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The effect of wildfires on asthma and allergies

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Abstract

Climate change is a major driver of the frequency and severity of wildfires due to extended periods of drought and hotter, drier weather superimposed on the legacy of fire suppression in the Mountain West of the U.S. In recent years, increased wildfire smoke is negating the improvements in air quality made by clean energy transitions. Wildfire smoke is a complex mixture of gases and solids, a chief constituent of which is fine particulate matter (PM2.5). PM2.5 exposure is associated with adverse respiratory outcomes, including exacerbations of asthma and chronic obstructive pulmonary disease (COPD). In the face of increasing wildfire smoke exposures, it is critical that adaptation and mitigation strategies are put in place to minimize health effects. Individual strategies include modifying behavior and creating clean air spaces in homes to avoid wildfire smoke exposure. Community strategies include regulations promoting fire-resistant buildings and landscaping, establishing wildfire monitoring and alert systems, safe clean spaces where individuals can minimize wildfire smoke exposure, evacuation routes, and health care response teams. Mitigation to prevent wildfires include forest management and establishing monitoring systems and protocols to control forest fires in the wildland urban interface (WUI) before they increase in size and intensity. Research into understanding the mechanism by which wildfire smoke mediates adverse health effects can inform guidelines to further mitigate its health effects.

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Keywords

wildfire; climate change; respiratory health; climate justice; mitigation; prevention

Introduction

Climate change has become a major driver of the frequency and severity of wildfires because of hotter, drier weather, including extended periods of drought. The frequency of catastrophic wildfires around the world has more than doubled during the past two decades.[1] Fire seasons have become longer in many countries and catastrophic wildfires have occurred in Australia, Canada, Chile, Greece, Portugal, Russia, Spain, and the United States. The number of acres burned per year in the U.S. has more than doubled since 2000.[2] The legacy of fire suppression in the U.S. is an important contributor to the risk of catastrophic wildfires. Wildfire emissions are a complex mixture that includes particulate matter (PM), carbon dioxide, water vapor, carbon monoxide, nitrogen oxides, polycyclic aromatic hydrocarbons (PAHs) and other organic compounds as well as toxic gases such as acrolein, benzene, and formaldehyde.[3] Fine particulate matter (PM <2.5 microns in diameter) in wildfire smoke can travel long distances and dramatically decrease air quality in regions far downwind from catastrophic fires. When catastrophic fires overrun areas in the wildland urban interface (WUI), which is the area where buildings and wildland vegetation meet or intermingle, emissions become even more hazardous as manmade materials in buildings and motor vehicles burn and generate toxins such as phosgene, hydrochloric acid, hydrogen cyanide, and heavy metals.[4] The devastation of Paradise in California (2018) and Lahaina on Maui (2023) remind us of the extreme dangers of WUI fires.

Exposure to wildfire smoke is highest in people living immediately downwind from fires and among wildland firefighters who spend long hours working on fire lines, for whom there is currently no practical respiratory protective gear available. Outdoor workers in agriculture and construction jobs requiring heavy physical exertion also have high exposures. Exposures to wildfire smoke are distributed inequitably across communities. In the U.S., between 2011-2021, annual exposure to heavy smoke days increased 358% for census tracts with the highest social vulnerability index (e.g., low-income communities of color).[5] Indigenous populations may have the highest burden of wildfire smoke exposure.[6] Young children are at greater risk for adverse effects due to their higher minute ventilation relative to their weight and still developing organ systems. They also may experience exposures at school and daycare.[7] Older adults, especially those with preexisting cardiopulmonary disease, are at increased risk for exacerbations of underlying medical conditions. Pregnant women and their developing fetuses are also considered to be at increased risk for adverse birth outcomes and potential adverse fetal programming leading to post-natal health problems.

Emissions from wildfires depend on both type of fuel and burn conditions. While the composition of wildfire smoke varies, one constituent that is always present is PM2.5 (particles 2.5μm or smaller in diameter), including its subcomponent, ultrafine particles (<0.1μm or smaller in diameter). PM2.5 is the best studied and most readily measured pollutant in wildfire smoke and is used to assess air quality and risk to public health. In the

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U.S., up to 25% of PM2.5 has been attributed to wildfire smoke, with up to 50% in some Western regions,[8] thereby negating the reductions in non-wildfire PM2.5 due to cleaner motor vehicles and electricity generation.

Effects of wildfire smoke exposure on respiratory health

Exposure to high levels of PM2.5 from wildfires is associated with adverse respiratory effects, such as exacerbations of asthma and chronic obstructive pulmonary disease (COPD). The evidence for asthma exacerbations is robust, with most studies of community exposures to poor air quality from wildfire smoke associated with increased symptoms and/or health care utilization.[9] A recent review estimated the association between short-term exposure to wildfire smoke and acute health care utilization for asthma at a risk ratio of 1.10 (range, 1.07–1.68) per 10 μg/m3 increase in wildfire PM2.5.[10] All patients with asthma are considered at increased risk, but women and those of low socioeconomic status (SES) may be more susceptible.[11] When smoke from Quebec wildfires blanketed New York City in June 2023, emergency department visits for asthma syndrome increased by 44%.[12] The risk for ED visits was highest in the second day of the smoke wave and affected individuals aged 5 to 64 years. PM2.5 from wildfire smoke may be more potent at adversely affecting respiratory health than PM2.5 from other sources (e.g., traffic or industrial). A study of pediatric health care utilization in San Diego County found wildfire-specific PM2.5 to be approximately 10 times more harmful to children's respiratory health than PM2.5 from other sources, particularly for children ≤5 years of age.[13] The risk of new-onset asthma with exposure to high concentrations of wildfire smoke is a theoretical possibility but has not been well studied, although a post-fire increase in asthma diagnosis was reported for firefighters exposed to the 2016 WUI Fort McMurray fire in Alberta, Canada.[14]

Although there is evidence that exposure to wildfire smoke is associated with COPD exacerbations,[9] it is not as robust as for asthma.[15] A recent study from Utah showed relatively strong association between short-term increases in PM2.5 during wildfire season and hospitalizations for asthma, but a weaker association with hospitalizations for COPD.[16] Similar to asthma, low SES may be a risk factor for wildfire smoke-induced COPD exacerbations.[17] There is also evidence that wildfire smoke increases the risk for acute respiratory tract infections, but the evidence is mixed.[15] Notably, a study of exposures to wildfire-specific PM2.5 in the U.S. Pacific Northwest showed an association with COVID-19 infection and mortality.[18]

There is a paucity of evidence on long-term respiratory effects of exposure to wildfire smoke, but based on what is known about chronic exposure to non-wildfire PM2.5 and lung function, young children may be at risk for a decreased growth trajectory.[19] This statement comes with the caveat that wildfire smoke exposures are recurrent rather than chronic. Occupational exposure of wildland firefighters has been associated with short-term and across fire season decreases in spirometric lung function and increased airway hyperreactivity,[20] but long-term effects on lung function are inadequately studied. In the cohort of firefighters (both structural and wildland) who fought the Fort McMurray fire, higher exposure to PM2.5 was strongly related to a decrease in forced expiratory volume (FEV1) and forced vital capacity (FVC) but not to FEV1/FVC measured weeks to months

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after the fire.[15] Rhesus monkeys have lungs very similar to human lungs so the long-term effects of exposure to high concentrations of wildfire smoke in a cohort of infant monkeys is of relevance given the difficulty of conducting such a study in humans. A decrease in lung function was observed in 3-year-old (adolescent) rhesus monkeys who were infants during the 2008 California wildfires; such a decrease was not observed in an unexposed cohort born a year later.[21]

Although there have been no published studies of a link between exposure to wildfire smoke and exacerbations of allergic rhinosinusitis, evidence from studies of non-wildfire PM2.5 suggests that such an association may exist.[22] A study of clinic visits for patients with atopic dermatitis showed that visits for exacerbations increased following exposure to wildfire smoke during the Camp Fire in 2018 compared to periods without exposure.[23]

Mechanisms

The mechanism by which exposure to wildfire smoke results in poor health outcomes is an active area of investigation but may be similar to those previously identified for ambient PM exposure. The epithelial barrier hypothesis suggests that wildfire smoke damages the epithelial barrier of the skin, lungs and gastrointestinal tract, altering the microbiome and initiating events leading to oxidative stress, systemic inflammation, immune dysfunction and epigenetic changes.[24, 25] Ultimately, repeated exposures to wildfire smoke result in chronic disease.

More specifically, while a major function of the mucosal barrier is to prevent the movement of toxic compounds, such as PM, from the apical to basal surface, PM may affect the integrity of the airway epithelial barrier by degrading tight junction proteins such as occludin, claudin-1, and Zonula Occludens 1 (ZO-1) through reactive oxygen species (ROS)production.[26] This disruption in epithelial homeostasis by PM and other environmental toxins causes increased epithelial barrier permeability, allowing PM to enter the subepithelial tissues.[27] In addition, activation of the pattern recognition receptors of the epithelial cells trigger immune responses, such as the release of proinflammatory cytokines, causing alterations in Th2 and Th17 responses.[27] Oxidative stress induced by PM drives inflammatory mediators key in macrophage activation, transcriptional responses and gene expression that increase the risk of morbidity and mortality associated with infections like SARS-COV-2.[28] PM exposure also activates the aryl hydrocarbon receptor (AhR), leading to alarmin release and IL-17 and IL-22 production.[29] Overall, exposure to PM, which includes wildfire smoke. initiates multiple pathways that are associated with immune dysfunction leading to both acute and chronic health outcomes.

There have been limited field studies which focus on the mechanisms associated with exposure to wildfire smoke, especially in regard to long-term impacts. Studies involving firefighters show increased biomarkers of inflammation (e.g., soluble adhesion molecules, tumor necrosis factor, interleukins, and leucocyte count)[30] and oxidative stress[31], using hydroxylated polycyclic aromatic hydrocarbons in urine as a biomarker to demonstrate recent smoke exposures.[32] An air pollution study examining metadata from three independent reports using genome-wide data identified potential biological pathways that associate pollution exposure and health outcomes.[33] Specific for wildfire smoke exposure,

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DNA methylation changes 20-37 months after exposure occurred at 680 CpG sites, associated with the cumulative amount of time spent fighting fires but not dependent on the amount of time since the last fire.[34] Moreover, epigenetic age has also been indirectly associated with wildfire smoke exposure, with experienced firefighters (n=379) having greater epigenetic age acceleration compared to new recruits (n=100). Additional information is needed to identify the nature of the relationship between changes in methylation attributed to wildfire smoke exposure and the increased cancer rates observed in firefighters. Mechanistic studies in the general population are even more limited: During the San Francisco Bay area wildfires in 2020, non-outdoor workers had increases in numerous biomarkers after wildfire smoke exposure, including granzymes A, B, and H, IL-16, poly (ADP-ribose) polymerase 1 and von Willebrand factor.[35] In addition, teenagers exposed to wildfire smoke over 60 miles away from the source of the fire had an increase in inflammatory markers IL1-B and CRP in comparison to controls.[36]

Wildfire smoke impacts the respiratory system by acting as an irritant and contains allergens and pathogens, potentially inducing allergic airway sensitization. Sensitization may lead to the development of asthma, rhinitis and increased allergies. Consistent with the epithelial barrier hypothesis discussed above, smoke is thought to cause oxidative injury to the mucosal barrier. DNA methylation in peripheral leukocytes changes within hours of exposure to PM.[37] In subjects exposed to 234.0 μg/m^3 PM2.5 for 2 hours, DNA methylation changes in genes responsible for mitochondrial oxidative energy metabolism were observed in CD4$^+$ T helper cells.[38] However, gaps remain in understanding how wildfire smoke induces allergic airway sensitization and the mechanism by which it differentially impacts allergies, asthma and COPD. For example, IL-17 increases with wildfire smoke exposure, but it is also associated with steroid-resistant neutrophilic asthma.[39] As such, it is unclear whether exposure to wildfire smoke will be associated with or result in increased difficulty to control symptoms, especially in those with preexisting respiratory disease.[40]

Vulnerable populations and climate justice

Increased vulnerabilities due to socioeconomic factors are not fully considered and addressed in defining the populations shown to be at increased risk from the harmful impacts of exposure to wildfire smoke. Groups more at risk for all climate-related health impacts such as wildfire smoke include children, the elderly, patients with preexisting respiratory or cardiac diseases, pregnant women, outdoor workers, and historically overlooked populations including those who do not speak the primary local language, communities of color, newcomers, Indigenous and lower socioeconomic status communities.

Many historically overlooked populations also have decreased ability to prepare for and mitigate climate exposures. There are unequal burdens of wildfire emissions on communities of color and socioeconomically disadvantaged communities[41, 42] in part due to inequitable resource distribution.[43] Higher $PM_{2.5}$ concentrations have also been positively correlated with poverty and housing inequities[44] and people of color are more likely to live in areas of lower air quality regardless of income[45]. Given that air quality monitors are placed more frequently in areas of higher population density, those living in more rural areas, on reservations and in small towns have less access to accurate air quality information.

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Indigenous communities in Canada are more likely to live further from air quality monitoring stations and a recent study in the United States found that Native American and Alaska Native, multiracial, and non-Hispanic white populations were disproportionately exposed to wildfire smoke, with other constraints (housing, occupational, behavioral, economic) probably resulting in additional disparities.[6]

Ethnicity alone is a risk factor for vulnerability from smoke exposure. In the US, those in primarily Black, Hispanic, or Native American census tracts have a 50% greater vulnerability to wildfire.[41] Liu, et al.[46] found that risk of respiratory admission from wildfire smoke was significantly elevated for women versus men (10.4% vs. 3.7%) and blacks versus whites (21.7% vs. 6.9%), but no difference when comparing lower-education versus higher-educated counties (12.7% vs. 6.1%). This is in contrast, however, to a survey in Canada which found that the highest level of education obtained is an important factor in determining whether protective action is taken during a wildfire smoke exposure.[47] Other studies have reported less consistent results regarding variation in smoke exposure by socioeconomic status, at least in the southern US.[48] Overall, vulnerability is thought to be intensified by the presence of a climate threat such as a wildfire, but multiple climate threats (e.g., additionally heat and drought) occurring simultaneously compound their vulnerability and pose more severe consequences.

Adaptation to increased air pollution due to wildfire smoke

Patients and physicians need to work together to reduce health risks of wildfire smoke exposure (Figure 1). There are concerted efforts to detect and report wildfire smoke so that appropriate adaptive actions can be taken. Air quality is communicated to the public through the Air Quality Index (AQI) (e.g., USA's AirNow[49]), or similar platforms (e.g., Canada's Air Quality Health Index (AQHI).[50] These regionally accurate but expensive systems may miss local heterogeneity and underserved areas, which frequently bear the brunt of wildfire smoke.[51] Microsensors are a less accurate but relatively inexpensive option to measure PM2.5. Merging these data into dashboards that support interpretation is an attractive option to fill current reporting gaps.[52-54] The US EPA AirNow.gov website now has a Fires pull down menu with a Fire and Smoke map that uses microsensor data to report community-level exposures in many areas of the US and Canada. Microsensors also have the potential to increase public knowledge through citizen science.[55] Barriers to public risk perception include comprehension, unclear sources, and variations between resources (e.g., AQI).[56-58] Solutions include employing multiple media trusted by different demographics and providing clear, accurate, consistent information and actionable advice.[59]

Avoidance: Limiting exposure to "as low as reasonably achievable" and avoiding co-exposures like heat are protective.[60] Staying indoors, minimizing strenuous activity, and rescheduling outdoor functions to a different date, unaffected location, or indoors, decrease smoke exposure.[60]

Personal respiratory protection: Masks can decrease smoke exposure, but studies on public use, especially in children, are limited. Due to their heterogeneity, cloth masks have limited known benefit.[61] Surgical masks can remove up to >90% of particulate matter

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(average ~50%), but air can bypass them and study results are highly variable.[61, 62] Respirators (N-95 or equivalent) can remove 95% of particles ≥0.3 μm when adequately fitted. Even without fit testing, respirators offer more protection than other options, including for children.[63] Surgical masks and respirators are well tolerated with minimal negative physiological effects, although breathing resistance may increase during strenuous activities.[64] The most common negative effect is discomfort.

Other actions to minimize risk: People with respiratory and cardiac diseases can minimize their risk of exacerbation from wildfire smoke by using their control medications as prescribed. Keeping a medication list, exacerbation plan and supplies available can ensure accessibility in case of service disruptions or evacuation.[60]

Prevention, planning and action

Considerable overlap exists between community and household strategies to prevent, prepare for and manage wildfires. Central coordination between jurisdictions promotes effective management, resource allocation and cost efficiencies; supplementary local initiatives address unique local needs, together resulting in resilient communities.[65, 66]

Regulation: Regulations can ensure that buildings, developments, and activities minimize fire risk, adopting resources that promote wildfire and smoke resistance for homes and commercial buildings.[67] Firewise USA[68], FireSmart Canada[69], and the Federal Emergency Management Agency (FEMA)[70] provide information on fire-resistant building materials and clearing land of flammable materials. Outdoor workers and housing-insecure people have higher exposures; barriers to communication, harm mitigation (e.g., masks) and safe spaces and therefore may require additional protections.[71] Power disruptions may incidentally occur during wildfires or may be employed to decrease risk during severe weather events.[72-74]

Safe spaces: Clean air and cooling shelters are necessary in communities facing concomitant wildfire smoke and extreme heat.[75, 76] Communities can leverage existing resources (e.g., malls, community centres). Air conditioning and filtration upgrades may be required. Closing doors and windows of weatherproofed homes and buildings can limit smoke migration indoors.[76] Air systems should have high efficiency particulate air (HEPA) or minimum efficiency reporting value (MERV)-8 or higher rated filters and be set to recirculate. Without central air filtration, a “clean room” with few windows and doors can be created using a portable HEPA air filter, with fans or air conditioning for cooling.[77] Vehicles should be closed; however, heat and carbon monoxide accumulation may require intermittent window opening. Children and pets should never be left in a vehicle, and vehicles should never be used as shelters.[78]

Evacuation: Evacuation routes and emergency alert systems should be reliable and universally accessible. Household emergency kits should include non-perishable food, water, masks and a “go-bag” with essential documents and medications. Plans should consider vulnerable family members, pets, communication and reunification strategies, and ensure access to evacuation orders.[70, 71] Preparing evacuees and host communities for

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social, physical and mental health challenges includes housing, supplies, healthcare access, socioeconomic disruptions and equitable access for vulnerable people.[65, 71, 79]

Health systems: Health systems benefit from multilevel, coordinated response plans including training, capacity for mass casualties and wildfire-related injuries, and resumption of services.[79, 80] Evacuating healthcare facilities presents unique challenges, particularly for isolated regions. Disaster planning resources are available for health systems and providers.[81]

Mitigation to reduce wildfire frequency and severity

Mitigation to reduce wildfire frequency and severity consists of monitoring systems to predict wildfires, preventative measures, and firefighting resources and expertise to control ongoing wildfires (Table 1).

Preventing and predicting wildfires: Forest management includes fuel reduction through thinning, prescribed burning, and husbandry of fire-resistant trees.[82] Cross-boundary resource management between jurisdictions promotes consistent strategies and minimizes human resource and financial expenditures.[83] Modeling fire risk using existing data and real-time weather information can help channel limited resources to high-risk areas, prioritizing lives and infrastructure.[84]

Firefighting: Wildfire fighting encompasses detection, response, containment and control.[85] Direct attacks remove unburned fuel and suppress fires, controlling the fire perimeter. Indirect suppression requires fire behavior prediction to allow fuel removal and retardant application ahead of the fire, leveraging landscape features like low-fuel terrain.[86] Resources include personnel, water and fire retardant provided by ground or air, and heavy equipment and prescribed burns to create fuel breaks. Satellites and drones allow for observation in dangerous areas; drones and robots are also being designed to deliver fire retardants.[86-88] Local government, available resources, expertise, and landscape influence variations in firefighting approaches. [85]

Conclusion

Wildfires and wildfire smoke, increasingly prevalent due to and often exacerbated by other aspects of climate change, negatively impact health and infrastructure. Vulnerable populations include children, people with increased fragility secondary to age, pregnancy or cardiorespiratory disease, and marginalized populations. A multifactorial approach to limit and control fires, evacuate impacted communities and prevent smoke exposures at community and individual levels is needed to control and mitigate long-term risk and harm.

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Abbreviations:

AhR	Aryl hydrocarbon receptor

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AQHI	Air Quality Health Index
AQI	Air Quality Index
COPD	Chronic obstructive pulmonary disease
FEMA	Federal Emergency Management Agency
FEV1	Forced expiratory volume
FVC	Forced vital capacity
HEPA	High efficiency particulate air
MERV	Minimum efficiency reporting value
PAHs	Polycyclic aromatic hydrocarbons
PM	Particulate matter
ROS	Reactive oxygen species
SES	Socioeconomic status
WUI	Wildland urban interface
ZO1	Zonula Occludens 1

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CME EXAM

Learning objectives:

1. To learn about the major components of wildfire smoke and those most damaging to respiratory health
2. To learn about the major mechanisms by which wildfire smoke exposure cause allergies and asthma
3. To understand which populations are most vulnerable to adverse health effects of wildfire smoke
4. To learn how individuals and communities can adapt to expected increases in wildfire smoke exposure
5. To learn how individuals and communities can prevent, prepare, and manage future large wildfires

Questions:

1. Fine particulate matter, which is a major component of wildfire smoke and capable of entering into the blood stream, refers to particles that are:
   - **a.** ≤ 100 μm in diameter.
   - **b.** ≤ 10 μm in diameter.
   - **c.** ≤ 2.5 μm in diameter.
   - **d.** ≤ 1.0μm in diameter

   Explanation: Fine particulate matter, also termed PM2.5, can reach the alveoli and then penetrate into the blood. Larger particles mostly remain in the nasal cavities and upper respiratory tract.

   Reference: https://www.epa.gov/pm-pollution/particulate-matter-pm-basics
2. Which of the following statements is true regarding exposure to wildfire smoke
   - **a.** All communities are equally vulnerable to the health effects.
   - **b.** Adolescents have greater risk of adverse effects than younger children.
   - **c.** The composition of smoke from urban interfaces are more toxic than those from forests.
   - **d.** In the U.S., less than 10% of PM2.5 has been attributed to wildfire smoke.

   Explanation: Smoke from wildfires that originate from wildland urban interfaces (WUI) are more hazardous as manmade materials in buildings and motor vehicles burn and generate toxins such as phosgene, hydrochloric acid, hydrogen cyanide, and heavy metals.

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Reference: Holder AL, Ahmed A, Vukovich JM, Rao V. Hazardous air pollutant emissions estimates from wildfires in the wildland urban interface. PNAS Nexus 2023; 2:pgad186.

3. Properly fitted respirators (N-95 or equivalent) can remove what percentage of particulates?

- **a.** 95% of particles ≥0.3 μm
- **b.** 95% of PM10
- **c.** 90% of PM2.5
- **d.** < 80% of PM10

Explanation: N95 respirators are named for their ability to filter 95% or more of tiny 0.3-μm particles.

Reference: Dugdale CM, Walensky RP. Filtration Efficiency, Effectiveness, and Availability of N95 Face Masks for COVID-19 Prevention. *JAMA Intern Med.* 2020;180(12):1612–1613. doi:10.1001/jamainternmed.2020.4218

4. Which of the following is a means of adapting to wildfires?

- **a.** Prescribed burns
- **b.** Use of HEPA filters
- **c.** Removal of unburned fuel from forests
- **d.** Retardant application

Explanation: Use of HEPA filters is an adaptive strategy to reduce exposure to wildfire smoke and decrease risk of adverse health effects. Prescribed burns, removal of unburned fuel from forest floors and retardant application are mitigation strategies for preventing or decreasing severity of wildfires.

5. Which of the following statements is true?

- **a.** Lower socioeconomic communities are closer to wildfire urban interfaces.
- **b.** Power disruptions are employed to decrease wildfire risk during severe weather events.
- **c.** Women have higher exposures to wildfire smoke than men.
- **d.** Surgical masks and N-95 masks are equally effective in decreasing wildfire smoke exposure.

Explanation: As high-voltage lines can spark fires, under severe weather conditions when risk of wildfire is very high, some utilities may make the difficult decision of shutting off power.

Reference: Tim CL. Shutting off power to reduce wildfire risk isn't a simple decision | PreventionWeb. Available

from https://www.preventionweb.net/news/shutting-power-reduce-wildfire-risk-windy-days-isnt-simple-decision-energy-expert-explains.

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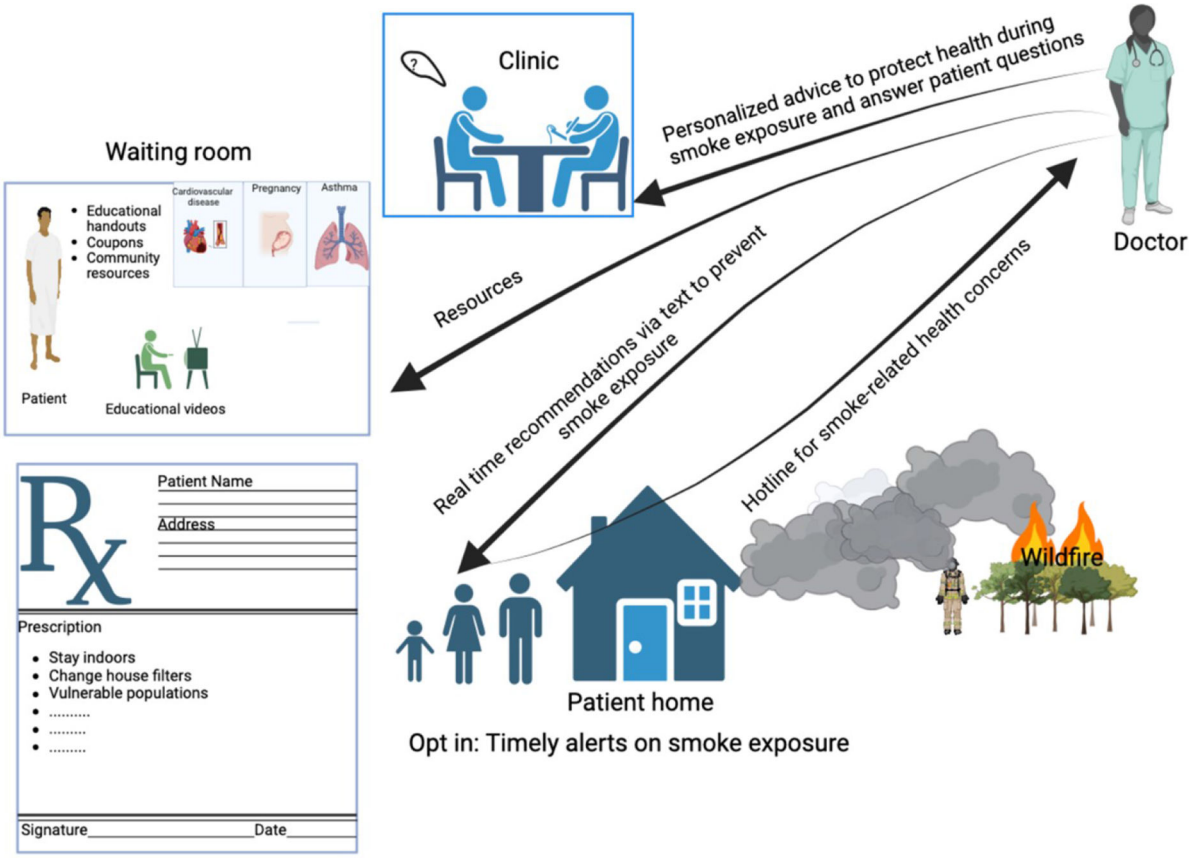


Figure 1:

Preventing adverse health effects of wildfire smoke exposure through education, timely alerts, real-time recommendations, and personalized advice.

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Table 1:

Organized response to wildfires

Group	Awareness	Preparation	Response
Individuals	• Air quality • Emergency alerts	• Clean air spaces • Reduce fire risk • Evacuation kit and plan	• Reduce exposures • Update medications • Follow emergency alerts
Communities	• Air quality monitors • Wildfire reports • Connection with resources	• Development and building code • Activity regulations • Clean air shelters • Evacuation routes and planning • Healthcare surge planning • Emergency alert systems • Repatriation strategies	• Emergency alert systems • Support vulnerable people • Healthcare surge capacity • Power and infrastructure • Evacuation • Leverage government supports • Post-wildfire repatriation planning
Health systems	• Monitor local conditions	• Specific training • Practice management • Surge capacity • Health facility evacuation planning • Restoration of service planning	• Activate surge protocols • Patient evacuation • First responder care • Facility closure • Post-wildfire restoration of service
Wildfire response	• Monitoring, early detection	• Multilevel resource and tactical planning • Equipment access • Personnel training	• Activate wildfire protocols • Monitoring • Deploy personnel, equipment • Prevent spread