Long-term exposure to wildfires and cancer incidence in Canada: a population-based observational cohort study

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Summary

Background Wildfires emit many carcinogenic pollutants that contaminate air, water, terrestrial, and indoor environments. However, little is known about the relationship between exposure to wildfires and cancer risk. We aimed to assess the associations between residential exposure to wildfires and the incidence of several cancer outcomes (lung cancer, brain cancer, non-Hodgkin lymphoma, multiple myeloma, and leukaemia) in Canada.

Methods We did a population-based observational cohort study of participants in the 1996 Canadian Census Health and Environment Cohort. The 1996 Canadian Census Health and Environment Cohort is a nationally representative sample of Canadian adults, followed up for cancer incidence and mortality from 1996 to 2015. For this analysis, we excluded participants who lived in major Canadian cities (with a population size greater than 1·5 million people), recent immigrants, and individuals younger than 25 years or 90 years of age or older at baseline. Exposures to wildfires were assigned on the basis of area burned within a 20 km or 50 km radius of residential locations and updated for annual residential mobility. Multivariable Cox proportional hazards models were used to estimate associations between exposure to wildfires and specific cancers associated with carcinogenic compounds released by wildfires, including lung and brain cancer, non-Hodgkin lymphoma, multiple myeloma, and leukaemia, adjusted for many personal and neighbourhood-level covariates.

Findings Our analyses included more than 2 million people followed up for a median of 20 years, for a total of 34 million person-years. Wildfire exposure was associated with slightly increased incidence of lung cancer and brain tumours. For example, cohort members exposed to a wildfire within 50 km of residential locations in the past 10 years had a 4·9% relatively higher incidence (adjusted hazard ratio [HR] 1·049, 95% CI 1·028–1·071) of lung cancer than unexposed populations, and a 10% relatively higher incidence (adjusted HR 1·100, 1·026–1·179) of brain tumours. Similar associations were observed for the 20 km buffer size. Wildfires were not associated with haematological cancers in this study, and concentration-response trends were not readily apparent when area burned was modelled as a continuous variable.

Interpretation Long-term exposure to wildfires might increase the risk of lung cancer and brain tumours. Further work is needed to develop long-term estimates of wildfire exposures that capture the complex mixture of environmental pollutants released during these events.

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Introduction

With the changing climate, wildfires are predicted to become more prevalent, severe, and longer in duration in the future,[1–4] and are increasingly recognised as a population health problem.[5,6] Wildfires emit a complex mixture of harmful pollutants into the environment, which have well known effects on outdoor air quality and can contaminate water,[7–9] soil and terrestrial environments,[10–12] and indoor environments.[13,14] Importantly, many of the pollutants emitted by wildfires are known human carcinogens, including polycyclic aromatic hydrocarbons, benzene, formaldehyde, phenols, and heavy metals, thus suggesting that exposure to wildfires could increase cancer risk in humans. However, little is known about the long-term health effects of wildfires,[5,15] including their potential effect on cancer risk.

This question is important for several reasons. In North America, wildfires typically occur in similar regions each year; consequently, people living in nearby communities might be exposed to carcinogenic wildfire pollutants on a chronic basis. Moreover, although some pollutants return to normal concentrations shortly after the fire has stopped burning (eg, fine particulate air pollution [$PM_{2·5}$]), other chemicals might persist in the environment for long periods of time, including heavy metals[16] and polycyclic aromatic hydrocarbons.[17] As such, exposure to harmful environmental pollutants might continue beyond the period of active burning through several routes of exposure.

The aim of this study was to characterise the relationship between residential exposure to wildfires and the incidence of several cancer outcomes in a

Research in context

Evidence before this study
In the past several years, unprecedented wildfires have ravaged many locations throughout the world. For example, some of the worst wildfire seasons were observed in 2017–18 in western Canada, 2019–20 in Australia, and 2020 in California, USA. Wildfires are increasingly recognised as a population health problem because they emit a heterogeneous mixture of harmful pollutants into the environment that can contaminate water, soil or terrestrial environments, and indoor environments, in addition to well known effects on air quality. Many of the pollutants emitted from wildfires are carcinogenic in nature, which brings about the question of whether exposure to wildfires increases cancer risk in humans. This is a relevant question because in Canada (and many other locations in the world), wildfires tend to occur in similar regions each year, so nearby communities might be exposed to wildfire-derived pollutants on a seasonal basis. Further, many of the pollutants emitted from wildfires are persistent chemicals, suggesting that exposure to wildfire-derived pollutants might continue beyond the period of active burning. We searched PubMed and Google Scholar on Feb 2, 2022, with no language restrictions, using the terms "wildfires", "forest fires", "bush fires", and "cancer", and did not find any epidemiological analyses investigating cancer risk of wildfires.

Added value of this study
To our knowledge, this is the first study in the world to examine associations between wildfires and the incidence of several cancer outcomes, including lung cancer, brain tumours, and numerous haematological cancers. In this longitudinal study of more than 2 million Canadians followed for 20 years, we defined residential wildfire exposure as area of forest burned within a 20 km and 50 km radius of residential locations, updated annually. Compared with unexposed populations, cohort members who were exposed to a wildfire within 50 km of residential locations in the past 10 years had a 4·9% (95% CI 2·8–7·1) relatively higher incidence of lung cancer than unexposed populations in adjusted models, and a 10% (2·6–17·9) relatively higher incidence of brain tumours. Similar associations were found for the 20 km radius.

Implications of all the available evidence
Residential exposure to wildfires might increase the risk of certain cancer types, but much more work is needed to develop exposure metrics to be used to estimate the chronic health effects of wildfires, as well as replication in different geographical locations and populations.

national, population-based cohort in Canada. We a priori selected specific cancer types, including lung cancer, brain cancer, non-Hodgkin lymphoma, multiple myeloma, and leukaemia, on the basis of evidence linking known wildfire pollutants to these types of cancers. Our primary exposure variable was defined as area burned within a given radius of residential locations. This surrogate measure of exposure aimed to capture pollutant mixtures released by wildfires, given that we were interested in the mixture in its entirety and not just traditional air pollutants. To our knowledge, this study is the first in the world to investigate whether long-term residential exposure to wildfires is associated with cancer.

Methods

Cohort description

See Online for appendix

This population-based observational cohort study included a subset of participants from the 1996 Canadian Census Health and Environment Cohort (CanCHEC). The 1996 CanCHEC has been described in detail elsewhere.[18,19] Briefly, this cohort is a population-based cohort that followed up approximately 3·6 million individuals for mortality and cancer outcomes from 1996 to 2015. Annual residential postal codes (from 1986 to 2015) were available through linkage to tax records and were assigned geographical coordinates on the basis of the nearest block face, dissemination block, or centroid of a dissemination area.[20] Postal codes were used to assign wildfire exposures (as a time-varying exposure) and to extract neighbourhood-level covariates.

We excluded people from cities with populations of more than 1·5 million people to improve computational efficiency and to limit potential residual confounding caused by differences among people who live in urban versus rural locations. Consistent with other analyses of the CanCHEC databases,[21–23] we also excluded people who immigrated to Canada during the 10 years before census day and people younger than 25 years or 90 years of age or older at baseline.

Outcomes
The outcomes of this study were the incidence of lung cancer, brain tumours, non-Hodgkin lymphoma, multiple myeloma, and leukaemia. These outcomes were selected a priori on the basis of existing evidence related to known carcinogens (and associated cancer types) emitted by wildfires (additional details in the appendix p 2). Other cancer outcomes were not examined. The CanCHEC is linked to the Canadian Cancer Registry, which reported cancer incidence from Jan 1, 1992, to Dec 31, 2015, except for the province of Quebec, where data were available to Dec 31, 2010. Outcomes were identified using the International Classification of Diseases for Oncology typography and morphology codes (codes are listed in the appendix p 3). Individuals with a cancer diagnosis from 1992 to 1995 were excluded.

Wildfire exposure assessment
Wildfire exposures from 1986 to 2015 were assigned using the National Burned Area Composite (NBAC).[24,25]

The NBAC is a Geographic Information Systems (GIS) database and system that generates composite maps of burned-area polygons for all of Canada's forests on an annual basis, indicating where and when a fire has occurred, and an estimate of the total area burned. The NBAC was developed jointly by the Canadian Centre for Mapping and Earth Observation and the Canadian Forest Service of Natural Resources Canada and relies on three different sources to map area burned: the Canadian National Fire Database; the Multi-Acquisition Fire Mapping System (MAFiMS), and the Hotspot and Normalized Difference Vegetation Index Differencing Synergy (HANDS) algorithm. Burned areas reported by all three sources are stored in the NBAC spatial data warehouse, and the NBAC then applies user-defined decision rules to select the best source of data for each fire to be used as the final NBAC product. Generally, the NBAC selects polygons generated through MAFiMS when available, followed by agency polygons, then HANDS polygons.[25] Additional details are provided in the appendix (p 4).

Using these GIS surfaces, we calculated the total area of forest burned (in hectares) within a 20 km and 50 km radius of all residential six-character postal code representative locations, for each year between 1986 and 2015 (ie, a time-varying exposure; appendix p 8). We estimated area burned within two different radii to evaluate the sensitivity of our results to the selection of buffer size.

To capture long-term exposures to wildfires, we calculated 3-year, 5-year, and 10-year moving averages of area burned with a 1-year lag. For example, for the 20 km radius, the 3-year moving averages in 1996 were based on average hectares burned within 20 km of residential location from 1993 to 1995, the 5-year moving averages were based on 1991–95, and the 10-year moving averages were based on 1986–95. These calculations were done for each year of follow-up, and for each of the two radii.

Statistical analysis

Multivariable Cox proportional hazards models were used to estimate associations between exposure to wildfires and the incidence of lung cancer, brain cancer, non-Hodgkin lymphoma, multiple myeloma, and leukaemia. We considered each outcome separately. Time-to-event was calculated as the duration between census day (time 0) and a diagnosis of a particular cancer. People who did not have a diagnosis of lung cancer, brain cancer, non-Hodgkin lymphoma, multiple myeloma, or leukaemia during their follow-up were right-censored at death, loss to follow-up, or the administrative end of follow-up (Dec 31, 2010, for the province of Quebec, and Dec 31, 2015, for the rest of Canada). Cox models were stratified by baseline age (5-year groups), sex, and immigrant status, and adjusted for a range of personal covariates (marital status, income adequacy quintile, education, labour force status, occupation, Indigenous status, visible minority status, and baseline age centred at the median of each 5-year strata) and neighbourhood-level covariates (population size, urban form, regional airshed, and the Canadian Marginalization Index;[26] appendix p 5).

As a first analysis, we dichotomised the individual values of the 3-year, 5-year, and 10-year moving averages of area burned within a 20 km or 50 km radius as ever or never exposed to wildfires within the past 3 years, 5 years, or 10 years. Next, we examined three levels of exposure—never exposed to wildfires, and two exposed groups (ie, low exposure and high exposure) separated at the median of the respective moving average of area burned within each buffer size. Adjusted hazard ratios (HRs) and 95% CIs were then estimated for each of the two exposed groups, relative to the unexposed category. Finally, we examined continuous exposures. To reduce bias that could result when modelling continuous exposures with many zeros (ie, cohort members who were never exposed),[27,28] we included in the model both a binary variable (reflecting ever or never exposure in the past 3 years, 5 years, or 10 years) and a continuous exposure (reflecting the 3-year, 5-year, or 10-year moving averages of area burned). For exposed person-years, the continuous variable was centred at the median area burned, whereas for unexposed person-years, the continuous variable was kept at a value of zero.[27] In this model, the coefficient for the binary term compares risk between those never exposed to wildfires and those with a median level of exposure, whereas the estimate for the continuous term reflects the quantitative effect of increasing exposure among those exposed. In two alternative preliminary analyses, we modelled the continuous exposure term in this model as a linear term or with cubic-B splines with one interior knot. However, because model fit did not meaningfully improve with flexible modelling (on the basis of the minimum Akaike information criterion), using the parsimony principle, final models included only a linear term for the continuous exposure. For all models, the proportional hazards assumption was checked through graphical diagnostics based on weighted Schoenfeld residuals.

Sensitivity analysis

Several sensitivity analyses were done using models with three categories of wildfire exposure (unexposed, low exposure, and high exposure). We evaluated effect modification by sex (on the multiplicative scale) by doing analyses stratified by sex and included an interaction term between sex and exposure categories (where $p<0·05$ was interpreted as evidence of effect modification); we removed values of area burned in the 95th percentile or higher; adjusted for ambient $PM_{2·5}$ (as a 3-year moving average with a 1-year lag); and lagged the exposures by 3 years instead of 1 year (for example, the 3-year moving average in 1996 was based on average area burned from 1991 to 1993). In addition, we repeated the lung cancer analyses using six categories of exposure (an unexposed

	Cohort characteristics
People in cohort	2 040 995
Total person–years*	34 022 680
Years of follow-up, median (IQR)	20 (15–20)
Age in years, median (range)	45 (25–89)
Sex	
Female	1 047 730 (51%)
Male	993 265 (49%)
Marital status	
Never married or common law marriage	217 470 (11%)
Common law marriage	179 370 (9%)
Married	1 376 180 (67%)
Separated	48 510 (2%)
Divorced	100 420 (5%)
Widowed	119 045 (6%)
Income adequacy quintile	
1 (lowest)	373 490 (18%)
2	404 750 (20%)
3	417 405 (20%)
4	421 965 (21%)
5 (highest)	423 385 (21%)
Highest level of education	
Less than high-school graduation	714 060 (35%)
High-school graduate with or without trade certificate	728 495 (36%)
Post-secondary non-university degree	356 670 (17%)
University degree	241 765 (12%)
Labour force status	
Employed	1 252 175 (61%)
Unemployed	116 160 (6%)
Not in labour force	672 660 (33%)
Occupational class	
Management	131 225 (7%)
Professional	210 155 (10%)
Skilled, technical, or supervisory	451 795 (22%)
Semi-skilled	474 395 (23%)
Unskilled	157 720 (8%)
Not applicable	615 710 (30%)
Indigenous	123 270 (6%)
Visible minority	45 205 (2%)
Immigrant	224 545 (11%)

Data are n (%) unless otherwise stated. All values have been randomly rounded to the nearest five to conform to institutional confidentiality requirements. Percentages are based on total number of people. *Includes person–years with at least one non-missing 3-year, 5-year, or 10-year moving average exposure from 1996 to 2015.

Table: **Cohort characteristics at baseline**

group, and exposed person-years grouped by quintiles) to further explore non-linear trends, and estimated associations between lung cancer and the cumulative frequency of fires in a moving 10-year window (with a 1-year lag), where the cumulative frequency of fires was modelled both as a continuous variable and a categorical variable (zero, one to three, four to six, and seven to ten fires). Lastly, data on smoking status, an important predictor of lung cancer, was not available in the CanCHEC database. We applied an indirect adjustment method to mathematically adjust lung cancer HRs for unmeasured confounders[29] (details on the sensitivity analyses are provided in the appendix pp 6–7).

The CanCHEC dataset was created under the authority of the Statistics Act and approved by the Executive Management Board at Statistics Canada (reference 045-2015). This study was also approved by the McGill Faculty of Medicine Research Ethics Board (reference A02-M09-20B). All statistical analyses were done using SAS software (version 9.4) at the Statistics Canada Research Data Centre located at McGill University.

Role of the funding source

The funders of the study had no role in the study design, data collection, data analysis, data interpretation, writing of the report, or decision to submit for publication.

Results

Our analyses included more than 2 million people followed for a median of 20 years, for a total of 34 million person-years (table; appendix p 10). There were some differences in baseline covariates between those ever exposed to a wildfire within a 50 km radius of their residential location from 1986 to 2015 and those never exposed; for example, exposed populations were less likely to live in a census metropolitan area or census agglomeration and were more likely to live in western Canada than unexposed individuals (appendix p 11). A flow chart describing exclusions from the main cohort and those included in this analysis is shown (appendix p 9). We present the total area of forest burned in Canada from 1986 to 2015 and highlight the fact that wildfires tend to occur in similar areas each year (figure 1). The person–year distribution of area burned within a 20 km and 50 km radius of residential locations based on 3-year, 5-year, and 10-year moving averages with a 1-year lag is right-skewed, with most person-years unexposed to wildfires (appendix p 13).

There were approximately 43 000 incident lung cancer events, 3700 brain cancer events, 12 000 cases of non-Hodgkin lymphoma, 3900 cases of multiple myeloma, and 7700 cases of leukaemia (appendix p 14). The adjusted HRs and 95% CIs for cancer outcomes comparing ever and never exposure to wildfires in the past 3 years, 5 years, or 10 years are shown (figure 2; appendix p 14). Small risk increases were consistently observed for associations between wildfires and lung cancer, with the strongest association observed between any exposure to wildfires in a 50 km radius of residential location in the past 5 years (HR 1·061, 95% CI 1·038–1·083). Positive associations were also observed between wildfires and brain tumour incidence, with the strongest association observed between any exposure to wildfires in a 50 km radius of residential location in the past 10 years (HR 1·100, 1·026–1·179).

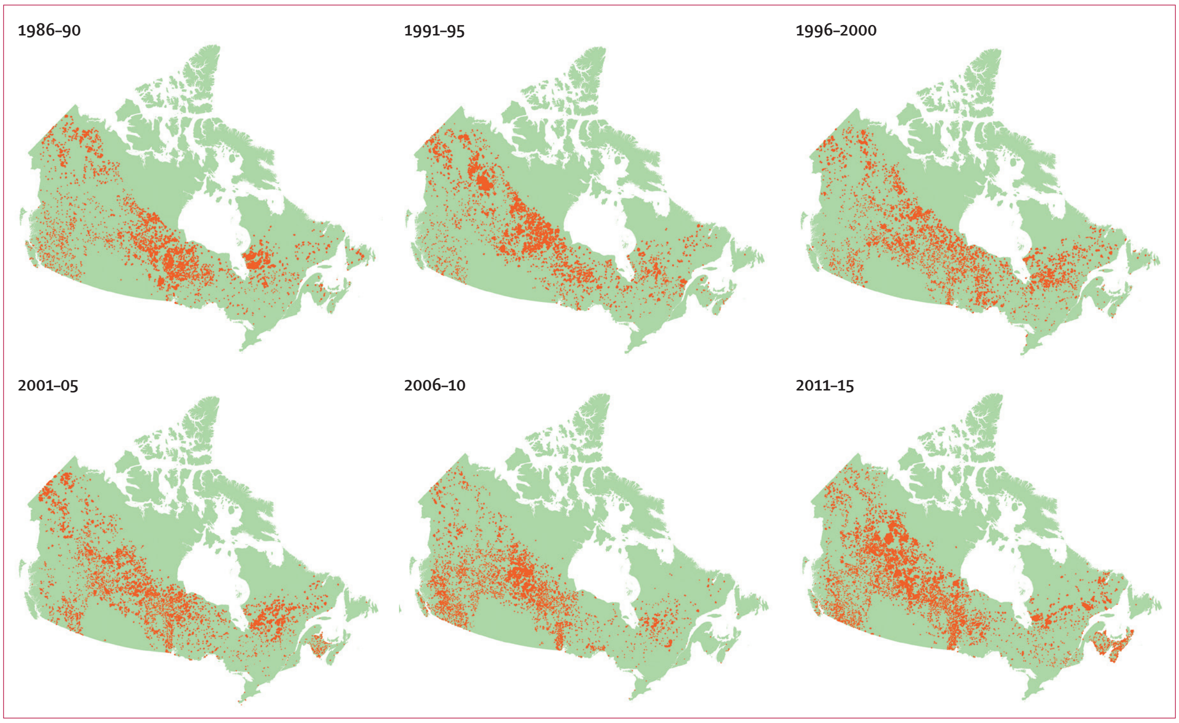

Figure 1: **Area of forest burned in Canada from 1986 to 2015**
Orange colour shows burned area.

The adjusted HRs and 95% CIs for cancer outcomes comparing categories of area burned (low exposure and high exposure) to the unexposed group are shown (figure 3; appendix p 16). As with the dichotomous exposure models, positive associations were consistently observed between wildfire exposure and lung and brain cancer. For lung cancer, the strongest association was observed in the low-exposure category of the 5-year moving average within the 50 km buffer (HR *vs* unexposed 1·074, 95% CI 1·047–1·101). For brain cancer, the risk was elevated in both categories of exposure compared with the unexposed group when exposure was based on a 10-year moving average of area burned within a 50 km radius (low exposure HR 1·096, 1·012–1·187; high exposure HR 1·105, 1·009–1·210), and the strongest association was observed among the low-exposure category of the 10-year moving average of area burned within a 20 km radius of residential location (HR 1·144, 1·038–1·259).

There was some evidence of effect modification (on the multiplicative scale) by sex for lung cancer analyses. For example, when exposure was estimated in a 20 km radius, associations were generally stronger in the less-exposed category of the 3-year, 5-year, or 10-year moving average among women than men, whereas the opposite was found in the more exposed category (appendix p 18). When exposures were estimated in a 50 km radius, associations were typically stronger among men than women for both exposure categories (appendix p 18). Results were similar when exposures equal to the 95th percentile or higher were excluded (appendix p 21), after additional adjustment for ambient $PM_{2.5}$ (appendix p 23), and when moving averages were lagged 3 years instead of 1 year (appendix p 25). When the lung cancer estimates were indirectly adjusted for missing covariates, most HRs were attenuated slightly, and in some instances, the CIs now included the null (appendix p 27). When the moving averages were categorised into six groups for lung cancer analyses (an unexposed category and quintiles of exposure, in which quintile one reflects lowest exposure and quintile five reflects highest exposure), increased lung cancer risk was generally observed for quintiles one to three compared with the unexposed group, whereas HRs and 95% CIs included the null for the fourth and fifth quintile (appendix p 28). When we considered associations between lung cancer and the cumulative frequency of fires in a 10-year moving window, the adjusted HR for exposure to one to three fires was 1·043 (95% CI 1·017–1·069), for four to six fires was 1·071 (1·012–1·132), and for seven to ten fires was 1·055 (0·963–1·156) within a 20 km radius in reference to zero fires, whereas a more apparent dose-response trend was observed in the 50 km radius (HR for one to three fires 1·055, 95% CI 1·031–1·079; HR for four to six fires 1·067, 1·029–1·106; and HR for seven to ten fires 1·080, 1·031–1·131; appendix p 29).

When the models included both a dichotomous exposure term (reflecting whether the moving average

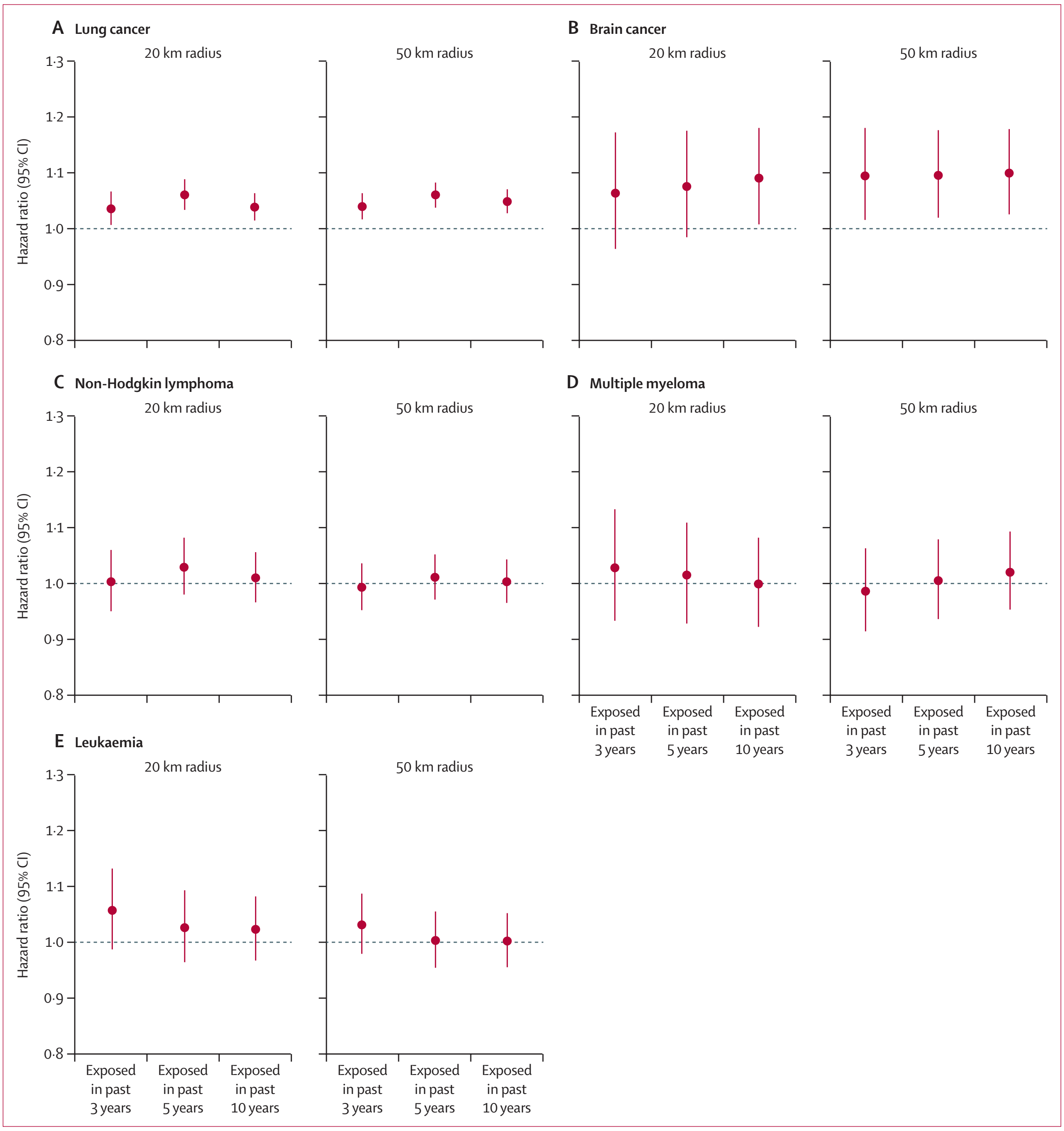

Figure 2: **Adjusted associations between any exposure to wildfires in the past 3 years, 5 years, or 10 years within a 20 km or 50 km radius of residential location**

Adjusted associations in reference to the unexposed group and the incidence of lung cancer (A), brain cancer (B), non-Hodgkin lymphoma (C), multiple myeloma (D), and leukaemia (E).

was zero *vs* greater than zero) and a continuous exposure variable (centred at the median among exposed person-years), the HR and 95% CI for the continuous exposure term included the null for all models (appendix p 30), indicating that among those with exposure greater than zero, there was no evidence of a clear association between area of forest burned and the risk of any cancers. However, the dichotomous exposure terms, which compared risk between people unexposed to wildfires versus those exposed to the median area burned, were greater than one and excluded the null for both lung and brain cancer models. Together, this evidence suggests that exposure to wildfires might be associated with an increased lung cancer and brain tumour risk, but a clear concentration-response relationship was not apparent in terms of area burned within a given buffer distance surrounding residences. Wildfires were not associated with haematological cancers in this study (figures 2, 3; appendix pp 14–26, 30).

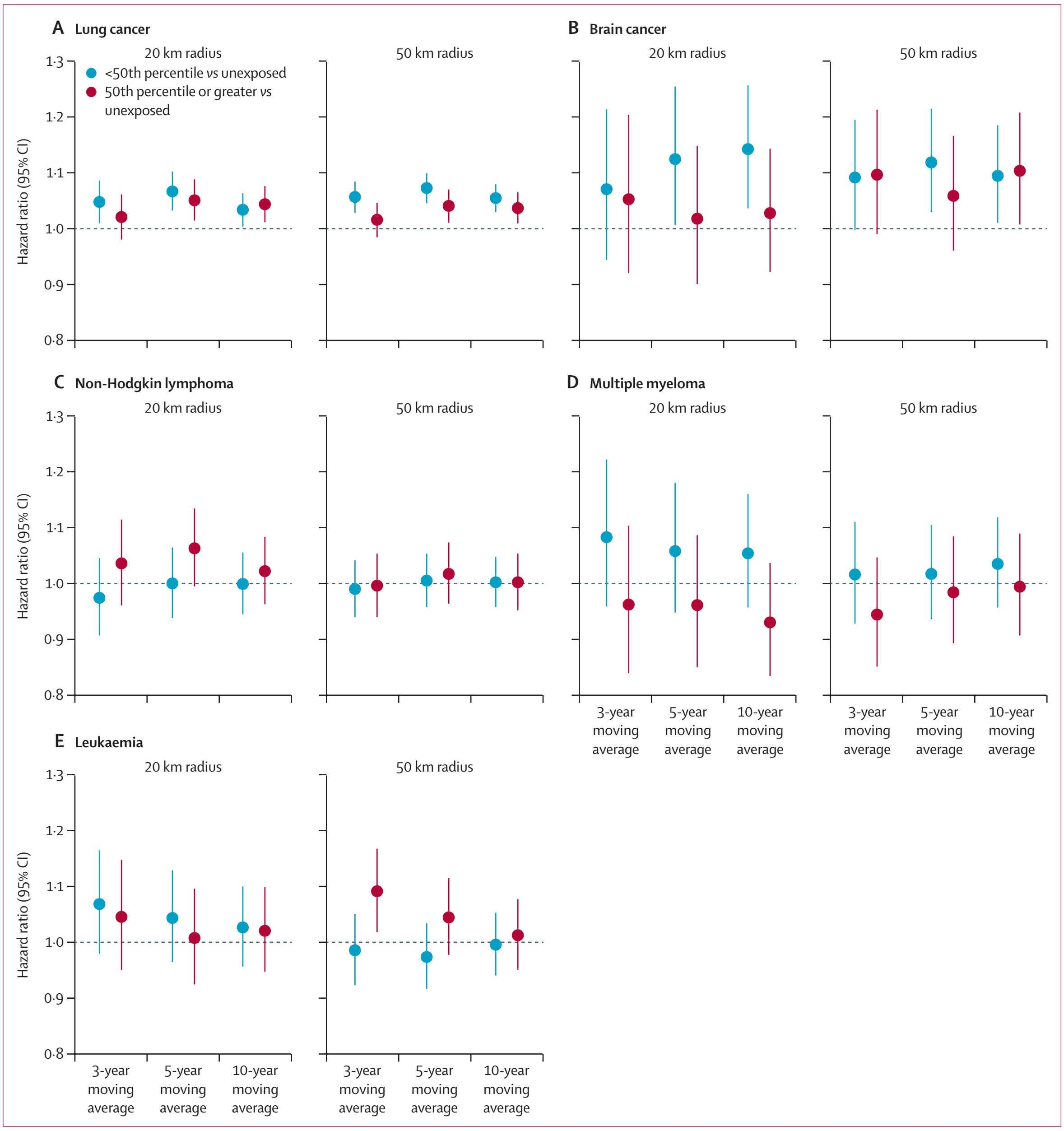

Figure 3: **Adjusted associations between categories of area burned**
Adjusted associations between categories of area burned (low exposure and high exposure, separated at the median distribution of the 3-year, 5-year, and 10-year moving average of area burned within a 20 km or 50 km radius) in reference to the unexposed group and the incidence of lung cancer (A), brain cancer (B), non-Hodgkin lymphoma (C), multiple myeloma (D), and leukaemia (E).

Discussion

In the past half century, the total area of forest burned in Canada has increased,[30] and projections at a global scale indicate greater fire activity in the future with the changing climate.[2,3] We did, to our knowledge, the first cohort study of long-term residential exposure to wildfires and cancer incidence, including more than 2 million adults followed for a median of 20 years, with the size and locations of wildfires identified across Canada from 1986 to 2015. In doing so, we noted several interesting results.

Compared with cohort members who were never exposed to wildfires, exposed populations displayed consistent elevations in the incidence of both lung cancer and brain tumours. Risks were similar between low-exposure and high-exposure groups (and sometimes larger in low-exposure groups) in the categorical analyses. However, no clear associations were observed for the continuous term in models including both a dichotomous term (describing risk in median-exposed populations *vs* never-exposed groups) and a continuous variable (describing the change in risk with increased area burned among exposed populations). We suspect that several factors might have contributed to this result. The area-burned measure was probably affected by exposure measurement error, and although the methods used to compile these data were probably adequate in identifying the presence or absence of fires and their location, estimates of total area burned might be less accurate or precise. Moreover, as environmental concentrations of pollutants emitted from wildfires depend on a range of different factors, including vegetation type and fire characteristics,[31] and because other external factors such as wind patterns have an important role in determining where pollutants travel and deposit, a larger area burned might not directly translate into higher risk. In short, our surrogate measure of area burned within a given buffer is probably a reasonable indicator of whether exposure occurred but might not be ideally suited to accurately quantify cumulative-exposure gradients for environmental carcinogens over a continuous scale.

Wildfires are traditionally associated with elevated smoke and air pollution concentrations, and outdoor air pollution is carcinogenic to humans,[32] with some evidence suggesting elevated lung cancer risk can be attributed to biomass burning sources in particular.[33] However, there are several different ways in which people living near wildfires could be exposed to carcinogenic pollutants; for example, emerging evidence indicates that wildfires can contaminate soil and terrestrial environments, water, and indoor environments. Specifically, high concentrations of environmentally persistent free radicals have been found in charcoal samples that remained stable for at least 5 years after fire events.[11] Moreover, many heavy metals sequestered in soils and vegetation become more mobile and bioavailable following wildfires because of increased soil erosion and ash dispersal.[12] Heavy metals can then be deposited in nearby bodies of water and contaminate watersheds,[7] and might also accumulate in fish living in the affected watersources,[34] which might be a potential health concern if consumed by humans. Similarly, wildfires are an important source of polycyclic aromatic hydrocarbons to both terrestrial and aquatic ecosystems.[35] In addition, violations of exposure limits for nitrates, disinfection byproducts, and arsenic in surface and groundwater have been observed in wildfire-affected areas.[8] Widespread drinking water distribution-network contamination was also discovered following several fires in California, USA, where concentrations of benzene and other volatile organic compounds (at least partially from the melting of plastic water pipes) were found to be higher than exposure limits.[9]

Moreover, there is also a concern that wildfire-derived pollutants could be retained in indoor environments for long periods of time, but few studies have examined this question. One study reported detectable concentrations of char in wipe samples collected from homes 3–8 months after a major wildfire event in New Mexico, USA.[14] In another study done during the wildfire season in Oregon, USA, indoor concentrations of gas-phase polycyclic aromatic hydrocarbons (PAHs) were higher than outdoor concentrations,[13] suggesting that once these pollutants enter the home they might persist for long periods of time. On the other hand, two studies found limited retention of heavy metals and PAHs in house dust collected 1–2 years after a major wildfire event in Fort McMurray, Canada.[36,37] Further work is needed to measure persistent chemicals after wildfires to better understand the long-term effects on human health. This information will be particularly helpful in determining why some cancers were associated with residential proximity to wildfires (ie, lung cancer and brain cancer) and some were not (ie, haematological cancers).

This study had several important strengths, including a detailed assessment of wildfire locations across Canada from 1986, application of this exposure information in a large population-based cohort with exposures updated over time for residential mobility, and detailed adjustment for a number of personal-level and neighbourhood-level covariates. However, it is important to recognise several limitations. First, as noted previously, exposure measurement error probably affected our estimates of area burned within various buffers around residential locations. For example, there are probably spatial errors in the methods used to identify wildfire perimeters and area burned and six-character postal code centroids are imperfect measures of residential home addresses. Furthermore, the chemical composition of wildfire emissions is affected by numerous factors (eg, climate, burn conditions, and fuel type),[31] and this probably also contributes to variability in the toxicity of emitted pollutants and subsequent health effects. One additional limitation in our approach to assign exposures to wildfires on the basis of residential proximity is that we might not capture pollutants from wildfires that travel long distances. However, we expect that individuals living near wildfires that occur regularly in the same area are more consistently exposed to local wildfire pollutants than individuals exposed to pollutants transported over long distances from remote fires. In addition, although we conceptualise the pathway from wildfire exposure to cancer risk primarily through exposure to environmental pollutants, other pathways could also have a role (eg, wildfires are inherently stressful events and psychological stress could have a role in cancer causes)[38] and this study is unable to disentangle these different mechanisms. Moreover, our study focused on a small number of specific cancer types, and we acknowledge that other types of cancer might be associated with wildfires. For example, arsenic is a known risk factor of bladder cancer[39] and air pollution has been associated with breast cancer;[40,41] as such, future studies might wish to explore other chronic health outcomes. Lastly, we cannot rule out residual confounding by covariates that were not measured in this study.

In summary, this study provides the first epidemiological data that suggest long-term exposure to wildfires might be associated with an elevated risk of lung cancer and brain tumours. These findings are relevant on a global scale given the anticipated effects of climate change on wildfire frequency and severity. However, in light of the study limitations, and because this is the first epidemiological study investigating associations between wildfires and cancer risk, we emphasise that a causal effect cannot be ascertained from this single study. Further work is needed to refine exposure metrics used in estimating the chronic health effects of wildfires as well as replication in different geographical locations and populations.

Contributors

SW conceptualised the study. JK refined the research question and did the literature review. RTB and SW designed the study. LP generated the exposure surfaces. JK, LP, and TC prepared the data and verified the underlying data. All authors contributed to statistical methods and MA provided statistical oversight. JK did all statistical analyses and all authors contributed to the interpretation of the results. JK wrote the first draft of the manuscript, and all authors reviewed and revised the final draft. All authors had full access to the data and accept responsibility to submit for publication.

Declaration of interests

We declare no competing interests.

Data sharing

The CanCHEC database is protected by Statistics Canada confidentiality policies and cannot be made publicly available. The National Burned Area Composite is a publicly available geographical information systems database that can be accessed on the Natural Resources Canada website for free (https://cwfis.cfs.nrcan.gc.ca/datamart/metadata/nbac).

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