REVIEW

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# Particulate-Matter Related Respiratory Diseases

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Particulate matter (PM) is suspended dust that has a diameter of <10 μm and can be inhaled by humans and deposited in the lungs, particularly the alveoli. Recent studies have shown that PM has an adverse effect on respiratory diseases. The aim of this article is to review respiratory diseases associated with PM. According to existing studies, PM is associated with chronic obstructive pulmonary disease, bronchial asthma, and several other respiratory diseases and increases the mortality rates of these diseases. Moreover, increased exposure in the high concentration of atmospheric PM is associated with the development of lung cancer. The most simple and common way to protect an individual from airborne PM is to wear a face mask that filters out PM. In areas of high concentration PM, it is recommended to wear a face mask to minimize the exposure to PM. However, the use of N95 or KF94 masks can interfere with respiration in patients with chronic respiratory diseases who exhibit low pulmonary function, leading to an increased risk of respiratory failure. Conclusionally, reduction of the total amount of PM is considered to be important factor and strengthening the national warning notification system to vulnerable patients and proper early management of exacerbated patients will be needed in the future.

**Keywords:** Face Mask; Particulate Matter; Respiratory Diseases

## Introduction

Particulate matter (PM) is suspended dust that has a diameter of <10 μm ($PM_{10}$) and can be inhaled by humans and deposited in the lungs, particularly the alveoli. In addition to $PM_{10}$, PM with diameter <2.5 μm ($PM_{2.5}$) and <0.1 ($PM_{0.1}$) is classified as fine and ultrafine PM, respectively[1,2]. A major source of PM is the combustion of fossil fuels from human activity; however, natural sources, such as yellow dust, are also significant. Domestic PM consists of fine dust from China, seasonal yellow dust, and domestic-generated air pollutants[3,4]. As PM poses considerable health risks, individual countries have set maximum acceptable concentrations of PM within the atmosphere, based on the results of concentration prediction systems to estimate levels of PM[1,5-7].

In 2005, as outlined by the World Health Organization (WHO), the maximum acceptable annual average concentration of $PM_{10}$ was ≤20 μg/m$^3$, with a limit of ≤50 μg/m$^3$ per 24-hour period. In Korea, the annual and daily average concentrations of $PM_{10}$ are <50 and <100 μg/m$^3$, respectively. The annual and daily average concentrations of $PM_{2.5}$ are <15 and 35 μg/m$^3$, respectively. Overall concentrations of $PM_{10}$ and $PM_{2.5}$ are above 81 μg/m$^3$ and 36 μg/m$^3$, respectively, and therefore the PM concentration forecast grade is designated as 'bad' in Korea (Tables 1, 2)[1,8].

According to current literature, exposure to PM leads to increased pulmonary inflammation and respiratory symptoms aggravation due to oxidative stress and direct toxic injury[5,6]. This is particularly dangerous for patients with pre-existing respiratory diseases, as exposure to PM can lead to acute ex-

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**Table 1.** Overview of guidelines for particulate matter (PM)

| | $PM_{10}$ (μg/m$^3$) | | $PM_{2.5}$ (μg/m$^3$) | |
|---|---|---|---|---|
| | Daily average | Annual average | Daily average | Annual average |
| WHO | 50 | 20 | 25 | 10 |
| Republic of Korea | 100 | 50 | 35 | 15 |

$PM_{10}$: PM with diameter <10 μm; $PM_{2.5}$: PM with diameter <2.5 μm; WHO: World Health Organization.

**Table 2.** Particulate matter (PM) concentration forecast grade in Korea

| | PM concentration (μg/m$^3$) | | | |
|---|---|---|---|---|
| | Good | Moderate | Bad | Very bad |
| $PM_{10}$ | 0–30 | 31–80 | 81–150 | ≥151 |
| $PM_{2.5}$ | 0–15 | 16–50 | 51–100 | ≥101 |

$PM_{10}$: PM with diameter <10 μm; $PM_{2.5}$: PM with diameter <2.5 μm.

acerbation of their ailment. It has also been reported that long-term exposure to high concentrations of PM increases the prevalence of chronic obstructive pulmonary disease (COPD) and lung cancer in adults, leading to a decline in pulmonary function[9-12]. The high concentration of PM in the atmosphere has a profound effect on the prevalence of chronic respiratory diseases, and the risk of acute exacerbation (which can prove fatal)[13,14]. Additionally, $PM_{2.5}$ exposure is associated with a long recovery time, more leading to an increase in both the mortality rate and the overall medical burden. Therefore, it is of the utmost importance that effective policies and medical practices are put into place to minimize the public health risks associated with PM exposure (Table 3)[15].

## PM and Pulmonary Function

Pulmonary function is an indicator of respiratory health. Generally, pulmonary function increases from birth until the mid-20s, after which it begins to decrease. Air pollution, especially PM exposure, is associated with decreased pulmonary function, leading to an increase in the rate of lung function decline in adults[16-19].

Large-scale cohort studies of the effect of fine dust on pulmonary function in adults are typically based on National Health and Nutrition Examination Surveys (NHANEs). Notably, the Swiss Study on Air Pollution and Lung Diseases in Adults (SAPALDIA), and the German study on the Influence of Air Pollution on Lung Function, Inflammation, and Aging (SALIA), show interesting results. In the SAPALDIA study, 9,651 adults, aged 18–60 years, were monitored over a period of 11 years. The average forced vital capacity (FVC) and mean forced expiratory volume in 1 second ($FEV_1$) decreased by

**Table 3.** Influence of PM on the respiratory system

| Influence of PM on the respiratory system |
|---|
| Increases mortality |
| Increases the incidence of malignant tumors |
| Increases the incidence of chronic respiratory disease exacerbations such as COPD and asthma |
| Increase or worsen overall respiratory symptoms |
| Reduce lung function growth in children |
| Causes temporary loss of lung function in normal people |
| Increases airway inflammation and increases airway hyperresponsiveness |
| Reduces pulmonary diffusing capacity in lung function |

PM: particulate matter; COPD: chronic pulmonary disease.

3.4% and 1.6%, respectively. The $PM_{10}$ concentration declined during the observation period, which was associated with reduced lung function decline[18]. In the SALIA study, $FEV_1$ and FVC decreased by 4.7% and 3.4%, respectively, and the $FEV_1$/FVC decreased by 1.1%, with an increase in $PM_{10}$ concentration by 10 μg/m$^3$ between 1985 and 1994. Thus, lung function was negatively affected, but the decline in pulmonary function was attenuated by reducing PM exposure through environmental improvement[13]. However, it is not yet fully understood how other factors affect pulmonary function, such as age, other pollutants, individual susceptibility, and genetic factors.

## Effect of PM on COPD and Bronchial Asthma

COPD has been widely studied in relation to fine dust exposure in pulmonary diseases[1,8,20]. Studies showed that the rate of hospitalization of patients suffering from COPD increased with increasing exposure to PM[20-22]. A meta-analysis carried out in Korea showed that COPD admissions increased by ~2.7% (95% confidence interval [CI], 1.9%–3.6%) with an increase in $PM_{10}$ concentration of 10 μg/m$^3$ (odds ratio [OR], 1.027; 95% CI, 1.019–1.036). In addition, a positive correlation between an increase in $PM_{10}$ concentration and COPD mortality was also found: COPD mortality increased by 1.1% (95% CI, 0.8%–1.4%) with an increase in $PM_{10}$ concentration of 10 μg/m$^3$ (OR, 1.011; 95% CI, 1.008–1.014)[8]. These results strongly suggest that exposure to PM increased both the hospital admission and mortality rate of COPD. Recent studies have shown that hospitalization due to deterioration of COPD is associated more with atmospheric concentrations of $PM_{2.5}$ versus $PM_{10}$. This is especially significant for the 14–90-day period prior to hospital admission (relative risk, 1.06–1.32)[14,15]. About 1.6 million deaths from COPD are believed to be due to air pollution[23]. In Korea, there has been no detailed study on the effect of air pollution and PM on the aggravation of COPD patients; thus, further research is imperative to better understand the effect of PM exposure on COPD patients.

In addition to COPD, asthma has also been studied in relation to fine dust exposure[4,24]. Exposure to PM can cause allergic sensitization and asthma exacerbation[24,25]. In asthmatic patients, both the exhaled nitric oxide fraction (FeNO) and airway hyperresponsiveness increases due to aggravation of the allergic inflammatory response. Moreover, asthmatic patients also show reduced lung volume or lung diffusion capacity[24]. Subsequently, PM exposure has been reported to lead to an increase in hospital visits as symptoms including decreased lung function, coughing, wheezing, and dyspnea worsen. In particular, $PM_{2.5}$ significantly increased the incidence and prevalence of asthma. According to recent reports, for every 10 $\mu g/m^3$ increase in $PM_{2.5}$ concentration, the total number of hospital, out-patient, and emergency room visits increased by 0.67, 0.65, and 0.49%, respectively. These findings indicate a significant correlation between PM exposure and acute asthmatic exacerbations[26]. In addition, both domestic and international studies have shown that long-term exposure to PM increases the overall prevalence of asthma[12].

## PM and Interstitial Lung Disease

In 2014, an international study of the relationship between air pollution and idiopathic pulmonary fibrosis (IPF) reported that concentrations of ozone and nitrogen dioxide in airborne fine dust were associated with acute exacerbation of IPF at 6 weeks after initial exposure[27]. A recent study reported that the FVC of IPF patients was reduced by 46 mL with an increase in $PM_{10}$ exposure concentration of 5 $\mu g/m^3$, indicating that the increase of PM was closely associated with the progression of IPF[28]. In the 2018 French cohort study, Cohorte Fibrose (COFI), it was reported that as the concentration of $PM_{10}$ and $PM_{2.5}$ increased by 10 $\mu g/m^3$, the IPF mortality rate increased significantly, by 2.01- and 7.93-fold, respectively[29]. These results suggest that an increase in PM exposure significantly decreases pulmonary function, leading to an increase in mortality, as well as acute exacerbation, of IPF[30].

## PM and Lung Cancer

In 2013, the WHO and the International Agency for Research on Cancer (IARC) announced that PM is carcinogenic[31], and that increased atmospheric PM concentrations are associated with lung cancer development[32,33]. In the European Study of Cohorts of Air Pollution Effects (ESCAPE), the hazard ratio of lung cancer was 1.22 and 1.18 for an increase in $PM_{10}$ concentration of 10 $\mu g/m^3$, and in $PM_{2.5}$ of 5 $\mu g/m^3$, respectively[34,35]. In a comprehensive meta-analysis conducted in Korea in 2015, the risk of lung cancer increased by 1.09-fold (95% CI, 1.01–1.14) when the concentration of $PM_{2.5}$ increased by 10 $\mu g/m^3$. A correlation between $PM_{10}$ concentration and lung cancer incidence was also observed; however, the correlation was comparatively weak compared to that between lung cancer risk and $PM_{2.5}$ concentration (1.08-fold increased risk; 95% CI, 1.00–1.17)[8]. In addition, lung cancer incidence was higher in smokers who were exposed to high amounts of $PM_{2.5}$; it was confirmed that fine PM affects smokers' lung cancer development to a significantly greater degree relative to healthy people[6,31,32]. It is estimated that about 500,000 lung cancer deaths can be attributed to air pollution[23]. Both $PM_{10}$ and $PM_{2.5}$ were reported to significantly increase the mortality rate in lung cancer patients in 2017 and 2018 meta-analyses[36]. Thus, to reduce lung cancer prevalence and mortality, control of PM generation and avoidance of PM exposure, together with smoking cessation, are of the utmost importance[33].

## PM and Pneumonia Mortality Rate

PM increases airway inflammation in the lungs, leading to increased levels of both inflammatory cytokines and neutrophils, and an increase in serum 8-isoprostane in bronchoalveolar lavage fluid or induced sputum[25,37]. These findings accord with the incidence of pneumonia, and it is known that the risk and mortality rate of pneumonia increase in both children and adults with higher PM exposure[34,38,39]. A recent meta-analysis showed that the incidence rate of pneumonia in children increased by 1.5% and 1.8% for every 10 $\mu g/m^3$ increase in $PM_{10}$ and $PM_{2.5}$, respectively, demonstrating the relationship between PM and pneumonia[11]. In another meta-analysis, the overall mortality rate (relative risk, 1.02) of respiratory disease patients was significantly increased for every 10 $\mu g/m^3$ increase of $PM_{2.5}$ in fine dust[10].

## PM and Protective Face Masks

The most simple and common way to protect against airborne fine dust is to wear a mask that filters out fine dust or gas. Protective masks against PM used in Korea include the N95, KF94, and KF99 models. Such precautionary measures are vital, as natural air pollution phenomena, such as yellow sand, pose severe health risks in Korea. To specifically combat the danger posed by yellow sand, a specialized mask (KF80) has been developed[40]. Among filtering face respirators, the N95 and KF94 masks are the most commonly used, protecting the respiratory tract from fine dust exposure in industrial workers. These masks are also used to protect against respiratory pathogens in hospitals and public places[41]. Both the N95 and KF94 masks are superior to the KF80 mask in preventing PM inhalation. However, industrial workers who wear these masks for long periods tend to have subjective complaints, including discomfort when breathing. It is known that, in addition to carbon dioxide accumulation, a decrease in the concentration of inhaled oxygen can lead to an increase in respiratory dead space[42]. Although the N95 and KF94 masks have no significant effect on pulmonary function in healthy people or patients with mild respiratory issues, for patients with low pulmonary function and high levels of respiratory distress, caution should be taken when using these masks. All filtration masks (KF80, KF94, and N95) are commercially available and can prevent harmful exposure to PM due to the inflow of fine dust into the body. It is recommended that both the general public and people suffering from mild and moderate chronic respiratory diseases and/or cardiovascular diseases use these preventative measures[40,41]. However, the use of N95 and KF94 masks by people with COPD (stage C/D), or advanced IPF is associated with severe respiratory failure; thus, caution is necessary regarding their use. Further research on the effectiveness of masks for preventing PM exposure is needed for patients with advanced respiratory diseases[8].

## Conclusion

Several studies have shown that exposure to high concentrations of PM leads to an increase in hospitalization and mortality rates in patients suffering from COPD. Acute exacerbation of bronchial asthma and IPF is also linked to high concentrations of PM. Long-term exposure to PM is associated with lung cancer development; particularly, high concentrations of $PM_{2.5}$ have been linked with acute exacerbation and increased prevalence of chronic respiratory disease in smokers aged 60 years and over. Therefore, patients with chronic respiratory diseases are vulnerable to high concentrations of environmental PM and should limit outdoor activities and use medication regularly to reduce the risk of acute exacerbation. Visiting a medical institution for immediate treatment is recommended if any acute exacerbation symptoms are experienced. In addition, in high PM concentration environments, it is recommended that a face mask be worn to minimize exposure. However, for patients with chronic pulmonary diseases and very low pulmonary function, caution must be taken when using the N95 and KF94 masks. Numerous health problems are associated with PM exposure, all of which can lead to the progression and worsening of lung disease; thus, it is extremely important that national policy helps manage resources of PM and focuses on preventative medical care. Strengthening the notification system to vulnerable patients and proper management of PM production control are considered to be important factors in suppressing prevalence in chronic respiratory disease, decreasing the hospitalization rate, and reducing the mortality associated with acute exacerbations.

## Authors' Contributions

Conceptualization: Jeong SH. Methodology: Kyung SY. Formal analysis: Jeong SH, Kyung SY. Writing - original draft preparation: Jeong SH, Kyung SY. Writing - review and editing: Jeong SH. Approval of final manuscript: all authors.

## Conflicts of Interest

No potential conflict of interest relevant to this article was reported.

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