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Links between air pollution and COVID-19 in England[☆]

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A B S T R A C T

In December 2019, a novel disease, coronavirus disease 19 (COVID-19), emerged in Wuhan, People's Republic of China. COVID-19 is caused by a novel coronavirus (SARS-CoV-2) presumed to have jumped species from another mammal to humans. This virus has caused a rapidly spreading global pandemic. To date, over 300,000 cases of COVID-19 have been reported in England and over 40,000 patients have died. While progress has been achieved in managing this disease, the factors in addition to age that affect the severity and mortality of COVID-19 have not been clearly identified. Recent studies of COVID-19 in several countries identified links between air pollution and death rates. Here, we explored potential links between major fossil fuel-related air pollutants and SARS-CoV-2 mortality in England. We compared current SARS-CoV-2 cases and deaths from public databases to both regional and subregional air pollution data monitored at multiple sites across England. After controlling for population density, age and median income, we show positive relationships between air pollutant concentrations, particularly nitrogen oxides, and COVID-19 mortality and infectivity. Using detailed UK Biobank data, we further show that $PM_{2.5}$ was a major contributor to COVID-19 cases in England, as an increase of 1 m^3 in the long-term average of $PM_{2.5}$ was associated with a 12% increase in COVID-19 cases. The relationship between air pollution and COVID-19 withstands variations in the temporal scale of assessments (single-year vs 5-year average) and remains significant after adjusting for socioeconomic, demographic and health-related variables. We conclude that a small increase in air pollution leads to a large increase in the COVID-19 infectivity and mortality rate in England. This study provides a framework to guide both health and emissions policies in countries affected by this pandemic.

1. Introduction

In December 2019, a high number of pneumonia cases with an unknown aetiology were detected in Wuhan, China. A molecular analysis of samples from affected patients revealed that their symptoms were caused by an infection with a novel coronavirus, later named severe acute respiratory syndrome (SARS) coronavirus (CoV) 2 (SARS-CoV-2), the pathogenic agent of coronavirus disease 19 (COVID-19) (Zhu et al., 2020a). Within five months, this disease had affected more than 210 countries and became a global pandemic, causing devastating consequences to public health (Wang et al., 2020a). Coronaviruses are a genus of enveloped, non-segmented, positive-sense RNA viruses belonging to the family Coronaviridae and classified within the Nidovirales order (Yi et al., 2020). Historically, illnesses caused by coronaviruses have ranged in severity, with some, including human coronaviruses-229E and -OC43, causing common cold symptoms, but SARS-CoV and Middle East respiratory syndrome coronavirus have initiated outbreaks of life-threatening pneumonia (Yi et al., 2020). While the initial symptoms of COVID-19 include fever with or without respiratory syndrome, a crescendo of pulmonary abnormalities may subsequently develop in patients (Huang et al., 2020). According to recent studies, most patients present with only a mild illness, but approximately 25% of hospital-admitted patients require intensive care because of viral pneumonia with respiratory complications (Wang et al., 2020a).

While extensive research into the pathogenesis of COVID-19 suggests that the severe disease likely stems from an excessive inflammatory response (Cao, 2020), the exact predisposing factors contributing to increased clinical severity and death in patients remain unclear. Individuals over the age of 60 years or with

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Abbreviations

AIC	Akaike Information Criterion
AQ	Air quality
BEIS	Business, Energy and Industrial Strategy
CI	Confidence intervals
CoV	Coronavirus
COVID-19	Coronavirus disease 19
DEFRA	Department for Environment, Food and Rural Affairs
DfT	Department for Transport
GHGI	Greenhouse Gas Inventory
HGV	Heavy goods vehicle
LGV	Light goods vehicle
MPRN	Meter point reference numbers
NAEI	National Atmospheric Emissions Inventory
NHS	National Health Service
PCA	Principal component analysis
PM	Particulate matter
PM2.5	Particulate matter with an aerodynamic diameter <2.5 μm
PM10	Particulate matter with an aerodynamic diameter <10.0 μm
PHE	Public Health England
SARS	Severe acute respiratory syndrome
SARS-CoV-2	Severe acute respiratory syndrome coronavirus 2
WHO	World Health Organization

underlying health conditions, including cardiovascular and chronic respiratory diseases, diabetes, and cancer, are at the highest risk of increased clinical severity and death (Verity et al., 2020). Since several studies have shown that chronic exposure to air pollution enhances both respiratory and cardiovascular toxicity (Faustini et al., 2014), it has been hypothesised that air pollution may also contribute to COVID-19 severity (Brandt et al., 2020; Conticini et al., 2020). Early reports have shown that the geographical patterns of COVID-19 transmission and mortality among countries, and even among regions of single countries, closely align with local levels of air pollutants (Conticini et al., 2020). For example, increased contagiousness and COVID-19-related mortality in northern Italian regions, including Lombardia, Veneto and Emilia Romagna, have been correlated with high levels of air pollutants in these regions (Conticini et al., 2020). This hypothesis has become increasingly popular because despite the progress in characterising the clinical features of patients with COVID-19, details regarding the risk factors for clinically ill patients remain elusive.

A recent analysis by the Lancet Commission indicated that air pollution is responsible for 16% of global deaths, making it the primary cause of preventable premature death worldwide (Landrigan et al., 2018). Although the recent implementation of emergency lockdown measures has contributed to a considerable improvement in air quality around the world (Bherwani et al., 2020; Gautam, 2020a, (Gautam, 2020b); Muhammad et al., 2020), the levels of most air contaminants remain considerably higher than the values recommended by the WHO in several countries (He et al., 2020; Wang et al., 2020b). The rapid expansion of anthropogenic activities such as transportation, industrial processes and mining caused a widespread increase in many harmful pollutants that pose a major risk to human health (Sharma et al., 2020). For instance, prolonged exposure to common road transport pollutants, including nitrogen oxides and ground-level ozone, can induce oxidative stress and inflammation within the airways, inducing and significantly exacerbating health conditions such as asthma, chronic obstructive pulmonary disease, cardiovascular diseases and diabetes (Guarnieri and Balmes, 2014; Strak et al., 2017). These conditions have been shown to overlap with pathological features of COVID-19 critical illness, reinforcing the hypothesis of a dichotomy between air pollution and COVID-19 (Conticini et al., 2020; Wu et al., 2020). Furthermore, airborne particulate matter (PM) was recently shown to increase the viability of SARS-CoV-2, suggesting that direct microbial pathogenic transmission occurs through the air and the opportunity for infection is increased in highly polluted areas (Setti et al., 2020). Therefore, air pollution has been suggested to contribute to COVID-19 severity, either directly, by compromising the lungs' immune response to the infection, or indirectly, by exacerbating underlying respiratory or cardiovascular diseases (Brandt et al., 2020; Conticini et al., 2020; Dutheil et al., 2020). However, most studies have failed to account for multiple confounding factors (Conticini et al., 2020; Ogen, 2020) while others have focused on relatively large geographical regions (Cole et al., 2020; Liang et al., 2020; Wu et al., 2020). A convincing link between COVID-19 and air pollution can only be established by combining data from available ambient sensors with individual-level information, where possible, to reduce uncertainty in exposure estimates based on ambient monitoring data.

Here, we aimed to explore the relationship between air pollution exposure and COVID-19 mortality and infectivity in England, at the population- and individual-level. In the UK, adverse air quality causes approximately 30,000 premature deaths a year, and the concentration of most air pollutants is predicted to exceed limits set by European Union (EU) legislation beyond 2030 (UK Goverment, 2019; Pannullo et al., 2017). For instance, data collected in 2018 shows that in England specifically, ambient nitrogen oxides concentrations exceed these limits in 89% of designated air quality assessment zones (Affairs, 2019). In addition, England experienced the highest excess all-cause mortality rate in Europe in the first five months of 2020 compared with 2015–19, making it one of the world's most affected countries by the COVID-19 pandemic, according to recent data (Raleigh, 2020). These observations indicate that England provides a unique setting in which to examine the link between air pollution and COVID-19.

In this study, we first investigated potential links between regional and subregional variations in air pollution and population-level COVID-19-related deaths and cases in England by employing coarse and fine resolution methods. Next, we addressed these associations between air pollutants and the risk of COVID-19 infection at the individual scale by analysing UK Biobank data obtained from a cohort of 1464 subjects. Combining individual-level data on COVID-19 with high-resolution air pollution data, we show a clear link between long-term exposure to air pollution and COVID-19 in England. There are important, practical implications from this research. The identification of key modifiable environmental factors may contribute to mitigating the risk of COVID-19 and minimise the impact of future pandemics. Moreover, increased knowledge about the link between air pollution and COVID-19 may be beneficial worldwide by informing public health measures and disease management strategies in clinical practice.

2. Methods

2.1. Data sources for COVID-19 deaths and cases

Our study utilised regional-level, subregional-level and individual-level information to estimate the relationship between