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REVIEW ARTICLE

Addressing Environmental Factors in COPD: The Role of HEPA Filters in Indoor Air Quality

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Abstract

COPD is a major public health issue globally, resulting in significant morbidity, loss of productivity, and increased health expenditure. Air pollution is considered the primary factor leading to the development and progression of COPD. While the role of outdoor air pollution was well outlined, studies have looked at how indoor air quality and indoor air pollution can cause or worsen the disease. Even though we know that outdoor air pollution has contributed to COPD, the question remains: how do outdoor air pollution and an increased outdoor air pollution load impact indoor air quality, and how will that impact COPD development and progression, and can indoor air filters tackle that? This narrative review focuses on air pollution, the air quality index, and the impact of environmental pollution on indoor air quality and COPD. We also describe the role of the HEPA filters in tackling indoor air pollution, their mechanism, and their impact on COPD and control of indoor air pollution.

Introdution

Chronic Obstructive Pulmonary Disease (COPD) is a significant global public health concern, with air pollution identified as a major contributor to its development and exacerbation, accounting for approximately 50% of the total attributable risk [1]. While outdoor air pollution's association with COPD is acknowledged, increasing attention is being paid to indoor air quality, where more time is spent by COPD patients than their age-matched counterparts, as highlighted by the National Human Activity Pattern Survey (NHAPS) [2,3]. Despite the safety standards and limits for air pollutants established by the National Ambient Air Quality Standards, recent studies indicate that the risk of hospitalization per unit increase in ambient air pollutant exposure is highest at levels well below the current standards. This is particularly problematic for patients who spend significant time indoors, as they are more susceptible to indoor pollutants [1,4,5]. In this review, we aim to establish the relationship between pollutants and COPD development or exacerbation and explore the potential of air filtration systems, particularly High-efficiency Particle Air (HEPA) filters, as essential devices in COPD management.

Discussion

Air pollutants are broadly divided into two main categories: outdoor and indoor air pollutants. Outdoor air pollutants, such as particulate matter (PM), nitrogen dioxide (NO2), sulfur dioxide (SO_2), ozone (O_3), carbon monoxide (CO), and volatile organic compounds (VOCs), arise from industrial emissions, vehicle exhaust, and fossil fuel combustion [6]. Conversely, indoor air pollutants originate from tobacco smoke, pet dander, and volatile organic compounds (VOCs) emitted by building materials and cleaning products [7]. These pollutants can exacerbate COPD symptoms by inducing inflammation, oxidative stress, and respiratory irritation. Particulate matter can infiltrate the lungs, instigating inflammation, oxidative stress, and tissue damage. Other air pollutants can provoke various inflammatory pathways, disrupt the equilibrium of respiratory cells, and weaken lung defense mechanisms, resulting in respiratory symptoms and exacerbations. In contrast, VOCs, alongside other indoor pollutants, can exacerbate COPD symptoms by

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irritating the airways and instigating bronchospasms. The distribution of outdoor pollutants varies based on geographic location and human activities, with urban areas experiencing higher concentrations due to industrialization and vehicular traffic. At the same time, rural regions face pollution from agricultural practices and urban emissions [8]. Conversely, indoor pollutant sources are primarily influenced by human behavior and product usage within enclosed spaces.

The role of PM 2.5

A systematic review by Chen J. and Hoek G. in 2020 found a supra-linear relationship between Particulate Matter (PM)2.5 and non-accidental mortality, with a meta-analytical effect estimate of RR 1.08 (95% CI: 1.06-1.09) per 10 microgram/m^3 PM2.5 [5]. PM, even at low levels, exacerbates COPD symptoms and decreases patients' quality of life, as evidenced by studies linking indoor PM to respiratory morbidity among former smokers with COPD [9,10]. Persistent exposure to high PM2.5 concentrations induces inflammation, oxidative stress, immune dysfunction, airway epithelial structure and microbiome alterations, all leading to increased COPD exacerbations [9,11]. Sun Y, et al. conducted a study on short-term exposure to low-level ambient fine particulate matter among insured adults in the United States, encompassing counties with PM2.5 levels well below the World Health Organization (WHO) standard of 15 µg/m^3. The study found a significant association between PM2.5 exposure and respiratory disease emergency visits, particularly among young and middle-aged adults. Additionally, they evaluated changes in PM2.5 and its impact on various morbidity outcomes. Notably, when examining the data for days with PM2.5 levels exceeding 15 µg/m^3 against those with lower levels, there appeared to be a suppression of impact. This observation challenges the notion of a "safe limit" for particulate matter [12].

Further supporting this skepticism, another study by Wei Y et al. investigating chronic exposure to PM2.5 and risks of hospital admissions for major cardiovascular diseases (CVD) revealed a monotonically increasing exposure-response curve with no discernible safe threshold for overall cardiovascular health. Notably, the risk of hospital admission for composite CVD increased from 2.59% to 3.35% as PM2.5 exposures rose, highlighting the enduring impact on the cardiovascular system. Consequently, reducing PM2.5 concentrations to WHO standards from the national US average could substantially improve cardiovascular outcomes [13].

How have wild fires in the recent times affected air quality?

The escalation of wildfires in recent times also raises significant concern, notably due to their profound effect on air quality and public health. Burning organic matter during wildfires releases various pollutants, including PM, CO, NO2, and VOCs [14]. While the evidence linking wildfire smoke exposure to COPD exacerbations is less robust compared to asthma, studies have shown a significant correlation between wildfire occurrences and spikes in emergency room visits and hospitalizations for respiratory ailments, including COPD exacerbations and worsening respiratory symptoms [14-19]. Magzamen, et al. identified that a ten µg/m^3 increase in wildfire PM2.5 is associated with more significant COPD hospitalizations three days after the exposure [20]. However, the worsening symptom scores returned to baseline after exposure removal [21]. The primary public approach to counter the effects of wildfire smoke involved closing windows and staying indoors. However, indoor particulate matter monitors detected significantly high levels of indoor smoke during these events [22]. Therefore, interventions aimed at improving indoor air quality, including air filters such as HEPA filters, need to be investigated further as they hold promise for mitigating the impact of outdoor air pollution on COPD outcomes.

The role of HEPA filters

HEPA filters are recognized as crucial in mitigating indoor air pollution and improving COPD outcomes. HEPA filters can remove 99.97% of particulate matter, including pollutants such as PM2.5, smog, and bacteria, with a size over 0.3 µm. The 0.3-micron specification corresponds to the worst-case scenario. The use of the worst-case particle size is in accordance with the worst-case efficiency rating (i.e., 99.97% or better for all particle sizes) as per the United States Environmental Protection Agency and the United States Department of Energy [23]. HEPA filters utilize four pollutant-trapping mechanisms- interception, inertial impaction, diffusion, and sieving. Diffusion removes the most minuscule particles, whereas the other three mechanisms are more effective in filtering large particles [24]. Portable air cleaners equipped with HEPA filters provide a practical and accessible means of reducing indoor pollutant concentrations. Cubic Feet of Air Processed per Minute (CFM) rate, Clean Air Delivery Rate (CADR), and Air Changes per Hour (ACH) are measures to assess the effectiveness of air filters. Mølgaard, et al. assessed the air filter efficacy by comparing particle filters, HEPA filters, Ionization (ION), and Electrostatic Precipitator (ESP) for particles between 0.012 and 10 micrometers and found that HEPA air filters demonstrated the highest efficiency in particle removal (as indicated by the highest CADR) and maintained consistent effectiveness across various particle sizes [25].

Randomized clinical trials and meta-analyses have described the effectiveness of air cleaners with HEPA and carbon filters in reducing indoor PM2.5 concentrations by 61% and a 4% reduction in NO_2 concentrations at six months in homes of former smokers with COPD compared to sham air cleaners [10,26]. HEPA filtration devices used in the bedroom for particulate matter filtration resulted in significant improvements in small airway functions in children without eosinophilic airway inflammation and airway mechanics and function [27]. However, the studies evaluating the impact of HEPA filters on lung function revealed mixed results. Park, et al. found that changes in FEV1 after air filter use had a pooled estimate of -1.71% change in predicted FEV1, with no significant improvement observed with longer air filter use duration (more than six months) [26]. The Beijing Indoor Air Purifier Study (BIAPSY) employed a randomized crossover intervention to assess the impact of portable HEPA filters on indoor air quality and systemic inflammation in elderly residents. Participants used either active HEPA filters or sham filters for two-week intervals. The findings demonstrated a significant reduction in indoor PM2.5 concentration following active filtration, with ten-day averages decreasing from 60 ± 45 $\mu g/m^3$ to 24 ± 15 $\mu g/m^3$. Similarly, black carbon levels exhibited a notable decline, dropping from 3.87 ± 1.65 $m^{-1} \cdot 10^{-5}$ to 1.81 ± 1.19 $m^{-1} \cdot 10^{-5}$. This reduction extended to significant components of PM2.5, including water-soluble organics, nitrate (NO_3^-), sulfate (SO_4^{2-}), zinc (Zn^{2+}), lead (Pb^{2+}), and potassium (K^+), which saw decreases ranging from 42% to 63%. Furthermore, the study observed a significant reduction in systemic inflammation as measured by interleukin-8 (IL-8) levels. The total participant group experienced a 58.59% reduction in IL-8 (95% CI: -76.31, -27.64) with active filtration compared to sham filtration [28].

The reduction of respiratory symptoms is a crucial goal in COPD management. A randomized clinical trial by Hansel, et al. evaluated the impact of HEPA air cleaners on respiratory health outcomes in former smokers with COPD and found no significant improvement in health-related quality of life in the intention-to-treat analysis. However, subgroup analyses revealed promising results, particularly among individuals with higher adherence to air cleaner use, showing significant improvements in respiratory symptoms and reduced exacerbation [10]. Additionally, HEPA air purification has demonstrated the potential to reduce concentrations of inflammatory biomarkers associated with cardiovascular disease, indicating broader health benefits [29]. Conversely, Blagev, et al., in a randomized, blinded, crossover-controlled trial investigating the association of respiratory symptoms with HEPA filter use, did not find a significant difference in St. George's Respiratory Questionnaire for COPD (SGRQ-C), COPD Assessment Test (CAT), or Modified Medical Research Council Dyspnea Scale (mMRC) scores, suggesting a limited impact on respiratory symptoms. This negative finding underscores the variability in study outcomes and emphasizes the need for further research, including meta-analyses to elucidate the role of HEPA filters in COPD management comprehensively [30]. Furthermore, the ongoing Air Purification for Eosinophilic COPD Study (APECS) by Saeed, et al. at Beth Israel Deaconess Medical Center aims to evaluate whether reducing home PM exposure through HEPA filtration improves respiratory health in eosinophilic COPD patients, acknowledging the unique characteristics of this subgroup [31].

Conclusion

In conclusion, implementing public health strategies to reduce air pollution exposure and improve indoor air quality, such as issuing air quality alerts and enhancing air filtration systems, holds significant promise in mitigating COPD exacerbations. Efforts to integrate high-efficiency air filters in public spaces show potential in reducing indoor pollutants and minimizing COPD risks. However, further studies, including ongoing trials like APECS, are necessary to assess the effectiveness and cost-effectiveness of HEPA filters across different COPD subtypes. Real-world impact will depend on availability, affordability, adherence, duration of use, and baseline pollutant subtypes, highlighting the need for continued research in this area. With further research to support its use, HEPA filters can arise as harmless armament in our battle against COPD.

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