Research Article

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Burden of Cancer Mortality in the Canadian Armed Forces, 1976–2012: A Retrospective Cohort Study

Elizabeth Rolland-Harris[1], Kristen Simkus[1,2], and Murray Weeks[1]

Abstract

Background: Military personnel may have potential exposures to carcinogens during their military careers. However, the generalizability of causal evidence between occupational exposures and cancer outcomes in military personnel is limited. This study aims to describe the epidemiology cause–specific cancer mortality in still serving and released Canadian Armed Forces (CAF) personnel recruited between 1976 and 2012.

Methods: Data came from the Canadian Forces Cancer and Mortality Study II (CF CAMS II), a record-linkage study of approximately 228,685 CAF Regular Force personnel and Reservists. Sex-stratified standardized mortality ratios (SMR) were calculated for each neoplasm subcategory, with the Canadian general population (CGP) as the reference.

Results: Approximately 1,450 deaths were attributable to neoplasms. Cancer mortality was lower in both men and women with military service (SMR = 0.77 and 0.78, respectively) versus CGP. Females had a significantly lower risk of breast cancer. Males in the cohort had a significantly lower risk of lip, oral cavity and pharynx, digestive organs, respiratory and intrathoracic organs, bone and articular cartilage, and mesothelial and soft-tissue cancers. However, males also had a significantly increased risk for neoplasms of the central nervous system and lymphoid cells, as well as for certain specific cancer diagnoses.

Conclusions: Current and former CAF personnel were at comparable, or lower risk than, the CGP for cancer-related deaths. However, there was an increased risk for certain neoplasm subcategories and specific cancers.

Impact: These findings contribute to the limited body of evidence investigating the link between military service and cancer mortality.

Introduction

Military personnel represent a small subset of the workforce [e.g., 0.8% in the United States, 0.4% in the United Kingdom, and 0.3% in Canada; ref. 1) that fulfills a vital role in the national security and protection of national interests. The population of those with past military service (i.e., veterans) is much larger, for example, constituting 1.8% of the Canadian general population (CGP) in 2017 and 5% of English, and 6% of Welsh residents in 2016. The military employer has the same fundamental obligations for prevention and control of occupational health problems as any other employer. This obligation also continues after release from service, which is important because some health diagnoses such as cancer may only become apparent years after occupational exposure.

The past 16 years of conflict in Southwest Asia have directed renewed attention to the health effects of military service, with a particular focus on physical and psychologic injuries related to armed conflict. Military personnel may also have exposure to environmental agents, including potential carcinogens such as petrochemicals (2), ionizing radiation (3), airborne particulates (4), electromagnetic radiation (5), or hydrofluorocarbons (6). Conversely, military service may also confer protective factors against cancer-related death, related to stringent medical exclusion criteria at recruitment (7), differential access to health care (including periodic health exams in military settings), a more active lifestyle (8), better access to protective equipment (9) in riskier job settings, and the positive ramifications of having a social support system (10).

There is an extensive literature that provides compelling evidence of a greater neoplasm (cancer) risk among workers employed in a number of occupations. In some instances, the causal link between occupational exposure(s) and cancer outcome(s) has also been empirically established. Examples include engine exhaust and mechanics (11), cosmic radiation and flight crews (3), and combustion products and firefighting (12).

An earlier record linkage effort (13) found a lower overall risk of cancer in both men and women with military service in the modern era. While this was reassuring, it is possible that the overall trend is obscuring higher risks for particular types of cancer. Research about cancer incidence in military populations has provided some insight. However, their generalizability is hindered by their focus on small subgroups [e.g., specific exposures (e.g., nuclear weapons testing; ref. 14); specific cancers (e.g., testicular cancer; ref. 15); specific deployments (e.g., Vietnam; ref. 16); or specific occupations (e.g., air force pilots (3), radar operators (5))], their historical nature [e.g., Vietnam era (16); studies on nuclear weapons testing (14)], and their U.S. centricity. The mechanism of how the unique and contemporary pattern of risk and protective factors influence

[1]Directorate of Force Health Protection, Department of National Defence, Ottawa, Ontario, Canada. [2]Research Directorate, Veterans Affairs Canada, Charlottetown, Canada.

Corresponding Author: Elizabeth Rolland-Harris, Department of National Defence, Carling Campus 9S1, 101 Colonel By Drive, Ottawa, Ontario K1A 0K6, Canada. Phone: 613-219-4477; Fax: 613-901-1752; E-mail: Elizabeth.harris@forces.gc.ca

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the incidence of cancer mortality in military personnel and veterans is unknown.

This study aims to address the limitations in the existing literature. The specific study objective is to describe the cause-specific cancer mortality burden in still serving and released Canadian Armed Forces (CAF) males and females who enrolled for the first time between 1976 and 2012.

Materials and Methods

Cohort development and record linkage methodology

The Canadian Forces Cancer and Mortality Study II (CF CAMS II) is a retrospective cohort study whose main aim was to describe the mortality outcomes as well cancer incidence for all CAF Regular Force (RegF) and Reserve C (Reservists with past overseas deployment; ResC) personnel whose first date of RegF or ResC enrollment occurred between January 1, 1976 and May 31, 2015. At the time of analysis, mortality data to only 2012 were available.

The cohort subjects were identified using the CAF Computerized Central Pay System records. The cleaned and validated records were probabilistically linked to the Canadian Vital Statistics Database–Deaths, using each individuals' social insurance number as the primary linkage key, with a 97.0% linkage success rate. The protocol, including more detailed information on how the cohort was built, and on the record linkage methods is available in detail elsewhere (17).

International classification of disease comparability

As the cancer-related causes of death (COD) overlapped three different International Classification of Disease (ICD) coding periods (ICD-8, ICD-9, and ICD-10), neoplastic CODs recorded as either ICD-8 or ICD-9 were mapped to their ICD-10 equivalent using the US Centers for Disease Control's work on the comparability of ICD-8 and ICD-9 codes (for ICD-8; ref. 18), and the US National Cancer Institute's Surveillance, Epidemiology, and End Results ICD conversion program (for ICD-9).

Statistical analysis

Descriptive analyses, stratified by sex, were generated to describe full cohort and mortality subset demographics. Age and sex-standardized incidence mortality rates for the ICD-10 cancer subcategories were calculated. Rates were standardized using 5-year age-specific intervals (ranging from 15 to 89 years). Period intervals were not included.

Standardized mortality ratios (SMR) were also calculated for both males and females for all of the broad cancers subcategories. The CGP was used as the reference population. SMRs were calculated by creating a ratio of the observed number of deaths within the cohort relative to the expected number of deaths (19). For each cancer subcategory, SMRs were generated by 5-year age-specific intervals and were aggregated into an overall age-standardized SMR.

Both the rates and SMRs were based on the full study period (1976–2012), with the denominator for each of these analyses being the person-year time contributed by the overall cohort. 95% Confidence intervals (CI) were calculated using the Poisson distribution (when the number of events was less than 100) or the normal distribution (20). Unless otherwise specified, the use of the term "significant" implies statistical significance.

All reported values were rounded to the nearest five observations and SMR observed and expected values were suppressed, in accordance with Statistics Canada's confidentiality disclosure vetting rules.

Because of the census nature of this study, combined with the high level of data completeness resulting from the use of pay data, few methods to address potential sources of bias were necessary. However, approaches to managing missing data were implemented and are described in more detail elsewhere (17).

Ethical considerations

This study was conducted in accordance with the Declaration of Helsinki guidelines and was approved by QUORUM Review IRB in April 2016. A consent waiver was obtained in lieu of informed consent.

Role of the funding source

The funding source had no role in the design of this study; in the collection, analysis and interpretation of data; in the writing of the report; and in the decision to submit the paper for publication.

Results

Over the study period, 228,690 individuals with RegF and/or ResC service joined the CAF for the first time. Together, these individuals contributed more than 5 million person-years of observations, which resulted in a total of 6,870 deaths from all causes. Demographic information of the full cohort is provided in Table 1.

Of the total deaths, 1,450 (21.1%) were attributable specifically to cancer. The mean age at death from cancer was 48.9 years for males and 45.9 years for females. A larger proportion of females than males died of cancer between the ages of 25 and 39 years, but this translated into a smaller proportion of female deaths among those ages 60 and older (Table 2). In both sexes, a higher proportion of cancer-related deaths was denoted among those with RegF service. Those who released were at higher risk of dying from cancer, as were those who first enrolled between 1976 and 1987.

Overall, cancer mortality in males and females with a history of military service was significantly below expected levels. The male SMR was 0.77 (0.73–0.82) and the female SMR was 0.78 (0.68–0.88). Table 3 presents the SMRs and age-adjusted mortality rates, by sex, for each of the 18 subcategories of cancers captured in ICD-10 Chapter II.

Males had significantly lower rates of lip, oral cavity and pharynx cancers, digestive organ cancers, respiratory and intrathoracic organ cancers, bone and articular cartilage cancers, and mesothelial and soft-tissue cancers. Females had a statistically significantly lower risk of breast cancer, and SMRs were below 1.0. No other subcategories were statistically significant for females. In males, eye, brain, and other parts of central nervous system cancers, as well as primary malignant cancers of lymphoid, hematopoietic, and related tissue were significantly above 1.0. Also, the SMR of cancers of male genital organs was above 1.0 and approached statistical significance.

To ascertain whether the significant SMRs were the result of specific diagnoses, the subchapters for male genital organ cancers, cancers of the eye, brain and other parts of central nervous system, and malignant cancers, stated or presumed to be primary, of lymphoid, hematopoietic, and related tissue were broken down into diagnostic groupings (Table 4).

Table 1. Demographics of cohort participants, 1976–2012

	Male, *n* (%)	Female, *n* (%)
Age at 31 December, 2012 (still alive)		
< 25 years	14,050 (7.4)	1,715 (5.4)
25–39	52,595 (27.6)	8,745 (27.7)
40–59	121,190 (63.7)	20,450 (64.8)
60 +	2,405 (1.3)	665 (2.1)
Age at death (all causes)		
< 25 years	850 (13.4)	40 (7.5)
25–39	2,185 (34.5)	160 (29.6)
40–59	2,825 (44.6)	320 (59.3)
60 +	470 (7.4)	20 (3.7)
Last documented rank		
Junior NCM	132,720 (68.0)	20,750 (65.2)
Senior NCM	26,255 (13.5)	3,750 (11.8)
Officer	36,035 (18.5)	7,345 (23.1)
Component		
RegF only	147,795 (75.2)	22,755 (49.2)
ResC Force only	15,740 (8.0)	3,030 (6.6)
Both RegF and ResC	33,040 (16.8)	6,330 (13.7)
Military status		
Still serving	69,890 (35.6)	11,675 (36.4)
Released	126,685 (64.4)	20,440 (63.4)
Era of first enrolment		
1976–1987	98,295 (50.0)	14,815 (46.1)
1988–1999	44,845 (22.8)	8,255 (25.7)
2000–2012	53,435 (27.2)	9,040 (28.1)

NOTE: All numbers are rounded to the nearest five observations; totals many not equal 100% due to rounding.

In the male genital organ cancer subcategory, the only specific type of cancer that was significantly higher than in the CGP was testicular cancer. All other classifications (penis, prostate, testis, other/unspecified male genital organs) were nonsignificant.

In the subcategory dedicated to cancers of the eye, brain, and other parts of central nervous system, the SMRs for eye/adnexa, meninges, and spinal cord cranial nerves, and central nervous system were not significant. However, the SMR for brain cancer was approximately 1.8 times higher.

In the subcategory looking at malignant cancers, stated or presumed to be primary, of lymphoid, hematopoietic, and related tissue, the SMR associated with myeloma was found to be statistically nonsignificant. However, SMRs were significantly higher than expected for both leukemia and lymphoma. A further breakdown of lymphoma into Hodgkin and non-Hodgkin lymphomas found no significant excess Hodgkin lymphoma mortality in any of the age groups or overall, whereas significant excess mortality was noted in those with a COD of non-Hodgkin lymphoma.

Table 2. Demographics of cancer-related deaths, 1976–2012

	Male *n* (%) (*n* = 1,220)	Female *n* (%) (*n* = 230)
Age at death (cancer only)		
< 25 years	20 (1.6)	0 (0.0)
25–39	230 (18.9)	50 (21.7)
40–59	760 (62.6)	170 (73.9)
60 +	205 (16.9)	10 (4.4)
Last documented rank		
Junior NCM	865 (70.9)	180 (76.6)
Senior NCM	180 (13.9)	20 (8.5)
Officer	185 (15.2)	35 (14.9)
Component		
RegF only	880 (72.1)	180 (78.3)
ResC Force only	260 (21.3)	30 (13.0)
Both Reg and ResC Force	80 (6.6)	20 (8.7)
Military status		
Still serving	190 (15.6)	55 (23.4)
Released	1,030 (80.4)	180 (76.6)
Era of first enrolment		
1976–1987	1,070 (87.7)	200 (87.0)
1988–1999	130 (10.7)	20 (8.7)
2000–2012	20 (1.6)	10 (4.4)

NOTE: All numbers are rounded to the nearest 5 observations; totals may not equal 100% due to rounding.

Discussion

This study demonstrated that the overall risk of cancer-related death in Canadian males and females with a history of contemporary military service was lower than the risk in the CGP. This was true across almost all cancer subcategories for females, although only one subcategory (breast cancer) was statistically significant.

The results for males were more discordant. Many types of cancers had SMRs significantly below 1.0 (e.g., bone and articular cartilage, mesothelial and soft tissue, or lip, oral cavity, and pharynx). However, testicular, brain, leukemia, and lymphoma had SMRs indicating a significantly higher risk than in the CGP.

As discussed in the Introduction, there exists a limited body of evidence methodologically comparable with the results presented here. Nonetheless, similarities and discordances between published findings and our own do exist.

CF CAMS I, published in 2011, described age-adjusted causes of mortality in the CAF (13). Similar to the overall results reported here, the risk of cancer mortality was significantly lower for both males and females. It should be noted that there is some overlap in the CF CAMS I and II cohorts, which may explain some of the similarities. However, CF CAMS I did not report on subchapter mortality incidence.

To the best of our knowledge, there exist no other studies that describe cause-specific cancer mortality within a military population-level context.

Our findings of excess brain cancer in military populations corroborate a few other published studies of brain cancer in military populations. A study Pan and colleagues on occupational brain cancer risk by found that those reporting service as a noncommissioned member (NCM) in the Canadian Forces significantly higher adjusted odds of developing brain cancer (21). Furthermore, the adjusted odds were higher in those reporting their military employment as their "usual" employment versus those reporting "ever" having been employed as an NCM, suggesting a dose–response relationship. Zheng and colleagues (2001) also found a significantly higher adjusted OR of brain cancer in men who had been in a military occupation for less than 10 years (22).

Some other studies of military populations have reported elevated risks of brain cancer, but their findings have failed to reach statistical significance (23, 24). Other broader occupational studies included but did not specifically report on the brain cancer mortality in those military trades. These discordances may be, in part, due to the small sample sizes of some of these studies, as well as the heterogeneity of occupations and exposures, both within the military environment, but also within the broader occupational landscape.

Nonetheless, there is some compelling literature linking exposures also known to occur in military settings to cancer outcomes, including brain cancer. For example, Villeneuve and colleagues (25) reported a significant excess in glioblastoma multiforme

Table 3. SMRs (95% CI) and age-adjusted rates (per 100,000) by ICD-10 Chapter II Subcategories, Males only, 1976–2012

	Males		Females	
Chapter II subcategory	**SMR (95% CI)**	**Age-Adjusted Rate/100,000**	**SMR (95% CI)**	**Age-Adjusted Rate/100,000**
All neoplasms	0.77 (0.73–0.82)[a]	27.88	0.78 (0.68, 0.88)[a]	32.75
Lip, oral cavity, and pharynx (C00–C14)	0.42 (0.30–0.57)[a]	0.90	X	X
Digestive organs (C15–C26)	0.79 (0.71–0.89)[a]	6.99	0.92 (0.66–1.26)	5.73
Respiratory and intrathoracic organs (C30–C39)	0.80 (0.71–0.89)[a]	7.06	0.86 (0.62–1.15)	6.16
Bone and articular cartilage (C40–C41)	0.12 (0.06–0.22)[a]	0.28	X	X
Skin (C43–C44)	0.90 (0.71–1.14)	1.64	0.66 (0.24–1.43)	0.86
Mesothelial and soft tissue (C45–C49)	0.34 (0.20–0.54)[a]	0.42	0.84 (0.27–1.96)	0.72
Breast (C50)	0 (0.0)	0	0.69 (0.53–0.89)[a]	8.89
Female genital organs (C51–C58)	N/A	N/A	0.86 (0.59–1.22)	4.44
Male genital organs (C60–C63)	1.39 (0.99–1.87)	0.93	N/A	N/A
Urinary tract (C64–C68)	1.16 (0.88–1.50)	1.32	1.27 (0.41–2.97)	0.72
Eye, brain and other parts of central nervous system (C69–C72)	1.39 (1.14–1.64)[a]	2.75	0.82 (0.35–1.62)	1.15
Thyroid and other endocrine glands (C73–C75)	0.94 (0.34–2.04)	0.14	X	X
Malignant neoplasms of ill-defined, secondary and unspecified sites (C76–C80)	1.01 (0.75–1.30)	1.25	0.65 (0.24–1.42)	0.86
Malignant neoplasms, stated or presumed to be primary, of lymphoid, haematopoietic and related tissue (C81–C96)	1.24 (1.06–1.42)[a]	4.09	0.89 (0.50–1.46)	2.15
Malignant neoplasms of independent (primary) multiple sites (C97)	1.15 (0.37–2.69)	0.12	X	X
In situ neoplasms (D00–D09)	0 (0.0)	0	0 (0.0)	0
Benign neoplasms (D10–D36)	1.38 (0.45–3.21)	0.12	0 (0.0)	0
Neoplasms of an uncertain or unknown behavior (D37–D48)	1.64 (0.97–2.59)	0.42	X	X

NOTE: X SMR suppressed as based on $n < 5$.
[a]Statistically significant.

in men working in professions with high levels of magnetic field exposure (MFE). While their results were not military-centric, other studies have established a link between MFEs and cancer outcomes in military radar operators (5) and military air traffic controllers (26). Although the link between MFEs and cancer outcomes in the broader occupational literature is weak at best (27), we suggest that his may be a possible exposure mechanism that warrants further investigation.

Excess risk of testicular cancer has been seen in other military studies, especially among those in aviation-related occupations (28). However, a Canadian study did not substantiate an excess risk, at least among commercial pilots (29), suggesting that exposure to cosmic radiation is not a likely cause for the excess burden in aviation-related occupations in the military. Thus, exposures to hydrocarbon carcinogens (6) or glycol ethers in jet fuels (28) might be at play. However, given that aviation occupations are a relatively small segment of the CAF, the risk in that subgroup due to occupation-specific exposures would need to be incredibly high to account for the observed SMR for the Canadian military population as a whole. It therefore seems more likely that the excess risk is simply due to over-representation of Caucasian males in the Canadian military (30). Caucasians have been shown to have an excess risk of prostate cancer in a number of studies (31). Next stops to investigate this phenomenon will be (i) analysis of SMRs in those in aviation-related occupations; (ii) further stratification or adjustment for differences in the racial makeup of the CAF relative to the CGP.

Table 4. SMRs for specific cancers, males only, 1976–2012

Cancer type	**Cancer subtype**	**SMR (95% CI)**
Eye, brain, and central nervous system		
	Brain	1.83 (1.48–2.18)[a]
	Eye and adnexa	0 (0.0–0.0)
	Meninges	X
	Spine, nerves, other CNS	X
Lymphoid, hematopoietic, and related tissue		
	Leukemia	1.54 (1.21–1.94)[a]
	Myeloma	1.39 (0.75–2.39)
	Lymphoma	1.78 (1.44–2.18)[a]
	Hodgkin lymphoma	*1.32 (0.68–2.30)*
	Non-Hodgkin lymphoma	*1.88 (1.49–2.34)*[a]
Male genital organs		
	Testicular cancer	2.10 (1.15–3.52)[a]
	Penis	0.31 (0.04–1.13)
	Prostate	0 (0.0–0.0)
	Other/unspecified male genital organs	X

NOTE: X SMR suppressed as based on $n < 5$.
[a]Statistically significant.

While concerning, the possibility of excess leukemia and lymphoma (specifically non-Hodgkin lymphoma) among those who have served in the CAF is not entirely unexpected. However, a definitive causal link between military service and these types of blood cancers is lacking, particularly for non-Hodgkin lymphoma (3), although there is some evidence of excess hematolymphatic cancer risk among military radar operators (5). The influence of familial history (32), particularly between sisters (33), and white ethnicity (32) on the excess mortality reported here should not be discounted.

Despite these specific causes of significant excess cancer mortality, the overall cancer mortality in this large cohort of Canadians with military service in the modern era differs from that of other Canadians of the same age and sex. These differences must relate to differences with respect to the distribution of at least some of the many determinants of cancer in the two populations. A number of potential factors that might account for this include the following:

(i) stringent recruitment criteria that result both in the exclusion of people with certain past or preexisting cancers, as well the recruitment of individuals with overall better health (34);
(ii) the influence of the healthy worker effect and its possible conflation with the healthy soldier effect, although the

latter has been found to erode somewhat over time and to vary by COD (34);

(iii) the possibility of lower incidence of other comorbidities that can lead to cancer (e.g., obesity; ref. 35);

(iv) rapid and evidence-based access to periodic health exams and preventive cancer screening, resulting in the early identification of cancer cases (7).

It is also important to acknowledge that this article focuses on mortality. It is quite plausible that the cancer incidence landscape is quite different, and highlights other types of cancers as being more in need of existing resources and further study. Further work into cancer incidence is therefore warranted to shed light on the issue of whether the lower risk of cancer mortality is due to lower incidence as opposed to greater survival after diagnosis.

Strengths and limitations

Strengths of this study include the long follow-up period, the use of an entire targeted cohort with military service (36, 37) as opposed to small subgroups, and the high linkage success rate. On the other hand, the heterogeneity of our cohort likely limited our ability to detect important differences in cancer mortality in subgroups with particular exposures of interest, such as ionizing radiation or hydrocarbons. This heterogeneity makes it all the more surprising that we were able to identify significant differences in cancer mortality in a diverse military cohort relative to other Canadians.

There were a few key limitations in this study. First, we were unable to adjust for factors other than age and sex in our rates and SMRs. For example, we did not have information about employment history for the civilian comparison group, so we could not distinguish a generic healthy worker effect from a more military-specific healthy soldier effect. Second, weaknesses in the CAF's electronic data sources mean that we were unable to study cancer mortality experience in the much larger cohort of Reserve Force personnel without past deployments (38).

Implications

The primary implications of these findings pertain to future surveillance and research efforts. Deeper analysis of the study data will be needed to identify factors that may account for military-specific risk and protective factors, with particular urgency for understanding the excess risk of brain and testicular cancer, and of lymphoma and leukemia, in males. While less obvious, understanding the apparent protective factors for cancer-related death in the military may point toward opportunities for prevention and control in the general population.

We detected important differences in cancer mortality between the Canadian military and civilians. For some cancers, a statistically significant excess mortality risk was detected. For others, a lower risk was detected. Additional research and surveillance are required to understand differences in cancer mortality in military and civilian populations.

Disclosure of Potential Conflicts of Interest

No potential conflicts of interest were disclosed.

Authors' Contributions

Conception and design: E. Rolland-Harris
Development of methodology: E. Rolland-Harris, M. Weeks
Acquisition of data (provided animals, acquired and managed patients, provided facilities, etc.): E. Rolland-Harris
Analysis and interpretation of data (e.g., statistical analysis, biostatistics, computational analysis): E. Rolland-Harris, K. Simkus, M. Weeks
Writing, review, and/or revision of the manuscript: E. Rolland-Harris, K. Simkus, M. Weeks
Administrative, technical, or material support (i.e., reporting or organizing data, constructing databases): E. Rolland-Harris, K. Simkus, M. Weeks
Study supervision: E. Rolland-Harris

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