ORIGINAL ARTICLE

# Effect of COVID-19 on air pollution and respiratory viral infection of children in South Korea

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Running title: COVID-19, AIR POLLUTION, AND RESPIRATORY VIRUS

KEYWORDS: air pollution, COVID-19, respiratory tract infections, hospitalized children, virus infections

**Abstract**

**Background:** Air pollution can be a risk factor for respiratory viral transmission and infection. The COVID-19 outbreak in 2020 may have affected ambient air pollution levels. Therefore, this study aimed to investigate air pollution levels and respiratory virus infection rates before and after the COVID-19 pandemic as well as determine relationships between these factors.

**Methods:** The daily mean temperature and concentrations of air pollutants (PM2.5, PM10, O3, NO2, CO, and SO2) in five metropolitan cities in South Korea were collected for the months of February to May from 2015 to 2020. Results of 14 respiratory viruses isolated using polymerase chain reaction in children with upper or lower respiratory tract infections were gathered during the same period. Trends of respiratory virus infection, temperature, and air pollutant level from February to May for six years were evaluated and possible relationships between respiratory virus infections and ambient air pollutant levels were assessed.

**Results:** Most air pollutants exhibited significantly decreasing trends in 2020 compared to the years before COVID-19. There were no differences in temperature. Adenovirus, bocavirus, metapneumovirus, parainfluenza virus 3, and rhinovirus were the most frequently detected viruses from February to May from 2015 to 2019, and infection rates dropped significantly in 2020. The concentration of ambient O3 was associated with rhinovirus infection in hospitalized children (aOR [95% CI], 1.028 [1.002, 1.055]).

**Conclusions:** After the COVID-19 outbreak, ambient air pollution levels and respiratory virus transmission decreased in the pediatric population of South Korea.

## 1 INTRODUCTION

Since the initial outbreak of COVID-19 in South Korea on January 20th, 2020, the spread of the virus has been increased rapidly, leading to more than 71,241 infections and 1,217 deaths in South Korea alone as of January 15th, 2021.[1] COVID-19 was first recognized in early December 2019 in Wuhan, China, and was declared a global pandemic on March 11th, 2020 by the World Health Organization. This novel coronavirus-19 belongs to the coronavirus family and its clinical features are known to vary widely from asymptomatic to fatal respiratory syndromes which may require invasive respiratory supports and even cause death.[2]

COVID-19 has not only deeply affected health issues worldwide but also driven significant changes to our environment. Global lockdowns and social distancing have been in place in many regions since the beginning of the COVID-19 outbreak, resulting in a sharp decline in the world's economies, industries, and other human activities.[3] However, owing to COVID-19 lockdowns, worldwide air quality and air pollution levels seem to have improved compared to levels before the current pandemic.[4-8] Specifically, social distancing, reduced human activities, and lockdowns have also had a positive impact on overall air quality in Seoul, South Korea.[8,9]

Over the past few decades, air pollution has become an especially urgent health issue and global health burden because of the considerable health risks imposed.[10] In Seoul, the most populous city in South Korea, with approximately 10 million residents, air pollution originating from human activity as well as natural sources, such as Asian fine dust, has become a leading health concern.[11] Among the various known air pollutants, inhalable atmospheric particulates, particulate matter (PM) 2.5 and PM10 are recognized as two of the most common and critical pollutants, defined as ambient particulate matter with aerodynamic equivalent diameters less than 10 μm and 2.5 μm, respectively. Other major air pollutants

include nitrogen dioxide (NO2), carbon monoxide (CO), sulfur dioxide (SO2), and ozone (O3).[10,12]

Multiple studies have assessed and proven the adverse health impacts of air pollution.[13] Both short-and long-term exposure to air pollution irritates the respiratory system and worsens the clinical prognosis of respiratory diseases, including acute respiratory infections, asthma, and chronic obstructive pulmonary disease (COPD) exacerbations.[13-15] Additionally, as acute lower respiratory infections comprise a great proportion of morbidity and mortality in both children and adults, concerns about the relationship between air pollution and respiratory diseases are on the rise.[16,17] However, since the COVID-19 outbreak, owing to cross-national social distancing, lockdowns, elevated hygiene levels with daily hand washing, and compulsory mask-wearing, respiratory virus transmission rates have significantly decreased, especially in childhood populations.[18,19] However, no studies have revealed the relationship between improvements in air pollution and decreased common respiratory virus transmission in the pediatric population of South Korea after the COVID-19 outbreak.

We analyzed data on the trends of ambient air pollution levels and temperature between February and May, when air quality is relatively poor in Korea,[20,21] and compared values from before and after the COVID-19 outbreak. The aim of this study was to examine the change in respiratory virus transmission in 2020 compared to previous years and determine whether any relationship with ambient air pollutants existed.

## 2 MATERIALS AND METHODS

### 2.1 Air pollution and meteorological data

Air pollution data included six different parameters: particulate matter with aerodynamic diameters less than 2.5 μm (PM2.5) or 10 μm (PM10), NO2, CO, SO2, and O3. Daily data of air pollutant concentrations were measured and recorded by air pollutant observatory stations in each of the five metropolitan cities of South Korea (Seoul, Daejeon, Daegu, Busan, Gwangju). These centers are under surveillance of the National Ambient Air Quality Monitoring Information System (NAMIS) and data are also supervised and disclosed by NAMIS.[22] We obtained daily highest and median temperature (°C) data of the same five metropolitan cities from the Korea Meteorological Administration (KMA), which is under the Korea Ministry of Environment.[23] Daily air pollutant levels and temperature from February 1st to May 31st of 2015 through 2019 represented the ambient air pollution status and temperature before the era of COVID-19, while data from 2020 the represented post-COVID-19 era. We compared mean levels of air pollutants and temperatures from the five identified cities before the era of COVID-19 to the levels in 2020, post-COVID-19, and the trends of air pollutants and temperature levels from 2015 to 2020.

### 2.2 Respiratory virus data

We retrospectively collected the results of respiratory viruses from pediatric patients who were admitted to the hospital from February 1st to May 31st, 2015, to 2020. Patients who were diagnosed with upper or lower respiratory tract infections (pharyngitis, croup, bronchitis, bronchiolitis, pneumonia, and asthma) and had laboratory confirmed virus results from nasopharyngeal specimen or sputum were included in this study. Fourteen respiratory viruses were detected using a multiplex real-time polymerase chain reaction (PCR) kit (Seagen, Seoul, South Korea): adenovirus, rhinovirus, metapneumovirus, bocavirus, parainfluenza

virus 1, 2, and 3, influenza viruses A and B, respiratory syncytial viruses A and B, and coronavirus 229E, OC43, and NL63. Patients who had bacterial co-infection, underlying immune deficiency, or congenital airway anomalies were excluded from this study.

This study was approved by the Institutional Review Board of Kangbuk Samsung Hospital (no. 2020-12-031).

### 2.3 Statistical analysis

Analyses were performed using STATA software version 16.1 for Windows (StataCorp LLC., College Station, TX, USA). Multiple comparisons of continuous variables of more than three were analyzed using one-way analysis of variance (ANOVA) with Bonferroni correction. Linear regression analysis was used to measure the changes in air pollution level, temperature, and viral infection rate. The relationship between viral infection and air pollutants was analyzed using multivariate logistic regression analysis after adjusting for age, sex, month, and year. A two-tailed P-value $< 0.05$ was considered statistically significant.

## 3 RESULTS

### 3.1 Clinical characteristics of subjects and types of respiratory viruses

During the study period from February to May 2015 to 2020, a total of 981 pediatric patients with upper or lower respiratory tract infections were admitted to the hospital and received multiplex PCR tests for 14 respiratory viruses. Among them, 666 patients were positive for at least one respiratory virus. The median age of the patients was 2 years (interquartile range 1, 3 years) and 55.1% were male. Pneumonia occurred in 304 patients (46%), followed by upper respiratory tract infections (201 cases, 30%), acute bronchiolitis or bronchitis (143 cases, 21%), and asthma (18 cases, 3%). Among the 14 viruses, rhinovirus (n=247, 25.2%), adenovirus (n=91, 9.3%), bocavirus (n=60, 6.1%), metapneumovirus (n=158, 16.1%), and parainfluenza virus 3 (n=99, 10.1%) were the five most common pathogens detected during the study period. The number of co-infection with two viruses was 152 cases (22.8%), and co-infection with three viruses was observed in 20 cases (3.0%) (Table 1).

### 3.2 Trends of ambient air pollution level and temperature before and after COVID19

Mean air pollutant levels and the highest daily temperatures from 2015 to 2019 to levels in 2020 were compared. The levels of PM2.5, PM10, NO2, and SO2 in 2020 were all significantly lower than the levels in each year from 2015 to 2019. Levels of CO in 2020 decreased significantly compared to levels in 2016, while O3 levels decreased significantly only relative to 2017 and 2019 (Figure 1).

Ambient air pollution levels and the highest daily temperatures from 2015 to 2020 were analyzed. The levels of PM10, PM2.5, NO2, SO2, and CO showed significantly decreased trends over the years (p for trends <0.005). On the contrary, the highest temperature and O3 level demonstrated no significant trends (Figure 1).

Monthly air pollutant levels from 2015 to 2019 were compared to those of each month in 2020 (Figure 2). Levels of PM10, PM2.5, NO2, and SO2 in each month decreased significantly in 2020 compared to the levels in the same month from 2015 to 2019. The monthly O3 level in 2020 showed no consistent change compared to the same month of previous years; there was a decrease in May 2020 when comparing to May 2016, 2017, and 2019, but no difference was observed in February and levels increased in April 2020 compared to April 2015. The level of CO in 2020 was only lower in March and April 2020 than in March 2015 and 2016 and April 2016 and 2018, respectively.

PM10, PM2.5, NO2, and CO levels showed significantly decreasing trends from February to May (p for trend <0.001), while O3 levels significantly increased by month (p for trend <0.001). There was no significant trend in SO2 levels by month (data not shown).

### 3.3 Respiratory viral infections before and after COVID-19

We investigated the trends of the five most common respiratory viruses from February and May before COVID19: adenovirus, bocavirus, metapneumovirus, parainfluenza virus 3, and rhinovirus. The prevalence of adenovirus, bocavirus, metapneumovirus, and parainfluenza virus 3 infections showed an increasing tendency by month from February to May, whereas rhinovirus did not show a significant trend by month (Figure 3A). Rates of all five viruses decreased significantly in 2020 compared to previous years before the COVID-19 outbreak; rhinovirus and metapneumovirus in 2020 decreased significantly compared to all years before COVID19; adenovirus decreased significantly compared to 2019, bocavirus decreased compared to 2017 (p-value < 0.05). In the case of parainfluenza virus 3, there was no detection in 2020 (Figure 3B).

### 3.4 Relationships between ambient air pollutants and respiratory viruses

Given that decreasing trends of ambient air pollution and respiratory virus infection rates were identified after the COVID-19 outbreak, we investigated whether there were any relationships between air pollutants and respiratory virus infections. We analyzed the association between the rate of respiratory virus infection and 3-day mean ambient air pollutant levels before admission from 2015 to 2020 using multivariate logistic regression analysis after adjusting for age, sex, month, and year. Among the air pollutants, only the 3-day mean O3 level before admission was associated with rhinovirus infection (aOR [95% CI], 1.028 [1.002, 1.055]). The other air pollutants showed no significant relationships with respiratory viral infections (Table 2). The results were consistent when we analyzed the association of respiratory viral infection with 7-day mean air pollutant levels before admission (data not shown).

## 4 DISCUSSION

In this retrospective observational study comparing ambient air pollution level, temperature, and respiratory viral infections in hospitalized children specifically before and after the COVID-19 outbreak, we found significant decreasing trends of both ambient air pollution and respiratory viral infection rates after COVID-19, but no significant temperature differences. When we investigated the association between levels of ambient air pollutants and rates of respiratory viral infection, only O3 was shown to increase the risk of hospitalization due to rhinovirus specifically. Previous studies have mostly focused on the associations of ambient air pollution with asthma or lung function, and only a few studies have been conducted on respiratory tract infections.[14,24-26] However, there have been inconsistent results depending on the timing of measurement, weather conditions, humidity, seasonal variability, and selection of subjects. We found that 3-day mean O3 levels before admission were associated with hospitalization with rhinovirus-related respiratory tract infection.

COVID-19, a major hazardous health issue of our current era, has brought many changes in human societies and is still an ongoing problem. Common sources of air pollutants are usually power plants, industries, domestic heating, vehicle engines, and even natural emissions.[11] However, worldwide shutdowns of numerous industries and social distancing have paradoxically brought positive impacts on air pollution, which has been a major health concern over the last few decades. Traditionally, large cities in South Korea suffer from fine particles mostly in the winter and spring seasons, originating primarily from domestic heating, increased vehicle use, and geographical issues pertaining to the influence of Asian fine dust.[11,21] In this study, most air pollutants, except for O3, showed a decreasing tendency from February to May. Improvement of ambient air pollution levels in 2020 after

COVID-19 is a worldwide trend studied in prior researches.[5,6,8] In this study, we also found most air pollutant levels decreased in 2020 compared to the years before COVID-19.

Few studies have reported poor air quality as a factor promoting respiratory virus transmission and infections.[14,15] Air pollution can increase virus survival and modulate human immune responses, resulting in dysfunction of pulmonary tracheal cilia and decreased activity of alveolar macrophages. This adverse effect may be especially notable in pediatric patients due to immature development of the respiratory system, weaker immune response, and higher susceptibility to viral infections.[27,28] However, studies on the relationship between air pollution and pediatric respiratory health remain limited, and the results inconsistent. We found that air quality improved after the COVID-19 outbreak in South Korea, and respiratory viral infection rates decreased simultaneously. However, there were no positive associations between air pollutant levels and rates of respiratory virus infection in this study. We assumed that factors other than air pollutants have stronger effects on the reduction of respiratory viral infections and general health status. Factors may include online learning programs among children with decreased direct contact and outdoor activities, and elevated hygiene with frequent hand washing and facial mask wearing. These may result in a decrease in person-to-person aerosol virus transmissions and fewer hospital visits in children.

The current study is the first known study to demonstrate not only the relationship between decreases in air pollution and respiratory virus incidence after the COVID-19 outbreak in South Korea but also the actual relationship between air pollutants before admission and hospitalization due to respiratory viruses at the same time. Prior studies have focused on the improvement of air pollution or reduction in respiratory viral transmissions after the COVID-19 outbreak,[8,9,19,29] which did not show evidence-based correlations between each air pollutant and respiratory virus incidence. We also analyzed the 3-day and 7-day

mean air pollutant levels before admission, considering viral incubation periods before symptom onset.

There are some limitations to this study. We gathered air pollution and temperature data from a center located near the hospital and did not use geographical data based on patients' actual residences. In addition, respiratory viral infection was studied in a single tertiary hospital, so it was not possible to represent national data, and we investigated respiratory viral infections only in hospitalized children, not in outpatients. Furthermore, our study did not gather information on factors influencing person-to-person viral transmission, such as social distancing or hand washing. This may have resulted in some deviation from the exact impact of ambient air pollution on respiratory viral transmission.

## 5 CONCLUSIONS

Ambient air pollution levels, except for O3, improved since the beginning of the COVID-19 outbreak, but no temperature changes were identified in South Korea. Rates of respiratory viral infection other than the novel coronavirus significantly dropped among hospitalized children in 2020, and hospitalization due to rhinovirus has been shown to be related to the 3-day mean O3 level before admission. However, other air pollutants were not associated with the respiratory viral infection. Aside from better air quality, improvement of personal hygiene, online learning, or social distancing may all be factors contributing to reduced respiratory viral infection in children after the COVID-19 outbreak.

**REFERENCES**


1. Agency KDCaP. COVID-19. 2021; http://ncov.mohw.go.kr/. Accessed 15 Jan., 2021.
2. Zhu N, Zhang D, Wang W, et al. A Novel Coronavirus from Patients with Pneumonia in China, 2019. *N Engl J Med.* 2020;382(8):727-733.
3. Caribbean(ECLAC) ECfLAat. The effects of the coronavirus disease(COVID-19) pandemic on international trade and logistics. 2020; https://repositorio.cepal.org/bitstream/handle/11362/45878/1/S2000496_en.pdf. Accessed Dec 18, 2020.
4. He G, Pan Y, Tanaka T. The short-term impacts of COVID-19 lockdown on urban air pollution in China. *Nat Sustain.* 2020;3(12):1005-1011.
5. Wang M, Liu F, Zheng M. Air quality improvement from COVID-19 lockdown: evidence from China. *Air Qual Atmos Health.* 2020:1-14.
6. Zangari S, Hill DT, Charette AT, Mirowsky JE. Air quality changes in New York City during the COVID-19 pandemic. *Sci Total Environ.* 2020;742:140496.
7. Lovarelli D, Conti C, Finzi A, Bacenetti J, Guarino M. Describing the trend of ammonia, particulate matter and nitrogen oxides: The role of livestock activities in northern Italy during Covid-19 quarantine. *Environ Res.* 2020;191:110048.
8. Seo JH, Jeon HW, Sung UJ, Sohn J-R. Impact of the COVID-19 Outbreak on Air Quality in Korea. *Atmosphere.* 2020;11(10).
9. Han BS, Park K, Kwak KH, et al. Air Quality Change in Seoul, South Korea under COVID-19 Social Distancing: Focusing on PM2.5. *Int J Environ Res Public Health.* 2020;17(17).
10. Organization WH. Ambient air pollution: a global assessment of exposure and burden of disease. 2016; https://apps.who.int/iris/bitstream/handle/10665/250141/9789241511353-eng.pdf?sequence=1. Accessed Oct 10, 2020.

11. Kim HC, Kim S, Kim BU, et al. Recent increase of surface particulate matter concentrations in the Seoul Metropolitan Area, Korea. *Sci Rep.* 2017;7(1):4710.
12. World Health Organization. WHO Air quality guidelines for particulate matter, ozone, nitrogen dioxide and sulfur dioxide. 2005; http://whqlibdoc.who.int/hq/2006/WHO_SDE_PHE_OEH_06.02_eng.pdf. Accessed Oct 10, 2020.
13. Kampa M, Castanas E. Human health effects of air pollution. *Environ Pollut.* 2008;151(2):362-367.
14. Horne BD, Joy EA, Hofmann MG, et al. Short-Term Elevation of Fine Particulate Matter Air Pollution and Acute Lower Respiratory Infection. *Am J Respir Crit Care Med.* 2018;198(6):759-766.
15. Jo EJ, Lee WS, Jo HY, et al. Effects of particulate matter on respiratory disease and the impact of meteorological factors in Busan, Korea. *Respir Med.* 2017;124:79-87.
16. Michaud CM MC, Bloom BR. Burden of disease: implications for future research. *JAMA.* 2001;285(5):535-539.
17. Ortiz C, Linares C, Carmona R, Diaz J. Evaluation of short-term mortality attributable to particulate matter pollution in Spain. *Environ Pollut.* 2017;224:541-551.
18. Tan JY, Conceicao EP, Sim XYJ, Wee LEI, Aung MK, Venkatachalam I. Public health measures during COVID-19 pandemic reduced hospital admissions for community respiratory viral infections. *J Hosp Infect.* 2020;106(2):387-389.
19. Kuitunen I, Artama M, Makela L, Backman K, Heiskanen-Kosma T, Renko M. Effect of Social Distancing Due to the COVID-19 Pandemic on the Incidence of Viral Respiratory Tract Infections in Children in Finland During Early 2020. *Pediatr Infect Dis J.* 2020;39(12):e423-e427.

20. Choi T-Y, Moon H-G, Kang D-I, Cha J-G. Analysis of the Seasonal Concentration Differences of Particulate Matter According to Land Cover of Seoul -Focusing on Forest and Urbanized Area. *J Environ Impact Assess.* 2018;27(6):635-646.
21. Kim HC, Kim E, Bae C, Cho JH, Kim B-U, Kim S. Regional Contributions to Particulate Matter Concentration in the Seoul Metropolitan Area, Korea: Seasonal Variation and Sensitivity to Meteorology and Emissions Inventory. *Atmos Chem Phys.* 2017;17(17):10315-10332.
22. National Ambient air quality Monitoring Information System. Air pollution data 2020; http://www.airkorea.or.kr/web/pastSearch?pMENU_NO=123. Accessed 24 Dec, 2020.
23. Korea Meteorological Administration. Automated Synoptic Observing System (ASOS). 2020; https://data.kma.go.kr/data/grnd/selectAsosRltmList.do?pgmNo=36. Accessed 10 Sep, 2020.
24. Nenna R, Evangelisti M, Frassanito A, et al. Respiratory syncytial virus bronchiolitis, weather conditions and air pollution in an Italian urban area: An observational study. *Environ Res.* 2017;158:188-193.
25. Vandini S, Corvaglia L, Alessandroni R, et al. Respiratory syncytial virus infection in infants and correlation with meteorological factors and air pollutants. *Ital J Pediatr.* 2013;39(1):1.
26. Hei Collaborative Working Group on Air Pollution PHiHCMC, Le TG, Ngo L, et al. Effects of short-term exposure to air pollution on hospital admissions of young children for acute lower respiratory infections in Ho Chi Minh City, Vietnam. *Res Rep Health Eff Inst.* 2012(169):5-72; discussion 73-83.
27. Garcia E, Berhane KT, Islam T, et al. Association of Changes in Air Quality With Incident Asthma in Children in California, 1993-2014. *JAMA.* 2019;321(19):1906-1915.

28. Berhane K, Chang CC, McConnell R, et al. Association of Changes in Air Quality With Bronchitic Symptoms in Children in California, 1993-2012. *JAMA*. 2016;315(14):1491-1501.

29. Olsen SJ, Azziz-Baumgartner E, Budd AP, et al. Decreased Influenza Activity During the COVID-19 Pandemic — United States,Australia, Chile, and South Africa, 2020. *MMWR Morb Mortal Wkly Rep*. 2020;69(37):1305-1309.