

OCCUPATIONAL HEALTH OF FIREFIGHTERS: A SYSTEMATIC REVIEW

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Abstract

Background: Firefighting is a hazardous occupation exposure to a wide range of toxic chemicals, smoke, and other contaminant that is associated with many occupational health risks. As a result, there has been growing concern over the potential health effects of this exposure, including an increased risk of cancer, respiratory problems, and cardiac events. **Objective:** This systematic review aims to investigate the occupational health situation of firefighters, in the last 10 years. **Method:** Research via electronic databases: PubMed, Web of Science and ScienceDirect was conducted keywords related to occupational exposure, diseases, and firefighting. **Results:** A total of 20 studies that examined the association between occupational exposure and the incidence or prevalence of diseases were included in analysis. **Conclusion:** Despite ongoing research, the exact magnitude of the risks associated with occupational exposure for firefighters is still unclear. However, there is evidence to suggest that the risk of these occupational diseases increases with length of service and intensity of exposure to firefighting contaminants. Therefore, it is essential to develop effective measures to prevent and manage these risks to ensure the health and well-being of firefighters.

Keywords: Health Risks, Occupational Exposure, PRISMA

Introduction

Firefighters are exposed to numerous health hazards that can have long-lasting effects on their health (Demers et al., 2022). One of the primary threats faced by firefighters is exposure to combustion products during fire incidents. These products can contain polycyclic aromatic hydrocarbons (PAHs) and other particulates that, when inhaled, can cause respiratory problems (World Health Organisation, 2021). Additionally, building materials like asbestos, poses a risk to health (Suzuki & Yuen, 2002), which alongside with chemicals in firefighting foams and flame retardants, can have a detrimental effect on a firefighter's health (Rosenfeld et al., 2023). The use of these chemicals has been linked to certain cancers and other health issues (Messmer et al., 2022; Steenland & Winquist, 2021). Furthermore, non-fire events, as vehicle accidents, medical emergencies (Lawn et al., 2020) and night shift work (Brown et al., 2020) can also increase the risk of mental health problems. The World Trade Centre attack acted as a clarion call to the firefighting sector, unearthing a spectrum of diseases and health concerns among first responders, particularly firefighters, which were previously unattributable to the profession. (Cleven et al., 2021; Yip et al., 2016). Alongside with post-traumatic stress disorder (PTSD) (Berninger et al., 2010), firefighters began to develop autoimmune diseases such as asthma and chronic obstructive pulmonary disease (Cleven et al., 2021; Singh et al., 2018). Public and Occupational health began to re-evaluate firefighters' safety protocols and implement new measures to protect both public and professionals from exposure to dangerous substances. Despite this fact, the health risks faced by firefighters remains a concern, and many are still grappling with the long-term effects of exposure to harmful components. It is essential to prioritise the health and safety of firefighters, as they continue to serve their communities. The purpose of this systematic review is to investigate the relation between occupational exposure to risk factors and the potential development of health problems in firefighters. By analysing the latest scientific information, this review aims to provide updated knowledge to fire service leaders regarding the occupational health concerns faced by professionals.

Materials and Methods

Eligibility criteria, information sources and search strategy

The present systematic review is developed following the recommendations provided by PRISMA - Preferred Reporting Items for Systematic Reviews and Meta-Analyses (Page et al., 2021) once this methodology improves research quality and reliability. To generate the research question and inclusion/exclusion criteria, the PICOS (Population, Intervention, Comparison, Outcome, and Study Design) framework is used, to comply with Centre for Reviews and Dissemination (CRD) Guidance for undertaking reviews in healthcare (Table 1).

Table 1. PICOS eligibility criteria

PICOS	ELIGIBILITY CRITERIA
POPULATION	Firefighters
INTERVENTION	Occupational exposure to risk factors
COMPARISON	General population or firefighters less/not exposed
OUTOCOME	Incidence or prevalence of health problems
STUDY DESIGN	Observational studies (cohort studies, case-control studies, and prevalence studies) that investigate the association between occupational exposure to risk factors and the incidence or prevalence of health problems

Based on the PICOS model, the research question for this systematic review is: What is the relation found between occupational exposure to risk factors and the potential development of health problems in firefighters? As per Table 1, to develop this systematic review, specific eligibility criteria were established based on the PICOS model. The population of interest included firefighters worldwide. The intervention or exposure of interest was occupational exposure to risk factors, such as combustion products, chemicals, and physical strain during firefighting activities. The comparison group consisted of not exposed firefighters, or less exposed to risk factors. The primary outcome of interest was the incidence or prevalence of health problems related to occupational exposure to risk factors, such as respiratory conditions cardiovascular diseases, and mental health problems. Longitudinal studies, published within the last 10 years, in English, Portuguese, or Spanish language were included. Several factors were considered in the decision to limit the focus of this review to studies conducted within the past 10 years. Longitudinal studies focusing on the relationship between health problems in firefighters and their occupational exposure to risk factors have increased significantly over the past decade, particularly after the World Trade Centre disaster in 2001 drew attention to this issue. Incorporating multiple languages can improve the chances of locating a diverse range of studies relevant to the research question, thereby increasing the comprehensiveness of the search. Moreover, it can mitigate language bias and enhance the applicability of the findings across diverse settings and populations. Studies which did not meet these criteria were excluded from the review.

The search strategy was designed to be comprehensive and sensitive, while also being specific enough to exclude irrelevant studies, incorporating relevant medical subject headings (MeSH) terms and keywords related to occupational exposure, diseases, and firefighting. The strategy was tailored to meet the requirements of multiple databases, including PubMed, Web of Science, and ScienceDirect, while maintaining consistency in core search terms: Occupational exposure (Mesh), Occupational Disease (Mesh) and Firefighters (Mesh) and Firefighting (Mesh). Eligibility was assessed based on review of titles and abstracts, followed by further review of potentially eligible full-text studies. The included studies were further analysed by type of exposure and associated risk disorders. This adaptable search strategy can be used in other databases.

Study selection process, data collection process and Data items

The present search and data selection was conducted by two independent reviewers (SA and FS) through selection of scientific databases and evaluation of eligibility of studies, starting by analysing title and abstract. Afterwards, full text paper was screened by SA and reviewed by FS to verify if studies met the inclusion criteria. If discrepancies between reviewers occurred regarding eligibility, inclusion, or not, of studies, these were solved through consultation of two independent reviewers (JV and AF) to achieve agreement. Records were managed through Mendeley, specific software for managing bibliographies. For each study the following topics were retrieved: Study Characteristics, Exposure information, Outcome information and Measures of association.

Results and discussion

Search results

From the research conducted a total of 1260 studies were retrieved from the databases PubMed, Web of Science and ScienceDirect.

Following rejecting 197 duplicates, 1063 studies were assessed for eligibility. After analysis of abstract, 20 met the eligibility criteria and were included in the review. The flow diagram of retrieval trials is shown in Fig 1.

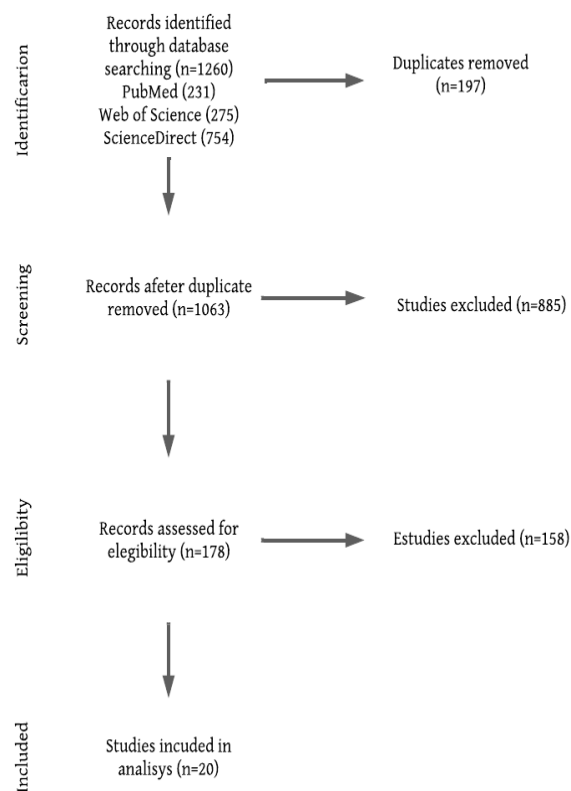


Figure 1. PRISMA diagram

To organize the analysis and improve readability, the review has been divided into several subheadings based on the outcomes of interest. Specifically, we will assess studies that report on the following topics: Cancer risk, Cardiac complications, Respiratory problems, PTSD. These subheadings emerged as major themes of interest and as the most reported health issues related to firefighters' occupational exposure on the eligible studies assessed. Furthermore, occupational-specific issues arising from the World Trade Centre disaster (WTC) will also be discussed, given its significant impact on the professionals' health and as a critical event in the literature.

Table 2. Studies' characteristics

Study	Year	Country	Sample size	Study design	Measures of association
Pukkala, et al.	2014	Finland, Norway, Sweden, Denmark and Iceland	16422	Cohort	SIR (standardized incidence ratio) was calculated by dividing the observed number of cancer cases by the expected number of cases, with a 95% confidence interval assumed from a Poisson distribution of the observed cases.
Ide, Christopher	2014	Scotland	2200	Cohort	Descriptive statistics and utilization of Minitab for statistical study with $P \leq 0.05$.
Marjerrison, et al	2022	Norway	3881	Cohort	SIR calculated as the ratio of the observed and expected number of cases, with the rates of the general Norwegian male population as the reference
Langevin, et al	2020	USA	718 cases and 905 controls	Case-control	Used Stata 13, with $p < 0.05$ Conducted two-sample t-test for normally distributed continuous covariates. Used non-parametric rank-sum test for non-normality covariates.
Peteresen et al	2017	Denmark	9061	Cohort	Estimated SIRs with corresponding 95% CIs by comparing overall number of observed versus expected cases.
Glass, et al	2016	Australia	163094	Cohort	Used Poisson regression modeling Calculated relative risks (relative mortality ratio (RMR) and relative cancer incidence ratio (RIR)) by comparing risks for longer service duration with that of shortest duration.
Daniels, et al	2014	USA	29 993	Cohort	Used NIOSH Life Table Analysis System to examine mortality and cancer incidence. Calculated SIR as the ratio of observed malignancies to the expected number of cases estimated using US incidence rates.
Vanchiere et al	2022	USA	10 860	Cross-sectional survey	Used χ^2 test and Fisher exact test. Conducted multivariable logistic regression to assess odds of having AF.
Dzikowicz & Carey	2021	USA	22	Correlation analysis	Statistical significance considered when $p < .05$. Findings reported according to STROBE recommendations for observational studies.
Farioli et al	2014	USA	206	Retrospective Cohort Study	Two-sided P value ≤ 0.05 considered statistically significant. Poisson regression models used with duty-specific RR and associated 95% confidence intervals (95% CIs).
Smith et al	2018	USA	276 cardiac cases and 351 noncardiac controls	Case-Control	Compared mean SD between groups using t-test of independence. Presented categorical variables as frequencies and percentages and compared using χ^2 test of association. All tests performed were 2-tailed with a significance level of 0.05.
Jeung et al	Korea	2022	363 137	Retrospective Cohort Study	Regression analysis used to assess hazard ratios (HRs) and 95% confidence intervals (95% CIs) for CVD between firefighters and public officials.
Webber et al	2021	USA	10786 FDNY	Cohort	Poisson regression models used to assess cancers in each group.

			firefighters and 8813 CFHS firefighters		Standardized incidence ratios (SIRs) and adjusted relative rates (RRs) estimated for each group.
Putman et al	2018	USA	11 926 FDNY WTC-exposed	Cohort	Poisson model used to compare CRS rates in firefighters versus EMS workers. Multivariable Cox regression used to assess associations of WTC exposure, haematological results, and chronic rhinosinusitis.
Moir et al	2016	USA	11457 WTC-exposed firefighters and 8220 non exposed firefighters	Cohort	PROC GENMOD used to model rate ratios for all cancers. Relative rates (RRs) modelled using Poisson regression. Comparison made between WTC-exposed firefighters and non-WTC-exposed firefighters.
Landgren et al	2018	USA	16 FDNY for MM screening and 781 FDNY for MGUS screening	Case series and screening	95% confidence intervals computed for directly standardized relative rates (RRs). Modified γ approximation method used, assuming a Poisson distribution
Gulliver et al	2021	USA	322 professional firefighters	Prospective cohort study	Descriptive statistics to determine PTE exposure level. Diagnostic assessments conducted by psychologists. Symptom checklists completed.
Kim et al	2019	Korea	535 firefighters	Cohort	Baseline health examination and mental health assessment. Factor analysis. Descriptive analysis. Internal reliability analysis of scales. Correlations between variables. Structural equation modelling (SEM) analysis. Bootstrap estimates.
Gianniou et al	2016	Greece	63 exposed firefighters and 29 control	Cohort	Fisher's exact test for linear regression. Kruskal-Wallis test, followed by Mann-Whitney rank test if significant. Spearman's correlation to show relationship between years in service and inflammation measures.
Cherry et al	2021	Canada	1234 firefighters	Cohort	Conditional logistic regression to estimate odds. Testing linearity of observed relation of means, predicted, and their ratio to exposure quartile. Poisson regression model to estimate prevalence

Cancer risk

Several epidemiological studies have investigated the potential association between the occupational exposure of firefighters and cancer incidence or mortality. A study conducted in Denmark, Finland, Iceland, Norway, and Sweden from 1961 to 2005 (Pukkala et al., 2014) found that firefighters had a higher risk of developing cancer compared to the general population, with higher rates among firefighters over the age of 70, of lung cancer,

adenocarcinoma, mesothelioma, nonmelanoma skin cancer and multiple myeloma. In contrast, higher rates of prostate cancer and skin melanoma were found in younger firefighters (Pukkala et al., 2014). Similarly, studies conducted in Norway from 1950 to 2008 (Marjerrison et al., 2022) and in Denmark from 1968 to 2014 (Petersen et al., 2017) found that firefighters had a higher risk of developing cancer compared to the general population. Marjerrison et al. (2022) found an increased incidence of laryngeal cancer, mesothelioma, and other cancers, particularly among firefighters with more than 40 years of service. Petersen et al. (2017) reported that firefighters had a higher overall incidence of cancer, particularly for skin, bladder, prostate, and testicular cancers. The risk of cancer increased with longer duration of employment and was higher among firefighters who were exposed to fires and other hazardous materials.

These results are consistent with studies conducted in other countries, such as Scotland (Ide, 2014) and Australia (Glass et al., 2017), which found that firefighters had a higher risk of cancer incidence and mortality, particularly for melanoma and kidney cancers. Additionally, a case-control study conducted in the US found that firefighters had a significantly increased risk of head and neck cancer compared to the control group, and this risk was even higher among professionals with longer duration of employment and a history of smoking (Langevin et al., 2020). Finally, a cohort research in the US, including female firefighters, found an increased risk of cancer incidence and mortality, particularly for respiratory, digestive, and urinary cancers, with an excess of mortality due to breast and bladder cancer within the female group (Daniels et al., 2014).

Overall, the studies provide consistent evidence that firefighters are at an increased risk of developing cancer compared to the general population. The risk may be influenced by a variety of factors, including age, duration of employment, exposure to fires and other hazardous materials, and smoking history. Further research is needed to better understand the occupational risk factors for cancer among firefighters and to identify ways to reduce exposure to harmful substances during firefighting activities.

Cardiac complications

The following studies discuss the risk factors associated with sudden cardiac death (SCD) and cardiovascular disease (CVD) among firefighters based on valuable insights provided by previous studies.

Farioli et al (2014), and Smith et al. (2018) found that the risk of SCD is higher during physical training and firefighting activities, and the most common underlying cause of SCD was coronary heart disease. Additionally, both studies found that older age, higher BMI, smoking history, and pre-existing cardiovascular conditions were associated with an increased risk of SCD. They also found that firefighters who died from duty-related cardiac events were more likely to have a history of hypertension, hypercholesterolemia, and smoking, and were older, heavier, and had longer years of service. These findings suggest that prevention of cardiovascular disease is critical for firefighters, and risk reduction strategies such as proper screening, management of cardiovascular risk factors, and cardiac rehabilitation may be beneficial.

Vanchiere et al. (2022) found that firefighting activity is significantly associated with an increased prevalence of atrial fibrillation (AF) in professionals, and the risk increases with age and the number of fires fought per year. The study also revealed that firefighters with a history of cardiovascular disease had a significantly higher risk of developing AF. The authors suggest that prevention and management of occupational exposure in firefighters can reduce the risk of AF and other cardiovascular diseases. Similarly, the article by Jeung et al., (2022) found that firefighters who had engaged in emergency duties were at a higher risk of developing CVD, with the risk increasing with the number of duties performed and being higher for those who had performed emergency duties for 10 or more years. These findings suggest that reducing exposure to emergency duties and managing cardiovascular risk factors may be effective strategies for preventing CVD in firefighters. These results are similar to the ones found by Dzikowicz & Carey (2021) who investigated the prevalence of ischemic heart disease (IHD) and the severity of myocardial ischemia in professional firefighters. It was found that the prevalence of IHD and the severity of myocardial ischemia were positively associated with career length but not with age. Firefighters with longer careers had a higher prevalence of IHD and more severe myocardial ischemia. Authors suggest that this may be due to the rigorous physical demands of the firefighting profession,

which can accelerate cardiovascular aging and lead to earlier onset of cardiovascular disease. Both studies' results suggest that job-related stress, physical demands, and exposure to toxins may contribute to the development of IHD (Dzikowicz & Carey, 2021) and CVD (Jeung et al., 2022) and implies that career length may be a more important predictor of cardiac effects in firefighters. Risk reduction strategies such as proper screening, management of cardiovascular risk factors, and cardiac rehabilitation may be beneficial, as well as reducing exposure to known risk factors such as smoking and obesity.

Respiratory problems

Two cohort studies, Cherry et al. (2021) and Gianniou et al. (2016), investigated the respiratory effects of prolonged occupational exposure to firefighting on professional firefighters. Both studies found that professional firefighters, who were exposed to occupational hazards, had a higher prevalence of respiratory symptoms, including cough, phlegm, dyspnoea, and wheeze, compared to control groups. In addition, the studies revealed that prolonged occupational exposure to firefighting led to chronic airway and systemic inflammation and allergic airway sensitization, increasing the risk of respiratory diseases among professional firefighters.

Cherry et al. (2021) conducted a cohort study with 1234 firefighters involved in the Fort McMurray wildfire suppression efforts in Canada. They found that longer exposure to the fire and smoke was associated with a higher risk of persistent respiratory symptoms and lung function abnormalities. The study also identified that using respiratory protective equipment during firefighting was associated with a reduced risk of respiratory symptoms and lung function abnormalities. One-third of the firefighters experienced persistent respiratory symptoms one year after the wildfire, and approximately one-fifth of the firefighters had persistent lung function abnormalities. Gianniou et al. (2016) enrolled 63 professional firefighters exposed to occupational hazards and 29 control subjects in their study. The analysis of the sputum for markers of inflammation discovered a significant increase of eosinophils in the group of the professional firefighters as compared to the healthy subjects' groups. Additionally, these results were higher in professionals with a longer duration of the occupation. Histological alterations were also found, observing atrophy of the bronchial epithelium and the squamous metaplasia in 85% of professional firefighters eligible for histology examination. Both studies provide evidence that professional firefighters exposed to prolonged occupational hazards face a higher risk of respiratory symptoms and reduced lung function, chronic airway and systemic inflammation, and allergic airway sensitization. The findings suggest that regular monitoring and early intervention are crucial to prevent or reduce the risk of these conditions among professional firefighters.

PTSD worries

A few studies were realized in order to explore the impact of occupational stress on the mental and emotional health of firefighters. A Korean investigation found that burnout among firefighters is associated with greater severity of post-traumatic stress disorder (PTSD) symptoms, particularly emotional exhaustion, and depersonalization, with younger and less experienced firefighters being more susceptible to these symptoms (Kim et al., 2019). Another study, which focused on firefighters in the United States, found that PTSD and depression symptoms were more prevalent during the academy training period and more common among firefighters who reported exposure to traumatic events on the job or had a prior history of PTSD or depression (Gulliver et al., 2021). While the Korean study suggests a strong association between burnout and PTSD symptoms, particularly in younger and less experienced firefighters, the US study reveals a pattern of resilience among firefighters during their initial years of service, despite repeated exposure to potentially traumatic events. Taken together, these studies indicate that PTSD and depression symptoms are common among firefighters, particularly during their early years of service, and that exposure to traumatic events on the job is a significant risk factor for the development these mental health conditions (Bezabh et al., 2018; Henson et al., 2022). To prevent and reduce the impact of PTSD and depression among firefighters, it is suggested that preventative interventions should focus on developing resilience, social support, and targeted support for those who have previously experienced trauma or stressful life events.

9/11 occupational diseases

The terrorist assault on the World Trade Centre (WTC) led to the release of vast quantities of toxic substances into the environment, including carcinogens and other hazardous chemicals (Klitzman & Freudenberg, 2003). In the aftermath of the attacks, firefighters who responded to the attacks were exposed to these toxins, as well as other hazards inherent in their profession. Consequently, numerous studies have been conducted to investigate the correlation between the exposure to these toxic agents during the World Trade Centre (WTC) attacks and the incidence of occupational diseases, including cancer, chronic rhinosinusitis, and pulmonary disorders, among firefighters (Cleven et al., 2021).

Moir et al., (2016) found that WTC-exposed firefighters had a 10% higher incidence of cancer, and that the incidence of certain types of cancer was particularly elevated, including thyroid (33% higher), prostate (44% higher), and melanoma cancers (27% higher). A study, from authors Landgren et al (2018), centred specifically on multiple myeloma (MM) and its precursor disease (MGUS) among WTC-exposed firefighters, had similar result, finding that exposed firefighters had a higher prevalence of haematological malignancies, compared to the general population. Similarly, Webber et al. (2021) found that WTC-exposed firefighters had a significantly higher overall cancer incidence rate compared to non-exposed firefighters and the US adult male population. They also found that the higher incidence of certain types of cancer, such as thyroid, liver, and soft tissue cancers, may be attributed to exposure to various carcinogens and toxins during their work at the WTC site.

Putman et al (2018) examines and identifies risk factors for the development of chronic rhinosinusitis (CRS) in Fire Department of the City of New York workers (FDNY) who were exposed to the WTC disaster. The study found that exposure to the WTC site was a significant risk factor for chronic rhinosinusitis, along with other factors such as age, smoking, and a history of allergies. A following study, from authors Cleven et al. (2021) provides similar pulmonary outcomes from FDNY rescue and recovery workers who were exposed to the WTC disaster. The study found that exposed workers had a higher incidence of pulmonary disease compared to the general population, including chronic rhinosinusitis and asthma, as well as a decline in lung function (Cleven et al., 2021). The risk of developing these respiratory illnesses was directly proportional to the duration of exposure to WTC dust and fumes (Cleven et al., 2021). Both studies suggest that the WTC exposure had a lasting impact on the respiratory health of FDNY workers, highlighting the need for ongoing monitoring and treatment of respiratory illnesses in this population.

Overall, all studies concluded that firefighters who were exposed to the WTC disaster had an increased risk of developing multiple myeloma and other types of cancer, compared to non-exposed firefighters. These studies emphasize the need for continued monitoring and screening of firefighters who were exposed to the WTC site to detect early signs of cancer and other occupational diseases.

Conclusions

Firefighters face a significant risk of occupational diseases such as cancer, respiratory, and cardiac events, as well as high levels of stress. While the present systematic review has highlighted the association between occupational exposure and health problems in firefighters, there is still a need for more research to fully understand the magnitude of these risks. Studies have already shown that firefighters have a greater risk to develop diseases than the general population, which increases with length of service and intensity of exposure to firefighting contaminants. Therefore, it is crucial for future studies to focus on identifying specific risk factors and develop effective strategies to prevent and manage these health risks and to protect the health and well-being of firefighters. Future perspectives could include exploring new technologies and equipment that could reduce exposure to harmful substances, as well as training programs to ensure that firefighters are aware of the risks and know how to protect themselves.

It should be noted that this systematic review is based solely on the available scientific literature on the topic. Therefore, the findings and conclusions presented in this review are limited to the existing literature and may be subject to change with future research. Nonetheless, this review provides a comprehensive summary of the

current knowledge on the occupational health risks faced by firefighters and the association between occupational exposure and the incidence or prevalence of various diseases.

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