p \leq .05$.

Table 2.—Cancer Risk Estimates, Based on Incidence or Morbidity (Occurrence)

Study	All cancers	Brain	Colon	Bladder	Kidney	NHL	Leukemia
Cohort							
				O/E SIR			
New Zealand (17)[b]	118/123.8	5/3.9	7/11.8	5/4.4	2/3.5		4/2.2[c]
	0.95	1.27	0.6	1.14	0.57		1.81
Seattle, Tacoma (27)	224/213.0	4/3.6	23/21	18/15.3	3/5.6	7/7.7	6/6.2
	1.1	1.1	1.1	1.2	0.5	0.9	1
Stockholm, Sweden (18)	127/127.4	5/3.7	8/8.9		2/5.6		
	1.0	1.37	0.9		0.36		
Melbourne, Australia (28)	50/44.25					4/2.2	
	1.13					1.85	
Case-control							
				O/E OR			
San Francisco (29)[a]		3/1.1[f]					
		2.7					
San Francisco (30)		6/1[g]					
		5.93					
Montreal, Canada (31)			8/5.3				
			1.5				
Registry or records							
				O/E SMorbOR			
Massachusetts (32)[c,d]		5/5.8	33/27.5	26/16.4		14/8.8	6/5.4
		0.86	1.2	1.59*		1.59	1.12
				O/E SIR			
Portland-Vancouver (33)							4/1.2
				O/E RR			3.46*
New Zealand (34)[a]					—		
					4.69		
SumRR							
All studies		1.39	1.06	1.36		1.34	1.34
95% CI		0.90–2.05	0.84–1.32	1.01–1.80		0.86–1.97	0.82–2.06
Cohort studies only	1.02	1.25	0.91	1.17	0.48	1.11	1.19
95% CI	0.93–1.11	0.68–2.10	0.64–1.25	0.74–1.75	0.19–0.98	0.55–1.99	0.57–2.19

Note. Numbers in parentheses refer to reference numbers (see the Reference section). O = observed; E = expected; SIR = standardized incidence ratio; SMorbOR = standardized morbidity odds ratio; RR = risk ratio; sumRR = summary relative risk; CI = confidence interval; NHL = non-Hodgkin's lymphoma. Registry or record studies are those in which occupation is derived from cancer registries or hospital records. The dash indicates that there was no data available.

[a]This study is not included in the sumRR (see text for explanation).
[b]Complete cohort, 1977–1996.
[c]Comparison group state males.
[d]White male firefighters.
[e]Myeloleukemia.
[f]Ever employed as firefighter.
[g]Males' longest held occupation as firefighter.
*$p \leq .05$.

According to the results of one study,[16] statistically significant increases in mortality risk for bladder cancer occur after a person has 40 or more years of employment as a firefighter, with a sumRR of 5.71 (95% CI = 1.56–14.63). After a person has 30 or more years of employment as a firefighter, statistically significant increases in mortality risk occur for brain cancer, with a sumRR of 2.53 (95% CI = 1.27–7.07), according to results of 3 studies[11,14,18]; for leukemia, with a sumRR of 2.87 (95% CI = 1.43–5.14), according to results of 2 studies[11,14]; and for colon cancer, with a sumRR of 1.51 (95% CI = 1.05–2.11), according to results of 3 studies.[13,14,16] The risk of colon cancer substantially increases after a person has 40 or more years of employment as a firefighter, with a sumRR of 4.71 (95% CI = 2.03–9.27), according to the results of one study.[16] The risk of colon cancer is also significantly elevated among those people with fewer than 10 years of firefighting employment, with a sumRR of 1.64 (95% CI = 1.04–2.45), according to results of 3 studies.[12,13,16] For kidney cancer, a person's risk increases significantly only after 10 or more years of work, with a sumRR of 2.86 (95% CI = 1.67–4.59), according to results of 2 studies.[12,19] The risk of kidney cancer remains stable for a person employed as a firefighter for 20 or more years, with a sumRR of 2.80 (95% CI = 1.60–4.55), according to results of 2 studies,[12,19] but then it increases steadily with every additional decade of employment that the person has as a firefighter: according to one study,[19] after 30 or more years the sumRR is 6.25 (95% CI = 1.70–16.00) and after 40 or more years it is 36.12 (95% CI = 4.03–120.42).

In addition to the notable dose–response relationship for kidney cancer mortality, there is an apparent dose–response relationship for brain and bladder cancer risk that is based on duration of employment; the sumRRs increase fairly steadily after a person has 10 years of employment. For the other malignancies a dose–response relationship is less obvious.

COMMENT

There are several published reviews that evaluate the risk of various cancers among firefighters.[4,35–37] Between them, there is some agreement and some marked differences in the conclusions regarding the risk of specific cancers among firefighters. All of them are concordant, with some differences in the level of certainty that work as a firefighter is related to a risk of brain cancer. In narrative reviews conducted over a decade ago, both Golden et al and Guidotti concluded that the evidence was strongly suggestive of an association and increased risk,[4,35] whereas, in an even older quantitative review, Howe and Burch concluded that the evidence was supportive of a causal association.[36] Haas et al[37] recently concluded that there was no convincing evidence that employment as a firefighter was associated with an increase in development of cancer. However, for brain cancer, these authors did note that the risk estimates were consistently elevated and further investigation was warranted.

Both Golden et al[4] and Guidotti[35] concluded that there was strong evidence for an association between bladder cancer risk and firefighting. For the remaining 4 malignancies, the available reviews are inconsistent. Guidotti concluded that there was sufficient evidence for an association between work as a firefighter and colon cancer risk.[35] Golden et al[4] concluded that the evidence was weak for this malignancy but the association was still plausible, whereas Howe and Burch[36] concluded there was a lack of association. Guidotti[35] concluded there was strong evidence for an association for kidney cancer but Golden et al[4] did not indicate there was an association. The author of these two reviews also disagreed on the risks for non-Hodgkin's lymphoma and leukemia. Golden et al[4] concluded that the evidence was strongly suggestive for an increased risk for both types of malignancies whereas Guidotti[35] believed there was insufficient evidence for cancers of the lymphatic and hematopoietic tissue.

In a recent meta-analysis commissioned by a provincial compensation board,[38] the authors reviewed cohort and case-control studies and concluded that, of the 6 cancers of interest, there was limited evidence for an increased risk for brain and colorectal cancers. There was no evidence to support an association between work as a firefighter and kidney cancer and insufficient evidence for an association with bladder cancer, leukemia, and non-Hodgkin's lymphoma.

That there is a lack of consensus among reviewers regarding the risk of the 6 specific cancers among firefighters is not surprising, given that there are frequent notable differences in the risk estimates for these cancers based on individual studies. For example, Demers et al[14] observed a significantly decreased risk of bladder and kidney cancer among firefighters in their cohort whereas Guidotti[19] and Vena and Fiedler[16] observed a significantly increased risk of kidney and bladder cancers in their respective cohorts. In a case-control study, Krishnan et al[30] observed a sixfold increased risk of brain cancer among firefighters compared with control subjects. In a similar fashion, the authors of 4 cohort studies[11,14,16,18] found at least a doubling of the risk of mortality from brain cancer among firefighters, with results in 2 of these studies attaining statistical significance.[11,14] Conversely, the authors of 4 other cohort studies observed a decreased risk of death from this malignancy.[12,13,15,20]

These apparent contradictory observations are not surprising and are the result of various factors, including slight differences in cohort identification, lack of statistical power related to small sample sizes and rarity of the tumors, as well as possible random Type I errors secondary to the multiple analyses performed in each study. Likely, one of the most important contributing factors to this heterogeneity of outcomes relates to the heterogeneous and unpredictable nature of exposure among urban firefighters. Throughout their careers, firefighters perform numerous and varied types of rescue work, some of which may involve high levels of exposure to carcinogens and some that involve none. Differences in job tasks, differences in crew and fire station assignments, the stochastic nature of the types of fires combated, the historic changes in firefighting activities, and the availability and use of personnel protective equipment all result in a wide range of exposures encountered by firefighters as a group.[3,12,39] Any study involving a large historic firefighter cohort is bound to contain a very heterogeneous group of individuals with markedly varied exposure histories. This heterogeneity will tend to dilute any specific cancer risk and push the risk estimates toward the null.

To a certain extent, one can overcome the limitations of evaluating individual studies by pooling the study results. There are a number of advantages in the quantitative pooling of outcomes of epidemiological studies. The method increases the statistical power to detect lower relative risks and reduces the probability of Type I errors caused by multiple comparisons in individual studies.[8,40] Use of this method also avoids the potential selection bias of the narrative qualitative review process, in which the reviewer arbitrarily assigns greater weight to certain studies over others.[41,42]

The pooling of risk estimates from various studies that I undertook in this review relies on one fundamental assumption: that, on average, firefighters in industrialized nations have similar firefighting exposure experiences with correspondingly equivalent risks for developing cancer (or not). The converse of this assumption is that each firefighter population in different countries and regions has specific cancer risks attributable to distinct regional exposures and these risks cannot be generalized to other firefighter populations in other municipalities or states. This implies that regional firefighter population risks have to be measured individually and cannot be surmised from other firefighter populations. The latter point of view is very restrictive and contrary to the overall principle of occupational epidemiology, which is that of generalizability of risk among comparable worker populations.

The assumption previously discussed in this article applies in particular to cohort studies because these studies use very similar methodologies so they can be combined. The heterogeneity observed between the risk estimates for certain cancers among the cohort studies can be related to the factors already described. However, in addition to cohort studies, there are a variety of other types of studies available, including case-control as well as survey and cross-sectional studies. The difference in cancer risk estimates provided by these various studies is to a large extent dependent on the disparate methodologies and outcome measures utilized. Many of these observational studies have a number of shortcomings compared with historic cohort studies, not the least of which is their inability to take into account the population at risk.[43,44] In addition, survey studies that rely on death certificates or hospital records to identify occupations frequently have significant problems with misclassification of occupations and exposure.[45,46] As a result of these shortcomings, the risk estimates based on cohort studies are favored in this review. However, instead of limiting the pooled analysis to cohort studies only and risk missing possibly pertinent information, I included observational studies in one set of pooled estimates of cancer risk among firefighters as a sensitivity analysis to ensure that useful information was not discarded.

Although most outcome measures from the various types of observational studies, such as OR, PMR, MOR, and morbidity OR, are surrogates for SMR or SIR estimates, combining these is usually not feasible. However, under specific conditions they may approximate the SMR (or SIR) estimates and may be combined. The OR of case-control studies approximates the SMR when the disease is rare. The MOR and morbidity OR outcomes measures of observational studies can approximate the SMR or SIR when the mortality or morbidity from cancers other than the one of interest is unaffected by the exposure. The PMR outcome measure can approximate the SMR when the overall mortality is constant between study population and comparison population.[9,43,44]

Fortunately, at least the first 2 conditions likely are true: the frequencies of the 6 specific cancers of interest are rare relative to the size of the populations examined, and the cancer mortality among firefighters is not markedly different than that among the general population (see Table 1). This implies that combining OR and MOR (and morbidity OR) outcomes with SMR (and SIR) outcomes may not be unreasonable. However, the third condition is not met because there appears to be a healthy worker effect among firefighters, with total mortality being 16% lower than expected. This will tend to bias the risk estimates based on PMR upward as a result of this healthy worker effect. This may explain the moderately higher sumRR estimates noted for kidney cancer and non-Hodgkin's lymphoma when all the studies were pooled compared with the pooling of cohort studies only.

Other than the minor differences in mortality risk for kidney and non-Hodgkin's lymphoma and morbidity for bladder cancer, the sumRR estimates based on all studies were not substantially different from the sumRR estimated from cohort studies only. One can conclude that, on the basis of the sumRR estimates for cancer mortality and incidence, firefighters do not appear to have a substantially increased risk for any of the six cancers of interest. In fact, for kidney cancer the risk of developing the disease appears to be less than half that of the general population (see Table 2).

That the risk of the 6 specific cancers among firefighters is not markedly different than the general population is not surprising, given the various factors that tend to dilute any risk and push the outcome measures based on the complete firefighter cohorts to the null as previously discussed. However, by subdividing the cohort into subgroups with more compatible exposure histories, one might identify a more representative estimate of malignancy risks among firefighters. A common method used to reduce the effect of heterogeneity of exposure is to assess the risk on the basis of duration of employment. This approach is based on the reasonable assumption that the cumulative exposure to carcinogens related to active firefighting is directly proportional to the time a person has spent employed as a firefighter.

In this review, I quantitatively pooled the subcohort defined by duration of employment intervals for each malignancy. In addition to increasing the statistical power, this approach also unified the study outcomes and facilitated the evaluations more than would be possible by considering individual studies alone.

Applying this analytical approach to the data did indeed identify high-risk subcohorts that were missed in the complete cohort analyses. Colon cancer mortality is 1.5 times higher than expected among firefighters employed 30 or more years and increases to nearly 5 times higher than expected after a firefighter has 40 or more years of employment; the risk for this malignancy is increased in the group with fewer than 10 years of employment, but this finding is unlikely to be biologically plausible. For leukemia as well as brain cancer, the mortality risk is doubled or tripled after a person has 30 or more years of employment as a firefighter. The risk of bladder cancer is tripled after a person has 30 or more years of employment, although this is not statistically significant, and the risk is nearly 6 times higher than expected for firefighters working 40 or more years. The risk of kidney cancer is nearly triple the expected rate for firefighters working 10 or more years, and the risk increases

Table 3.—Mortality and Incidence Risk Estimates for 6 Cancers Among Firefighters, Based on Duration of Employment

Duration (y)	Mortality studies O	E	SMR	95% CI	Reference	Incidence studies O	E	SIR	95% CI	Reference
Brain cancer										
< 10	8	6.50	1.23	0.70–3.65	12, 14, 16	1	0.6	1.60	0.0–8.80	27
10–19	12	7.41	1.62	0.78–4.45	12, 16, 18	0	0.8	0.00	0.0–4.60	27
20–29	11	6.30	1.75	0.88–4.87	12, 14, 16	4	3.18	1.26	0.91–4.48	18, 27
≥ 10	28	18.78	1.49	0.50–3.65	12, 14, 16	3	2.90	1.03	0.82–4.06	27
≥ 20	21	12.71	1.65	0.63–4.18	12, 14, 16, 18	8	4.61	1.73	0.99–5.15	18, 27
≥ 30	11	4.34	2.53	1.27–7.07	11, 14, 18	4	1.43	2.79	0.76–7.16	18, 27
Colon cancer										
< 10	23	14.06	1.64	1.04–2.45	12, 13, 14	3	4.90	0.61	0.13–1.79	17, 27
10–19	23	21.31	1.08	0.68–1.62	12, 13, 14, 16	3	4.90	0.61	0.13–1.79	17, 27
20–29	18	27.75	0.65	0.38–1.03	13, 14, 16	15	13	1.10	0.60–1.90	27
≥ 10	100	85.90	1.16	0.95–1.42	12, 13, 14, 16	27	24.1	1.12	0.74–1.63	17, 27
≥ 20	77	64.58	1.19	0.94–1.49	12, 13, 14, 16	24	19.2	1.25	0.80–1.86	17, 27
≥ 30	34	22.47	1.51	1.05–2.11	13, 14, 16	4	2.60	1.50	0.40–3.90	27
≥ 40	8	1.70	4.71	2.03–9.27	16	—	—	—	—	—
Bladder cancer										
< 10	5	3.14	1.59	0.52–3.72	12, 16	4	1.8	2.20	0.60–5.60	27
10–19	7	4.73	1.48	0.70–3.09	12	2	2.2	0.90	0.10–3.40	27
20–29	1	0.80	1.25	0.03–6.97	16	9	9.5	1.00	0.40–1.80	27
≥ 10	21	13.57	1.55	0.96–2.37	12, 16	14	13.5	1.04	0.57–1.74	27
≥ 20	14	8.84	1.58	0.87–2.66	12, 16	12	11.3	1.06	0.55–1.85	27
≥ 30	7	2.10	3.33	0.85–6.87	16	3	1.8	1.60	0.30–4.80	27
≥ 40	4	0.70	5.71	1.56–14.63	16	—	—	—	—	—
Kidney cancer										
< 10	2	2.78	0.72	0.18–2.87	12, 19					
10–19	1	0.23	4.30	0.11–24.23	12, 19					
20–29	2	0.52	3.84	0.47–13.89	19					
≥ 10	17	5.95	2.86	1.67–4.58	12, 19					
≥ 20	16	5.71	2.80	1.60–4.55	12, 19					
≥ 30	4	0.64	6.25	1.70–16.00	19					
≥ 40	2	0.06	36.12	4.03–120.42	19					
NHL										
< 10	6	4.08	1.47	0.56–3.26	12	1	1.1	0.9	0.0–4.9	27
10–19	5	4.85	1.03	0.43–2.47	12	1	1.6	0.6	0.0–3.5	27
20–29	—	—	—	—	—	5	4.3	1.2	0.4–2.7	27
≥ 10	14	10.09	1.39	0.76–2.33	12	6	6.5	0.9	0.34–2.01	27
≥ 20	9	5.23	1.72	0.90–3.31	12	5	4.9	1.0	0.33–2.38	27
≥ 30	—	—	—	—	—	0	0.6	0	0.0–5.8	27
Leukemia										
< 10	7	7.09	0.99	0.40–2.03	12, 14	0	0.8	0.0	0.0–4.40	27
10–19	9	8.06	1.12	0.35–1.79	12, 14	2	1.1	1.9	0.20–6.80	27
20–29	4	5.48	0.73	0.2–1.9	14	4	3.6	1.1	0.30–2.80	27
≥ 10	23	22.90	1.00	0.64–1.51	12, 14	6	5.4	1.1	0.41–2.42	27
≥ 20	14	14.84	0.94	0.52–1.58	12, 14	4	4.3	0.9	0.25–2.38	27
≥ 30	11	3.83	2.87	1.43–5.14	11, 14	0	0.70	0.00	0.0–5.40	27

Note. O = total number of cancer cases observed; E = total expected number of cancer cases; SMR = standardized mortality rate; NHL = non-Hodgkin's lymphoma; CI = confidence interval.

continuously to 6 times that expected after firefighters work 30 or more years and over 30 times for those with 40 or more years of employment. The risk of non-Hodgkin's lymphoma may be increased 1.7 times among firefighters working for 20 or more years, although this did not reach statistical significance.

The elevated risk estimate for non-Hodgkin's lymphoma is equivocal, and for bladder cancer the mortality risk estimates should be considered tentative, given that these results are based on single-study outcomes. The evidence is somewhat stronger for leukemia because it is based on data from 2 studies, and for colon cancer because it is based on data from 3 studies. The evidence is more convincing for brain cancer and kidney cancer given that it is derived from two or more studies and there is an apparent dose–response relationship.

Although a mortality analysis based on duration of employment demonstrated increases in risk of various tumors among firefighters, the risk analysis based on incidence analysis did not (see Table 3). How can firefighters be at increased risk of dying from a number of specific cancers but not at increased risk of developing these cancers? One possible explanation is that the occupational exposure of firefighters does not induce new cancer but rather increases the malignancy of the cancers that have already occurred. The carcinogen exposure during active firefighting may promote and enhance progression of specific cancers that are already present rather than induce them de novo.

The findings of this review are generally consistent with the legislative changes introduced in several Canadian provincial jurisdictions, at least for 5 of the 6 tumors. However, the duration of exposure criteria for the 6 tumors included in the legislation are not generally congruent.

On the basis of the analysis of this quantitative review, one can conclude that firefighters as a group do not have a significantly increased risk of dying from the 6 specific cancers. This is the case when cohort studies are considered. But when all the studies are combined, there appears to be a small risk of mortality from kidney cancer (22%) and non-Hodgkin's lymphoma (40%) among firefighters, but this increase may be related to a healthy worker effect bias that is inherent in some of the included studies. The mortality risk for at least 5 of the 6 tumors is less equivocal and more apparent when the risk estimates take into consideration the duration of employment. The risk of dying from brain cancer increases after a person has 30 years of employment and likely starts to increase somewhat earlier after the second decade of employment. For kidney cancers the risk begins as early as the person's second decade of employment, whereas for bladder cancer, leukemia, and colon cancer, the fatality risk increases in the third decade of employment. The mortality related to non-Hodgkin's lymphoma may or may not be increased among firefighters after their second decade of employment. One can hypothesize that the occupation of firefighting may not induce new tumor formation but rather increase the malignancy of preexisting tumors.

These findings are based on information garnered from older cohorts and studies. With changes in firefighting techniques, equipment, and use of personal protective equipment, whether these risks apply to contemporary and future firefighter cohorts is unknown.

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Requests for reprints should be send to Dr Sami Youakim, PO Box 53507, Broadmead RPO, Victoria, British Columbia, V8X 5K2, Canada.

E-mail: syouakim@telusplanet.net

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