Analysis of the effect of $PM_{2.5}$ on COVID-19 incidence and mortality among adults in the U.S.: An Integrative Literature Review

Presented by

Aissata Lo MPH, (George Washington University)

Broadstreet Health LLC., Covid-19 Data Project

ABSTRACT

SARS-CoV-2 pandemic (COVID-19) has created a serious public health concern around the world. However, some states have been more affected in terms of infections and fatality rates than others. There are no clear reasons explaining the association between $PM_{2.5}$ and COVID-19 incidence and mortality. This literature review aims to compare scientific evidence relevant to the hypothesis that exposure to $PM_{2.5}$ is or is not associated with COVID-19 outcomes in the U.S. and make recommendations to raise awareness to the policy makers, health professionals and the community. Findings of most studies revealed that both short-term and long-term exposure to particulate matter ($PM_{2.5}$) may contribute significantly to higher rates of COVID-19 infections and mortalities. A significant association has been found between $PM_{2.5}$ and COVID-19 epidemic. Studies demonstrated that $PM_{2,5}$ is a highly significant predictor of COVID-19 cases and hospital admissions. Disparities in COVID-19-related health effects were addressed in some papers where Black community is found to be more affected with COVID-19 hospitalization and deaths, as well as exposure to $PM_{2.5}$. Further research should be implemented focusing on individual level with a defined target population and a well-designed epidemiological study that will be less prone to biases such as a cohort study either prospective or retrospective. All possible confounders such as age, gender, socio-economic status, place, pre-existing medical conditions, and exposure to $PM_{2.5}$ should be considered for a better risk estimate of the association between $PM_{2.5}$ exposure and COVID-19. Finally, significant tools should be elaborated and implemented to communicate long-term exposure risk at neighborhood scales to address the major health risks associated with $PM_{2.5}$ exposure.

INTRODUCTION

In December 2019, a new strain of Coronavirus Disease caused by SARS-CoV-2 (COVID-19) began to infect people in Wuhan Province, China (Chinazzi et al., 2020; Li et al., 2020b; Wu et al., 2020a; Xu et al., 2020). Months after COVID-19 was discovered, the World Health Organization (WHO) declared a global pandemic as the disease spread to every country (Chinazzi et al., 2020; Gilbert et al., 2020). However, some states have been more affected in terms of infections and fatality rates than others. These facts raised important questions related to the impact of $PM_{2.5}$ on COVID-19 incidence and mortality rates globally. There are no clear reasons explaining the association between $PM_{2.5}$ and COVID-19 incidence and mortality, and some studies highlighted that further investigation on the topic is needed (Ali N et al., 2020). It has been demonstrated that exposure to air pollution has a substantial effect on human health, and annually $PM_{2.5}$ accounts for the greatest mortality of any environmental exposure, accounting for 4.2 million deaths worldwide (Cohen et al., 2017). According to the WHO, air pollution is considered as a human carcinogen (IARC 2016). An early study showed that $PM_{2.5}$ exposure is linked to infectious respiratory disease, chronic respiratory disease, inflammation, decreased lung function and asthma (Zhou et al., 2020). Air pollution-related deaths include but are not limited to aggravated asthma, bronchitis, heart disease, respiratory allergies, and stroke (Brauer M et al., 2010; Lelieveld J et al., 2015; Krewski D 2009).

There is a link between air pollution and infectious disease transmission (Li H et al., 2020). For example, a positive association was observed between acute and chronic pollution measures from the air pollution index (CO, NO2, SO2, O3, and PM_{10}) and SARS case-fatality rates during the 2003 SARS outbreak in China. In Hubei province, China, preliminary data showed similar significant positive correlation between air pollution levels and higher morbidity and mortality rates from COVID-19 (Cui Y et al., 2003). However, the association of $PM_{2.5}$ with an increased incidence of COVID-19 in practical situations remain largely unknown. A study has provided first evidence that COVID-19 RNA can exist on outdoor PM in high levels of PM_{10}, and certain conditions of atmospheric stability, hence this suggests a possible application as an indicator of epidemic recurrence (Setti L et al., 2020). The Wu et al. (2020) studies demonstrated that the prognosis in COVID-19 patients and their risk of death are related to long-term exposure to $PM_{2.5}$ which may also increase the risk of diseases in people with underlying health conditions such as: lung, cardiovascular and respiratory diseases. WHO highlighted a number of challenges related to the estimation of the effects of $PM_{2.5}$ on COVID-19 incidence and mortality in the pandemic period (WHO, 2020). Among these challenges, confounding factors such as male gender, age, smoking and high population density might be potential risk factors for higher morbidity and mortality of COVID-19 (Contini D et al., 2020; Pansini R et al.,2020). North America and Europe have a better improvement in air quality, however over 90% of the globe have not yet met the World Health Organization annual air quality guidelines of 10 $\mu g/m^3$ (Brauer M et al., 2012). Since there is a growing number of at-risk individuals and an aging population, significant reductions in PM2.5 levels will be needed to prevent a decrease in the high public health toll (Landrigan PJ et al., 2018; Cohen AJ et al., 2017). Up to now, there is no study to our knowledge that has examined the association between long-term or short-term exposure to particulate matter ($PM_{2.5}$) and the incidence of COVID-19 in a particular target population in the U.S. Most studies conducted in the U.S, were ecological studies (county or state levels), and no prospective studies have been implemented yet in the U.S. Since few studies have looked at long-term and short-term exposure to $PM_{2.5}$ in U.S., this literature review aims to compare scientific evidence relevant to the hypothesis that exposure to $PM_{2.5}$ is or is not associated with COVID-19 outcomes in the U.S. and make recommendations to raise awareness to the policy makers, health professionals and the community. In describing the findings, the review will also characterize the $PM_{2.5}$ exposure and Covid-19 incidence and mortality; $PM_{2.5}$ disparities and communication strategies to raise awareness of the effect of $PM_{2.5}$ on human health.

We sought to identify research articles relevant to the hypothesis that exposure to $PM_{2.5}$ affects the risk of developing or dying from COVID-19, and communication strategies used to raise awareness for different audiences and sectors. Peer reviewed publications were searched through PubMed and Google Scholar databases using the search terms: {Coronavirus, COVID-19 incidence, SARS-CoV-2, Air pollution, $PM_{2.5}$, U.S, population, Communication strategies on air pollution}. In addition, other papers were searched using the strategy "COVID-19 incidence and $PM_{2,5}$" and "Coronavirus and Air pollution", "COVID-19 mortality and Air pollution", "$PM_{2.5}$ and communication strategies". The reference lists of the papers retrieved were also sought. We also searched for the last five years of publication and filtered by text availably (abstract) and article type (journal article, meta-analysis, and systematic review).

Exposure to PM $_{2.5}$ and COVID-19 Incidence and Mortality

Exposure to ambient air pollution is the world's leading environmental risk factor which contributes more to global morbidity and mortality compared to other common risk factors (Landrigan PJ et al., 2018; Cohen AJ et al., 2017). Most of the studies related to $PM_{2.5}$ and COVID-19 have not yet been peer reviewed, but they still attract the attention of environmental policy decision makers (Grandoni and Firozi 2020; Griffiths 2020; Laing 2020; O'Sullivan 2020). Study findings revealed that both short- and long-term exposures to air pollutants are highly associated with adverse health effects including (Ferrante M et al., 2017; Fiore M et al., 2019), increased hospital admissions, higher fatality rates and outpatient visits (Cohen AJ et al., 2017; Dehghani M et al., 2017). While some reviews emphasized the association between $PM_{2.5}$ and COVID-19, there are still a limited number of data-dependent studies that have been conducted to explore the association between $PM_{2.5}$ and COVID-19 incidence and mortality (Domingo JL et al., 2020).

Short-term exposure

A recent study has been conducted in eight countries including Italy, Germany, France, Spain, UK, USA, China, and Iran in which geographical properties of the SARS-CoV-2 infection and the link with various annual satellite and ground level measure of air quality index was examined. The findings showed more viral infections in the regions where high levels of $PM_{2.5}$ and NO2 were present (Pansini R et al., 2020). Significant correlation was noticed between the levels of air quality and COVID-19 spread. In addition, an association between mortality and air quality in six countries except for Germany and Spain was observed. Among the eight countries, Italy showed the strongest associations for both infection and mortality, while population size and density did not show correlation with SARS-CoV-2 incidence. In USA and UK, population density had a stronger association with infection and mortality than air pollution, while in China, results showed similar positive correlation between infection and mortality than to air pollution in China.

On the other hand, population density showed a weak association with infections in Germany, while particulate matters ($PM_{2.5}$) showed a weak negative correlation. In Spain, the rate of infections and mortality were not explained by the levels of air pollution. The authors noted that the negative correlation between COVID-19 infection and population density might be due to the movement of people from big cities to the countryside circulating the virus with them (Pansini R et al., 2020). Another retrospective study conducted in China also showed a significant association between air quality index (AQI) and incidence of COVID-19 in Wuhan and Xiao Gan was ($p < 0.05$) and ($p < 0.01$) respectively. Li et al. (2020) demonstrated that only $PM_{2.5}$ and NO2 were strongly associated with the incidence of COVID-19. Furthermore, temperatures that showed persistent association with COVID-19 incidence in Wuhan and Xiao Gan were from the metrological parameter (Li H et al., 2020).

Another cross-sectional study of ecological data conducted by Yao et al. (2020) in China examined spatial associations of daily $PM_{2,5}$ and PM_{10} concentrations with mortality rates from COVID-19 in 49 Chinese cities by including in the analysis the number of hospital beds, the size of the population for each province and per capita gross domestic product (GDP). Results showed, with statistical significance, that increased $PM_{2,5}$ and PM_{10} concentrations were linked to higher death rates from COVID-19 with P =0.011 and P =0.015, respectively (Yao et al., 2020). In addition, nitrogen dioxide (NO2) was found to be significantly associated with COVID-19 mortality and case-fatality rates whereas $PM_{2.5}$ showed a slightly significant association with mortality (Liang et al., 2020). In Wuhan, a remarkable positive association with $p < 0.01$ was also observed between $PM_{2.5}$ and the daily COVID-19 deaths (Jiang Y et al., 2020). Another link was found between $PM_{2.5}$ and PM10 and the COVID-19 fatality in three cities in France (Magazzino C et al., 2020). The reasons might be that COVID-19 could be transmitted through aerosol and fomites since the virus can stay infectious and viable in aerosol for hours and on surfaces for many days (Van Doremalen N et al., 2020). In another study, $PM_{2.5}$, PM_{10} SO2, NO2, and CO showed a significant correlation with the COVID-19 epidemic (Bashir MF et al., 2020).

Similar positive associations were found in another published time series conducted by Zhu et al. (2020) where daily confirmed cases of COVID-19 in 120 cities in China were used (after lockdown started). The aim of his study was to evaluate associations between 1-, 2-, and 3-week measurements of ambient pollution ($PM_{2.5,}$ ozone and NO_2) and confirmed incident cases of COVID-19. For a mean of 10 μg/m3 increase across lags of 0–14 days, results were: $PM_{2,5}$, 2.24%

(95% CI: 1.02, 3.46); PM_{10}, 1.76% (95% CI: 0.89, 2.63); NO_2, 6.94% (95% CI: 2.38, 11.51); O3, 4.76% (95% CI: 1.99, 7.52); and SO2, −7:79% (95% CI: −14:57 to −1:01) (Zhu et al., 2020).

Long-term exposure

A nationwide unpublished ecological study in the U.S. that was conducted by Wu et al. (2020), attracted the media during this pandemic. The unit of observation were 3,080 counties. There are two versions of this manuscript with different methodologies. The study tested whether long-term average exposure to $PM_{2,5}$ over 17 years, was associated with increased risk of death from COVID-19. The first manuscript encompasses mortality data up to 4 April 2020, and for the second additional data were included until 22 April 2020. The exposure $PM_{2.5}$ concentrations were derived from 2000 to 2016. The researchers confirmed that for an increase of 1l g/m^3 of chronic $PM_{2,5}$ exposure, the rate ratio for COVID-19 mortality was 1.15 (95% CI: 1.05, 1.25) (Wu et al., 2020). The second paper slightly differed from the first one, by adding some new county-level risk factors such as: days since stay-at-home orders consignment, and days since the first COVID-19 case, capturing the proportion of people who were obese at that time, the population between the ages of 15-55 and 45–64 and a negative binomial mixed model was used instead of a zero-inflated one. The new obtained rate ratio for COVID-19 mortality in relation to 1μg/m^3 increase of $PM_{2.5}$ exposure was 1.08 (95% CI: 1.02, 1.15) (Wu et al., 2020). Similar association was found in a study which collected data from 25 cities in India, has also reported a direct relationship between the concentration of $PM_{2.5}$ and COVID-19 mortality (Mele M et al., 2020).

Furthermore, a study in Italy reported a positive association between $PM_{2.5}$ concentration and excess COVID-19 related deaths. A one-unit increase in $PM_{2.5}$ concentration (μg/m^3) was associated with a 9% increase in the COVID-19 related fatality (Coker ES et al., 2020). In David et al. (2020) study, where an ecological analysis of COVID-19 cases and 17-year average $PM_{2.5}$

concentrations among Canadian health regions was conducted, and it has been reported that long-term $PM_{2.5}$ exposure showed a positive association with COVID-19 incidence with an incidence rate ratio (IRR= 1.07, 95% confidence interval 0.97–1.18 per μg/m^3). The association was found to be larger in magnitude and statistically significant in analyses (David et al., 2020). Higher rates of spread of COVID-19 were associated with the previous long-term $PM_{2.5}$ exposure in Lima (Peru) (Vasquez-Apestegui V et al., 2020).

Another cross-sectional study of ecological data conducted by Yao et al. (2020) in China, which examined spatial associations of daily $PM_{2,5}$ and PM_{10} concentrations with mortality rates from COVID-19 in 49 Chinese cities by including in the analysis the number of hospital beds, the size of the population for each province and per capita gross domestic product (GDP). Results showed statistical significance that increased $PM_{2,5}$ and PM_{10} concentrations are linked to higher death rates from COVID-19 with P =0.011 and P =0.015, respectively (Yao et al., 2020). In addition, nitrogen dioxide (NO2) was found to be significantly associated with COVID-19 mortality and case-fatality rates whereas $PM_{2.5}$ showed a slightly significant association with mortality (Liang et al., 2020). In the Netherlands, an ecological analysis of incident COVID-19 cases against annual average concentrations of $PM_{2,5}$ across 355 municipalities was conducted by Andree (2020). The analysis included 4,004 confirmed cases of COVID-19 with available residential addresses. The results showed $PM_{2,5}$ as a highly significant predictor of COVID-19 cases and hospital admissions, an increase of 1μg/m3 of $PM_{2,5}$, increased the number of cases by between 3.5 - 10.2 cases per 100,000 (Andree, 2020). Similarly, the Center for Research on Energy and Clean Air (CREA) reported that greater levels of air pollution interfere with the immune system against COVID-19, and the air pollution increases the risk of hospitalization and death from COVID-19 (Myllyvirta L et al., 2020).

Disparities

The disparities in COVID-19-related health effects were addressed in some papers where Black community is found to be more affected with COVID-19 hospitalization and deaths, as well as exposure to $PM_{2.5}$. In a recent study, the impact of long-term $PM_{2.5}$ exposure on SARS-CoV-2 mortality rates in United States counties was quantified. The study included 3,087 counties in the U.S., covering 98% of the population. The long-term effects of $PM_{2.5}$ on mortality among 60 million United States' Medicare enrollees was estimated. The census data, nationwide air pollution data, and other potential confounding variables with health outcome data were linked through a well-tested research data platform. The results have shown that the estimated MRR for $PM_{2.5}$ is 1.08 (1.02, 1.15), which means that an increase of only 1 μg/m3 in long-term average $PM_{2.5}$ is strongly linked with a statistically significant 8% increase in the SARS-CoV-2 death rate. Moreover, significant predictors of COVID-19 death rate were found including population density, percent Black, median household income, days since first COVID-19 case reported, rate of hospital beds, and percent with less than a high school education (Wu X et al., 2020). The results were consistent with previously reported findings that Blacks/ African Americans are at higher risk of COVID-19 mortality compared to other communities in which there is a 45% increase in SARS-CoV-2 mortality rate linked with a 1-standard deviation (per 14.2%) increase in percent Black residents (Yancy CW, 2020).

Similarities were found in another study where, SARS-CoV-2 related mortality rates appear higher in densely populated urban areas compared to rural areas where COVID-19 can easily spread. It is one of the reasons why COVID-19 death rate is higher in urban settings such as New York and Michigan which were among the hardest COVID-19 hit states, and the highest air pollution states (Dyer, 2020; Yancy CW, 2020; Eric B et al., 2020). After adjusting for population, New York City and Detroit had a much larger portion of COVID-19 deaths, and these densely populated urban settings also had some of the highest air pollution, as assessed by yearly $PM_{2.5}$ levels (Impact of air pollution and racial disparities on COVID-19 mortality, 2020). In Michigan where Blacks represent only 14%, data showed that Black COVID-19 cases accounted for 33% of and 44% for deaths. In Louisiana, where Blacks represent 32%, deaths were accounted for 61%; in Detroit, COVID-19 fatalities for Blacks were up to 75%, while in Chicago, where Blacks represent 30%, COVID-19 cases were accounted for more than 50% and for COVID-19 deaths 70%. Many settings in the United States have incomplete data related to COVID-19 morbidity and mortality by racial breakdown. Blacks represent 28% of COVID-19 deaths which account for more than twice their population demographics (Eric B et al., 2020). The results also parallel with David M et al. (2020) study, where an ecological analysis of COVID-19 cases and 17-year average $PM_{2.5}$ concentrations among Canadian health regions were conducted. The results showed that Black community was positively associated with COVID-19 incidence (David M et al., 2020).

Communication strategies

The particulate matter is one of the air pollutants contributing to the largest global health threat. Most of the available interventions and potentially viable personal-level approaches are designed to reduce exposure to particles and may not be effective against gaseous co-pollutants. Current evidence for personal-level strategies to prevent $PM_{2.5}$ health effects, help guide and facilitate rational use of the most proven approaches and avoid the use of ineffective measures were summarized. However, staying indoors and changing driving patterns used to lower $PM_{2.5}$ exposure could also decrease exposure to other pollutants such as ultrafine particulate matter, and ozone (American Heart Association, 2020). Recent study has demonstrated that, at present there is no accepted international consensus to communicate air pollution levels and risk, because of the countless air quality indices around the world. The EPA's Air Quality Index, which is a threshold metric, recognized six regulated criteria air pollutants that increased human health concerns ($PM_{2.5}$, PM_{10}, ozone, carbon monoxide, nitrogen dioxide, and sulfur dioxide) (US Environmental Protection Agency, 2016). However, the Air Quality Health Index in Canada, recommendations were based on multipollutant concentration-response coefficients which derived from epidemiological acute exposure analyses (Abelsohn A et al., 2011). In both cases, behavioral recommendations and their indices are focused on the population health impact of short-term exposures and are applicable to reduce high air pollution episodes. Furthermore, the Air Quality Health Index (Chen R et al., 2012; Perlmutt L et al., 2017) has been shown to be predictive of individual clinical cardiovascular disease measures (Cakmak S et al., 2015; Stieb DM et al., 2017) and population health responses (To T et al., 2015; Chen L et al., 2014). Results demonstrated that only a small number of people follow the accompanying behavioral recommendations and reduced their $PM_{2.5}$ exposure (Abelsohn A et al., 2011; Wen XJ et al., 2009). The evidence which indicates that such communications and recommendations reduced health impact is still limited, specifically for cardiovascular diseases (Chen H et al., 2018; D'Antoni D et al., 2019). Significant tools should be elaborated and implemented to communicate long-term exposure risk at neighborhood scales to address the major health risks associated with air pollution (Radisic S et al., 2016). Such tools could be used for prevention strategies, target treatment, personal preventive measures (indoor air cleaners), and air quality management through the supervision of healthcare providers and public health officials. In addition, recommendations, open-source platform technologies, and harmonization of values are crucial needs before used in messaging (Cromar KR et al., 2019).

Since particulate matter ($PM_{2.5}$) is a global public health concern, awareness of the effect of $PM_{2.5}$ on population health should be addressed to the different audiences and sectors such as:

environmental health sector; policy makers; industries (factories; cars and trucks, construction sites; power plants and coal fires) and exposed populations. Policies, legislation, regulation, and technology, coupled with enforcement, need to be implemented as key components of successful programs (Landrigan PJ et al., 2018; Academy of Science of South Africa 2019). Actions should be taken to prevent $PM_{2.5}$ health impacts by implementing effective interventions through raising awareness and delivering significant messages through channels like social media (TV advertisements, Radio Ads, Facebook pages, Twitter feeds, Billboards, mobile phones), distribution of flyers in community settings (churches, mosques, fitness centers, schools, stores, parks, gas stations, car dealers), scientific websites, media reports, conferences where scientific posters, policy briefs and research can be presented to decision makers to provide new policies for air pollution reduction.

CONCLUSION

Exposure to $PM_{2.5}$ may increase the susceptibility of COVID-19 infection, transmission, and mortality from SARS-CoV-2. The rigorous analysis of the existing literature released a lot of challenges that need to deeply take into consideration. Additionally, attention should be paid to the Black community who are experiencing COVID-19 hospitalizations and deaths, as well as high exposure to $PM_{2.5}$. Significant tools should be elaborated and implemented to communicate long-term exposure risk at neighborhood scales to address the major health risks associated with air pollution. Air quality should be considered as a crucial part of a combined approaches regarding public health prevention, protection, and promotion to the spread of COVID-19 and other diseases. Further research should be implemented focusing on individual level with a defined target population and a well-designed epidemiological study that will be less prone to biases such as a cohort study either prospective or retrospective. Confounders such as age, gender, and pre-existing medical conditions along with prolonged exposure to $PM_{2.5}$ should be considered to have a better risk estimate of the association between $PM_{2.5}$ exposure and COVID-19 related outcomes.

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