The Threat of Wildfires and Pulmonary Complications: A Narrative Review

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Abstract

Purpose of Review The increase in wildfire prevalence and severity has generated alarm as wildfire air pollution is associated with significant respiratory morbidity. We aim to summarize the pathophysiology of wildfire air pollution causing lung disease, current knowledge of pulmonary health effects, and precautionary guidance to the public. We also propose specific guidance for high-risk patients during wildfires.

Recent Findings Health effects of wildfire air pollution have been difficult to evaluate; however, respiratory morbidity has been firmly established including exacerbation of known pulmonary disease and increased hospitalizations, emergency department visits, and dispensation of reliever medications. Public health agencies and officials provide wildfire preparation recommendations and active updates to the public during a wildfire event but fail to address specific needs of chronic lung disease patients considered high-risk for pulmonary complications. To fill this void, it is increasingly important for pulmonary physicians to understand wildfire-related pulmonary morbidity and provide specific guidance to their patients.

Summary This review summarizes the health effects of wildfire air pollution and provides guidance for the management of high-risk patients during wildfires.

Keywords Wildfires · Smoke toxicology · Particulate matter · Pulmonary complications

Abbreviations

ALA American Lung Association
ATS American Thoracic Society
CO Carbon monoxide
CV Cardiovascular
ED Emergency department
EPA Environmental Protection Agency
HVAC Heating, ventilation, and air conditioning
HEPA High efficiency particulate air
PM Particulate matter
USA Unites States

Introduction

The escalation of enlarging and prolonged wildfires is alarming in recent years. Air pollution caused by wildfires leads to a multitude of pulmonary complications. Presently, preventative guidance stems from national health organizations and agencies; however, there is a greater call for physicians to be actively involved in preemptive counseling of high-risk patients. Physicians must be prepared to manage high-risk and previously healthy patients following exposure to wildfires [1, 2]. We summarize current knowledge of wildfires pertinent to pulmonary health and propose an approach toward mitigation and treatment of pulmonary complications.

An increase in wildfire destruction is noted both nationally and globally [3]. In the USA, the National Interagency Coordination Center reports firefighting suppression costs soaring to over 2.2 trillion dollars and an increase to nearly 10 million acres burned per year representing a tenfold increase in acreage since the 1980s [4]. Internationally, there are 3 to 6 million kilometers burned each year with an estimated 339,000 annual deaths worldwide attributable to wildfires [6].
Wildfires are in part a natural phenomenon for the renewal of some ecosystems [2, 5], but climate change and human influence are increasing the frequency, size, pace of spread, and destruction of wildfires [7, 8]. Climate change alters natural conditions causing drought, strong winds, and higher temperatures which contribute to an environment conducive for ignitions [3] effectively causing a longer fire season and leading to wildfires in atypical areas [7]. Loss of forest and production of greenhouse gas during wildfires further perpetuate climate change [3]. Most alarming is that human-driven climate change alone accounts for nearly half of all acres burned from 1979 to 2015 [9]. Further, human ignitions pose a greater risk than natural lightning-related ignitions by causing fires in atypical, high moisture areas outside of fire season and often causing large-scale fires responsible for greater destruction [7].

Smoke Toxicology

Wildfires not only cause immediate danger due to flames but also produce air pollution in the form of particulate matter (PM) and hazardous gases which may spread over thousands of miles. When produced by human activities, these pollutants are regulated under the Clean Air Act due to their ill effects [1, 10]. The PM and hazardous gas content from wildfires is highly variable which creates a challenging landscape for researchers to clearly define adverse health effects from wildfires. Air pollution is dependent on fuel type ranging from natural vegetation to man-made materials such as plastic, glass, cement, asbestos, and other substances which are prevalent along the expanding rural urban interface experiencing greater incidence of wildfires. Factors such as moisture content, fire temperature, wind conditions, and topography also play a role in wildfire air pollution composition and spread [5].

PM has been the primary focus of research for wildfire health effects [3]. PM is a term for small particles and droplets released by chemical reactions. PM may occur from both natural processes such as volcanoes and fires and human activities such as industrial processes or vehicle emissions. PM is categorized by size from < 10 μm (PM<sub>10</sub>) or “coarse,” < 2.5 μm (PM<sub>2.5</sub>) or “fine,” and < 0.1 μm (PM<sub>0.1</sub>) or “ultrafine” [10]. Health effects of PM are studied based on size rather than composition due to highly variable content and lack of data linking specific PM composition to health outcomes [5]. Ninety percent of PM produced from wildfires is PM<sub>2.5</sub> which is the most dangerous PM type due to its ability to be inhaled to all areas of the respiratory tract and even translocate into the circulatory system [11]. Wildfires are well-known to cause a significant transient increase in PM<sub>2.5</sub> for greater than 2 days which has been termed as a “smoke wave” [12]. Hazardous gases produced by wildfires include ozone, carbon monoxide (CO), nitric oxide, nitrogen dioxide, benzene, and volatile organic compounds which are difficult to measure [3]. Although a secondary focus, adverse effects such as generalized symptoms of eye or skin irritation, drowsiness, and cough are established effects for some of these pollutants [5], in addition to specific toxicities such as CO poisoning [3] or possible carcinogenic effects [5].

Proposed Mechanisms of Pulmonary Disease

PM may lead to a range of health effects through different mechanisms of disease not clearly established in the literature [1]. Zhong et al. and Kim et al. suggest an endotoxin-like effect of coarse particles, while Cascio proposes coarse particle interaction with pulmonary neural receptors; both explanations account for observed autonomic effects of increased blood pressure and heart rhythm changes upon initial smoke exposure [1, 13, 14]. Cascio further surmises that smaller, inhaled particles likely cause oxidative reactions locally at the alveolar capillary level or systemically after translocation across the alveolar membrane leading to an array of health effects [1]. Of note, animal studies have shown lower number of lung macrophages, increased inflammatory cells and cytokines, greater antioxidant depletion, and reduced lung mechanics after wildfire derived PM exposure [15].

Adverse Health Outcomes

Establishing specific health outcomes of wildfires has been difficult not only due to variable content of wildfire smoke but also due to variable characteristics of an exposed population such as duration and intensity of exposure [2]. Studies have observed firefighters [16] and local populations during wildfire events [8], but studying long-term exposure continues to be challenging [3].

The literature supports a multitude of adverse pulmonary outcomes during wildfire events. On fire days, there is an increase in reported pulmonary symptoms such as cough and wheeze [8] with a significant increase in emergency department (ED) visits, physician visits, and hospitalizations for pulmonary complaints and an increase in dispensation of pulmonary reliever medication and oral steroids [15]. Specifically, asthma exacerbations occur more frequently on fire days with an Australian study showing a 2.4× increase in asthma-related ED visits on fire days compared to non-fire days [8]. Asthma exacerbations are worse specifically with wildfire PM rather than ambient urban PM, possibly due to composition and intensity of the wildfire PM [3]. There is also an increase in COPD exacerbations with some requiring

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hospitalization [15] along with increased incidence of bronchitis and pneumonia [5, 8, 15]. Some data also supports increase in upper respiratory tract infections [17]. Data otherwise is lacking for specific pulmonary diseases, and more information is needed. Pulmonary morbidity due to wildfires is disproportionately endured by the elderly, women, and those of lower socioeconomic class [1].

Firefighters are a population that may be studied for long-term pulmonary effects from wildfire PM exposure. Unfortunately, there is no standard respiratory safety equipment for outdoor fires, and respirators are otherwise impractical and rarely used due to self-perceived health [2]. Liu et al. studied lung function in California firefighters and demonstrated declines in forced vital capacity, forced expiratory volume over 1 s, and increased airway responsiveness [18]. Navarro also predicted total PM exposure of firefighters and demonstrated a likely 8 to 43% increase in lung cancer incidence [16].

Cardiovascular (CV) outcomes are worse in the setting of urban PM; however, data on adverse CV outcomes due to wildfire PM is mixed [15]. Among positive studies, results suggest an increase in out-of-hospital cardiac arrest, increase in hospitalizations for myocardial infarction [19], increase in ED visits for congestive heart failure [8], worsening hypertension, and a possible association with cerebrovascular disease and stroke [15].

Data also suggests an array of other adverse health outcomes related to wildfire PM including low birth weight of fetuses with mothers exposed to wildfire smoke in the second or third trimester [20], increased ambulance dispatches for diabetes, increased incidence of influenza [3], increased markers of systemic inflammation, changes in bone marrow content, and reported decreased physical strength and overall health [8]. Table 1 summarizes adverse health outcomes from wildfire exposure.

Direct exposure to an active wildfire may also cause direct harm in the form of burns, physical injuries, dehydration, heat stroke, or death. Heavy smoke exposure can also cause eye irritation and corneal abrasions. Involvement in a catastrophic wildfire can also cause immediate and long-lasting mental health impacts [3]. Other unknown health effects may occur because of utilizing water contaminated with ash, fire retardant, and dead animals [1, 3]. There is an observed increase in all-cause mortality due to nonaccidental death on fire days, although the exact etiology is unclear [15].

**Risk Assessment**

Public health agencies and medical organizations provide accessible online education regarding emergency preparedness and safety measures prior to wildfire events, although there is increasing expectation for direct physician guidance to patients [2]. The Environmental Protection Agency (EPA), the Centers for Disease Control and Prevention (CDC), the American Lung Association (ALA), the American Thoracic Society (ATS), and multiple state health departments have accessible online resources for the public; however, only the

| Table 1  | Summary of adverse health effects of wildfire smoke exposure |
|----------|-------------------------------------------------------------|
| Organ system | Health effects |
| Pulmonary | Increased pulmonary symptoms; cough, wheeze, etc |
| | Increased ambulatory visits, emergency department visits, and hospitalizations |
| | Increased dispensation of pulmonary reliever medications and steroids |
| | Increased asthma and COPD exacerbations, bronchitis, pneumonia, and upper respiratory tract infections |
| | Decrease in forced vital capacity, forced expiratory volume over 1 s, and increased airway responsiveness (observed in firefighters) |
| | Possible increase in lung cancer (observed in firefighters) |
| Cardiovascular | Increased out of hospital cardiac arrests |
| | Increased hospitalizations for myocardial infarction |
| | Increase emergency department visits for congestive heart failure |
| | Worsening hypertension |
| | Possible increased cerebrovascular disease and stroke |
| Other | Low birth weight for fetuses with mothers exposed in second or third trimester |
| | Increased ambulance dispatch for diabetes |
| | Increased incidence of influenza |
| | Increased markers of inflammation |
| | Changes in bone marrow content |
| | Worsened reports of physical strength and overall health |

*COPD* chronic obstructive pulmonary disease
EPA offers specific training online for healthcare professionals [2, 11, 21, 22]. During a wildfire event, public health officials assume the primary role of providing real-time updates and safety guidance through clearly established lines of communication. Recently, wildfire experts have been deployed to areas with ongoing fires to provide current, short-, and long-term smoke forecasts via public news casts to ensure public safety, although there is a growing need to reinforce these collaborative efforts. The public may also receive updated through AirNow which is a novel online tool that utilizes the US air quality index (AQI) to report current levels of air pollution. The AQI is a measurement of PM$_{2.5}$, PM$_{10}$, and ozone in a specific region which correlates to recommendations regarding outdoor activities. It is imperative to monitor AQI in the setting of a wildfire due to evolving conditions and ability of smoke to spread thousands of miles toward unsuspecting inhabitants. AirNow’s Fires: Current Conditions is intended to provide updated information in quickly changing wildfire conditions; however, updates may still lag real-time occurrences making awareness of public updates by health experts critical [2].

**Safety Measures**

The public is encouraged to utilize educational resources prior to a wildfire event for adequate preparation [11]. Emergency supplies should include clean water, food, medications, and emergency power sources. The public should also plan a means to receive updated wildfire information, air quality reports, and advisories [21]. Consideration may be given to upgrading heating, ventilation, and air conditioning (HVAC) units for improved air filtration, purchasing a portable air cleaner with a high efficiency particulate air (HEPA) filter, and obtaining a particulate respirator termed “N95” or “P100” masks (Fig. 1). Review of wildfire education prior to a wildfire will also allow for preparatory actions if advisories dictate limited outdoor activity, strictly indoor activity, or even evacuation [11], represented in Fig. 2.

Limited outdoor activity may be advised if the air quality index is poor. According to the EPA, the dose of air pollution a patient is exposed to is proportional to the concentration of air pollution (best represented by the AQI), a person’s minute ventilation, and the duration of exposure. Therefore, patients may be advised to limit physical exertion to minimize minute ventilation and to spend minimal time outdoors [11]. N95 masks are also recommended while outdoors to filter harmful PM, thus reducing the concentration of air pollution. Although universally recommended, N95 masks may provide false reassurance as a tight-fitting N95 mask is required to properly filter PM and cannot be used by those with beards or by children [21], offer no protection against hazardous gases [2], and may also cause shortness of breath for those with heart or lung disease [3]. If an individual is not outdoors but driving a vehicle, it is also recommended to keep windows up and switch the air conditioning to “recirculate mode” to avoid infiltration of air pollution to the vehicle [11, 21, 22].

Strictly indoor activity may be advised if the AQI is dangerously high. Although potentially cost prohibitive, ideal interventions include preemptive inspection of the HVAC system with upgrade to a higher efficiency filter [11] and use of an air purifier equipped with a HEPA filter. Despite significant reduction in PM, the filters offer no protection against hazardous gases, so inhabitants must remain vigilant [3, 11]. The ALA and EPA also recommend designating a “clean room” where an air filter is placed, and damp towels may be placed against window and door edges for times of extreme air pollution [11, 21]. It is also recommended to refrain from vacuuming or burning anything indoors including cigarettes or candles [21].

Evacuation may be necessary in extreme conditions to avoid direct dangers of flames. Evacuation planning is
Fig. 2 The graphics emphasizes that preemptive wildfire education, preparation, and knowledge of current information are crucial in taking appropriate action during a wildfire event. Evacuation, strictly indoor activity, or limited outdoor activity may be advised during an active wildfire pending proximity to the fire and air quality index which will be continually updated by local news sources and AirNow.gov.

paramount due to challenges such as increased cost, uncertain duration, and persistent air pollution despite significant distance from the fire. Furthermore, dense air pollution may cause poor visibility potentially causing traffic accidents. For those actively involved in extreme conditions in the immediate wildfire area such as firefighters, adequate personal protective equipment, hydration, rest, and psychological support are needed [3]. Continued use of N95s is needed even in cleanup efforts while managing wildfire ash [21].

Certain populations are at higher risk for health complications because of exposure to air pollution from wildfires. These at-risk populations include outdoor workers, children, elderly persons, pregnant women, and patients with chronic lung disease, and CV disease [1], and diabetes [23]. These sensitive groups are advised to strictly adhere to public advisories and consider physician consultation prior to a wildfire due to potential exacerbations of underlying disease [11, 21]. Physicians may educate patients regarding exacerbation symptoms and medication to have immediately available for emergency use [11]. It remains critically important that all healthcare professionals including physicians, nurses, and health educators deliver a consistent message of strict adherence to public advisories during wildfires and recommended at-home interventions [2]. At-risk populations should also be excluded in cleanup activities particularly in areas where hazardous waste may be burned [21].

Actions for Physicians

Although generalized information is readily available for the public, little is published regarding preemptive counseling or post-exposure treatment for patients with specific pulmonary diseases aside from avoiding, preparing for, and treating exacerbations. Furthermore, there are no current recommendations regarding surveillance imaging or pulmonary function testing for individuals with high intensity or recurrent exposure to wildfire air pollution despite evidence for increased incidence of lung cancer or decreased lung function [2]. Table 2 summarizes current recommendations for physicians supported by national health organizations and medical societies.
Conclusion

Worsening wildfires pose a persistent risk to human health. Public policy to address climate change is needed as projections indicate that small reductions in global temperature may positively impact mortality, morbidity, environmental impact, and overall cost savings [3]. Further investigations of effective public interventions to minimize climate impact are needed. Meanwhile, ongoing research is also necessary to learn how composition of wildfire smoke and duration of exposure impact long-term health outcomes, particularly for those with chronic lung disease. This research may be translated to actionable public health interventions and physician-based approaches during wildfire events [2]. From a global perspective, more information on wildfire smoke exposure and subsequent health impacts are greatly needed to study populations in developing areas frequently facing wildfire such as Africa and Southeast Asia which are underrepresented in current literature [1] and experience a disproportionate wildfire-related mortality [6].

The growing threat of wildfires is creating alarm within the medical community leading to publications in high-impact journals such as NEJM in 2020 and published workshop proceedings by the ATS in 2021. Further, climate change is a widely accepted cause of worsening wildfires; however, Abatzoglou and Williams in 2016 demonstrated that human-driven climate change is responsible for nearly half of all acres burned in recent decades. As clinicians caring for patients with lung disease, it is critical to remain informed of newly surfacing research findings, prevention strategies, management recommendations, and evolving legislation that can highly impact our patients.

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Compliance with Ethical Standards

Ethics Approval Ethical approval was not required because this study retrieved and synthesized data from already published studies.

Conflict of Interest The authors declare no competing interests.

Human and Animal Rights and Informed Consent This article does not contain any studies with human or animal subjects performed by any of the authors.

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