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REVIEW

The role of air purifier in reducing indoor airborne particulate matter to improve respiratory health

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Abstract

Introduction: The recent surge in respiratory diseases has heightened concerns about air quality, particularly for individuals who spend most of their time indoors. Air purifiers, alongside good ventilation and self-protection are now among the preferred methods for ensuring clean and breathable air. **Discussion**: Reducing the levels of airborne pollutants is crucial for maintaining respiratory health, reducing the incidence of respiratory diseases, and preserving pulmonary function. Particulate matter (PM) serves as a key indicator of air quality. **Conclusion**: Air purifiers, such as those with High-Efficiency Particulate Air (HEPA) filters, are closely linked to improved air quality by effectively reducing particulate matter (PM), thereby offering long-term health benefits.

Keywords: air purifier, respiratory disease, particulate matter, HEPA

Introduction

The rise in respiratory tract infections due to air pollution and the COVID-19 pandemic, which required extended periods of indoor living and self-isolation, has significantly raised awareness about the importance of indoor air quality.[1] Poor air circulation and air quality can have a profound impact on human health leading to various health risks, such as cardiovascular events, and respiratory problems.[1] Therefore, developments regarding these issues are being studied to improve air quality.

Air purifiers, which are devices designed to filter airborne particulates and improve respiratory air quality, have gained widespread attention.[2] Nowadays, a variety of air purifiers are available, incorporating different technologies.[3] It is categorized into several types, such as high-efficiency particulate air (HEPA) filters, ionization air purifiers, and electrostatic precipitator (ESP) purifiers. Each type of air purifier has its own advantages and limitations. For instance, while ESP purifiers are cost-effective and easy to use, they are less efficient at filtering particulate matter compared to HEPA purifiers. Ionization air purifiers are popular due to their low noise output, whereas HEPA purifiers are considered the most effective for improving air quality. Selecting the right air purifier is crucial to achieve optimal indoor air quality.

Air particulates and their impact on health

Air quality is determined by the content of airborne pollutant particulates. According to the U.S. Environmental Protection Agency (EPA), pollutants in the air are classified into six main categories: ozone (O3), particulate matter (PM 2.5µ, 2.5-10µ, and PM 10µ), nitrogen dioxide (NO2), sulphur dioxide (SO2), carbon monoxide (CO), and lead (Pb).[4] Larger particulates, sized 10µ, generally cannot penetrate the respiratory tract. However, particulates sized 2.5-10µ can penetrate the upper respiratory tract, and particulates smaller than 2.5µ can reach deeper into the lower respiratory system, including the alveolar sacs, in which they may cause significant health issues. As a result, the PM2.5 concentration is used as an indicator for assessing air quality.

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To monitor air pollution levels, air quality index (AQI) is used in several countries, including Indonesia.[4,5] The AQI assigns a numerical value to the level of air pollution, where a higher value indicates worse air quality and greater potential health risks. This index helps the public understand the level of pollution and its impact on health.[5]

Pollutants and particulates can be found both outdoors and indoors. While the types of particulates and pollutants circulating indoors and outdoors are similar, there are significant differences between the two based on their concentrations. These differences mainly occur because outdoor pollutants come from sources such as forest fires, trash burning, and transportation emissions. Indoor pollutants, however, are primarily generated by activities like cooking, heating combustion, poor ventilation, tobacco smoking, and certain building materials.[5] With proper ventilation in the room, reducing tobacco smoking, choosing the right furniture materials, and controlling sources like cooking and heating combustion might help improve indoor air quality.

Particulate sources in developed and developing countries are typically different. In developed countries, the primary source of particulates is environmental tobacco smoke (ETS). A study of 73 homes in Italy found higher levels of PM2.5 in homes with active smokers compared to those without. In developing countries, particulate sources include biomass, as well as the use of charcoal and coal for cooking or heating. The combustion of these materials results in the release of carbon monoxide, nitrous oxide, particulate matter (PM), and polycyclic aromatic hydrocarbons (PAHs).[5,6] The inhalation of these chemicals is believed to have a detrimental effect on human health, affecting mucociliary clearance, increasing the adherence of microorganisms to respiratory cells, impairing the immune system, and causing a decrease in lung function. This can also elevate the risk of infections, respiratory symptoms, and exacerbations of chronic obstructive pulmonary disease (COPD) and asthma, potentially leading to more hospitalizations.[5] PM2.5 can remain airborne and adhere to surfaces for hours after exposure, further impacting indoor air quality.[6,7] Additionally, the growing popularity of electronic cigarettes has contributed to increased PM2.5 concentrations indoors, reaching 197–818 µg/m3.[8]

A 2015 study in the U.S. found that long-term exposure to PM2.5 could cause changes in lung function, such as forced expiratory volume in one second (FEV1), forced vital capacity (FVC), and the FEV1/FVC ratio. The study indicated that an increase of 2 µg/m3 in PM2.5 was associated with a 13.5 ml lower FEV1 and an additional decline of 2.5 ml per year.[6] The main factor contributing to lung disease from PM2.5 exposure is increased oxidative stress. Oxidative stress is pathological damage resulting from excessive reactive oxygen species (ROS) production or an imbalance between antioxidant systems in tissues or cells.[9] ROS accumulation in mitochondria leads to increased membrane permeability, morphological and functional changes, and mitochondrial cell death and damage. Nuclear factor erythroid-2 related factor 2/antioxidant responsive element (NRF2-ARE) is a cytoprotective component crucial for maintaining cellular balance.[10] The antioxidant heme oxygenase 1 (HO-1) is regulated by the NRF2-ARE pathway and catalyses heme to produce carbon monoxide (CO) and biliverdin. HO-1 also plays a role in BEAS-2B cell damage.[9] BEAS-2B cells, derived from the bronchial epithelium, are involved in lung carcinogenesis and infections.[11]

Apart from oxidative stress mechanisms, exposure to indoor pollutants can increase neutrophil inflammation, damage macrophage phagocytosis, reduce bacterial and mucociliary clearance, and disrupt the alveolar and capillary barrier in the lungs, resulting in a decreased immune response to bacterial and viral infections.[12] Beyond respiratory infections, exposure to pollutants and particulates can induce genetic and epigenetic changes that persist after exposure ends. These changes may contribute to impaired lung development in children, airway hyperactivity, asthma, and chronic obstructive pulmonary disease (COPD) in adulthood.[12,13]

Air purifiers: types and effectiveness

Several strategies exist to reduce air pollution, such as switching to cleaner cooking fuels like liquefied petroleum gas (LPG) and reducing tobacco smoke. While these strategies focus on reducing pollutant sources, technological advancements have also introduced new methods for directly improving air quality. Recently, air cleaning interventions using machines, commonly known as air purifiers, have

gained attention.[12] Nowadays, there is a wide variety of air purifiers available, differing in models and technologies used. In general, air purifiers can be divided into two types: those which work by filtering and absorbing harmful particulates and gases or by catalysing oxidation reactions to neutralize pollutants.[14] Aside from that, air purifiers also reported to be effective in reducing pollutant and particulate concentrations indoors by diluting ventilation.[2,12,14] Based on the technology used, air purifiers can be categorized as filter-based, water-based, ionization, ozone, photocatalytic, and hybrid types.[14]

The most widely used air purifiers fall into categories based on the technology they use. These include those with mechanical filtration, such as high-efficiency particulate air (HEPA) filters, ionization air purifiers, and electrostatic precipitator (ESP) purifiers.[15] HEPA air purifiers are widely regarded as the most effective for removing particulate matter, with the ability to capture 99.97% of particles with a diameter of 0.3 µm. However, they require regular replacement and are difficult to clean, making them more expensive in the long run. [16]

ESP air purifiers, while less effective at filtering particulates, are easier to clean and do not require frequent replacements, making them more cost-effective. Ionization purifiers, known for their low noise production, are popular for use in schools and other spaces where noise is a concern.[15] One study concluded that ion-type air purifiers could reduce PM2.5 concentrations by 50% (from 8 µg/m3 to 4 µg/m^3) without significant changes in lung function in older adults. Another study involving 44 boys and girls aged 11–14 found improved lung function, reduced airway inflammation, oxidative stress, and a decreased risk of ischemia after using ion-type air purifiers. Measured parameters included FEV1, FVC, ambulatory electrocardiography, and FeNO levels.[15]

Despite their benefits, air purifiers have limitations. They are unable to eliminate all pollutants, and they may lead to higher energy consumption and noise levels, particularly when used continuously.[5] These factors must be considered when evaluating the effectiveness and suitability of air purifiers for improving indoor air quality. The effectiveness of air purifiers is also influenced by environmental factors, such as the ratio of the device to the room size, device placement, and ventilation.[5] Thus, while air purifiers can significantly improve indoor air quality, they should be considered as part of a broader strategy for managing air pollution.

Discussion

Numerous studies have shown that the use of HEPA air purifiers leads to improvements in air quality that is eventually beneficial to cardiovascular and respiratory function. Specifically, HEPA filters have been linked to improved peripheral artery tone, reduced systemic inflammation and enhanced endothelial function, all of which are associated with lower cardiovascular risks. Moreover, the use of HEPA filters has been shown to benefit individuals with asthma, particularly those living with pets, by reducing symptoms, airway hypersensitivity, nighttime symptoms, and medication use.[17] Additionally, air purifiers can alter airborne bacterial colonization compared to control conditions, which may reduce respiratory infections due to fewer bacteria and decreased transmission risk.[18]

Therefore, air purifiers using HEPA technology are reported to provide positive outcomes for respiratory and cardiovascular health. Though this is a promising study, they should not be seen as a standalone solution for improving indoor air quality. Other conventional interventions, such as improving ventilation, reducing tobacco smoke exposure, switching to cleaner cooking and heating methods, and using eco-friendly building materials, can lead to even more substantial improvements in indoor air quality. Combining these approaches with natural methods like plant-based air purifiers may result in more effective, long-term solutions for enhancing indoor air quality. Further research is needed to explore the long-term effects of air purifiers and integrated technologies to ensure optimal air quality outcomes.

Conclusion

In conclusion, the rise in respiratory diseases linked to poor air quality has highlighted the need for effective solutions, particularly in indoor environments. The COVID-19 pandemic has further emphasized the importance of indoor air quality, and the role air purifiers can play in mitigating health risks. While air purifiers with HEPA technology are shown to be effective, there are opportunities for further research,

particularly concerning their long-term health effects and the limitations of existing models. In addition to air purifiers, strategies such as improved ventilation, reduced tobacco smoke exposure, and optimized heating and cooking methods are essential for creating healthier indoor environments. Public awareness campaigns and policies that support cleaner air should also be promoted. These efforts are key to improving public health and ensuring the continued effectiveness of air quality management.

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