


# PM<sub>2.5</sub>, PM<sub>10</sub> and bronchiolitis severity: A cohort study

Gregorio P. Milani<sup>1,2</sup>  | Marco Cafora<sup>1,3</sup> | Chiara Favero<sup>1</sup> | Anna Lugini<sup>4</sup> | Michele Carugno<sup>1,5</sup> | Erica Lenzi<sup>1</sup> | Anna Pistocchi<sup>3</sup> | Eva Pinatel<sup>6</sup> | Luigi Pariota<sup>7</sup> | Luca Ferrari<sup>1,5</sup> | Valentina Bollati<sup>1,5</sup>

<sup>1</sup>Department of Clinical Sciences and Community Health, Università degli Studi di Milano, Milan, Italy

<sup>2</sup>Pediatric Unit, Fondazione IRCCS Ca' Granda Ospedale Maggiore Policlinico, Milan, Italy

<sup>3</sup>Department of Medical Biotechnology and Translational Medicine, Università degli Studi di Milano, Milan, Italy

<sup>4</sup>Department of Life Science and System Biology, Università degli Studi di Torino, Turin, Italy

<sup>5</sup>Occupational Health Unit, Fondazione IRCCS Ca' Granda Ospedale Maggiore Policlinico, Milan, Italy

<sup>6</sup>Institute of Biomedical Technologies, National Research Council, Milan, Italy

<sup>7</sup>Department of Civil, Architectural and Environmental Engineering, Federico II University of Naples, Naples, Italy

## Correspondence

Gregorio P. Milani, Pediatric unit, Foundation IRCCS Ca' Granda, Ospedale Maggiore Policlinico, via della Commenda 9, 20122 Milan, Italy.  
Email: [milani.gregoriop@gmail.com](mailto:milani.gregoriop@gmail.com)

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## Abstract

**Background:** A few studies suggest that particulate matter (PM) exposure might play a role in bronchiolitis. However, available data are mostly focused on the risk of hospitalization and come from retrospective studies that provided conflicting results. This prospective study investigated the association between PM (PM<sub>2.5</sub> and PM<sub>10</sub>) exposure and the severity of bronchiolitis.

**Methods:** This prospective cohort study was conducted between November 2019 and February 2020 at the pediatric emergency department of the Fondazione IRCCS Ca' Ospedale Maggiore Policlinico, Milan, Italy. Infants <1 year of age with bronchiolitis were eligible. The bronchiolitis severity score was assessed in each infant and a nasal swab was collected to detect respiratory viruses. The daily PM<sub>10</sub> and PM<sub>2.5</sub> exposure in the 29 preceding days were considered. Adjusted regression models were employed to evaluate the association between the severity score and PM<sub>10</sub> and PM<sub>2.5</sub> exposure.

**Results:** A positive association between the PM<sub>2.5</sub> levels and the severity score was found at day-2 ( $\beta$  0.0214, 95% CI 0.0011–0.0417,  $p = .0386$ ), day-5 ( $\beta$  0.0313, 95% CI 0.0054–0.0572,  $p = .0179$ ), day-14 ( $\beta$  0.0284, 95% CI 0.0078–0.0490,  $p = .0069$ ), day-15 ( $\beta$  0.0496, 95% CI 0.0242–0.0750,  $p = .0001$ ) and day-16 ( $\beta$  0.0327, 95% CI 0.0080–0.0574,  $p = .0093$ ). Similar figures were observed considering the PM<sub>10</sub> exposure and limiting the analyses to infants with respiratory syncytial virus.

**Conclusion:** This study shows for the first time a direct association between PM<sub>2.5</sub> and PM<sub>10</sub> levels and the severity of bronchiolitis.

## KEYWORDS

air pollution, bronchiolitis, environment, infants, particulate matter, respiratory syncytial virus, severity

## 1 | BACKGROUND

The association between air pollution and chronic respiratory diseases is well established in adults and the elderly.<sup>1,2</sup> Increasing

data suggest that this association might occur also among children.<sup>3–5</sup> Moreover, a few studies suggest that particulate matter (PM) might be implicated in the development of bronchiolitis in infancy.<sup>6,7</sup> PM exposure might modulate viral infectivity, alter cytokine expression

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and impair the phagocytic ability of immune cells, thus enhancing the infection burden on the infant.<sup>8,9</sup>

However, epidemiological studies on PM and bronchiolitis have provided partially conflicting data.<sup>6</sup> A meta-analysis published in 2018 pooled data from 8 studies to verify the association between particulate matter and risk of hospitalization for bronchiolitis and concluded that the effects of PM<sub>10</sub> were unclear, whereas increased PM<sub>2.5</sub> levels were not associated with a higher risk of hospitalization.<sup>10</sup>

One of the principal limitations of the available evidence is that it mainly comes from retrospective data or from International Classification of Diseases codes-based studies, and it is mostly focused on the risk of hospitalization.<sup>6,11</sup> Therefore, prospective cohort studies including clinical data from individual patients with different degrees of bronchiolitis severity would be of great importance to gauge the hypothesis of an association between PM and bronchiolitis.

Hence, the aim of this prospective cohort study was the investigate the association between PM (PM<sub>2.5</sub> and PM<sub>10</sub>) exposure and the severity of bronchiolitis in infants.

## 2 | MATERIALS AND METHODS

### 2.1 | Study population and procedures

This prospective cohort study was conducted between November 2019 and February 2020 at the pediatric emergency department of the Fondazione IRCCS Ca' Ospedale Maggiore Policlinico, Milan, Italy, a tertiary emergency department with more than 20,000 patients visited per year.

Eligible for this study were infants <1 year of age visiting the pediatric emergency department for bronchiolitis. The diagnosis of bronchiolitis was made in infants with a history of acute respiratory tract infection of the upper airways in the previous week, followed by an acute onset of respiratory distress, cough and diffuse crackles on auscultation.<sup>12</sup> Infants with underlying conditions potentially associated with a worse clinical course of bronchiolitis (e.g., infants with bronchopulmonary dysplasia or on chronic treatment with immunosuppressants) were excluded.

At enrollment, all infants underwent a nasal swab by a trained researcher. Once collected, the nasal swabs were stored at -80°C until nucleic acids extraction for the PCR-detection of the respiratory syncytial virus (RSV), the main cause of bronchiolitis in infancy.<sup>13</sup> In addition, the same trained researcher assessed the bronchiolitis severity score according to our standard protocol.<sup>14,15</sup> This score includes the evaluation of the following parameters: ambient air O<sub>2</sub>-saturation (>95% = 0; 95-90% = 1; <90% = 2), respiratory rate (<45/min = 0; 45-60/min = 1; >60/min = 2), thoracic retractions (none = 0; present = 1; present and associated with nasal flare = 2) and ability to feed (normal = 0; reduced = 1; strongly reduced = 2). The results of each parameter are summed to define the disease severity as mild (<4), moderate

### Key Message

Some studies suggested that particulate matter (PM) exposure might play a role in bronchiolitis. However, available data come mainly from retrospective studies and provide conflicting results. Our prospective cohort study showed for the first time a direct association between PM (PM<sub>2.5</sub> and PM<sub>10</sub>) exposure and the severity of bronchiolitis.

(4-6) or severe (≥7).<sup>12,16</sup> All hospitalized infants were reevaluated every day until their discharge. If hospitalization was not required, mothers were advised to return to the emergency department in case of a worsening condition. A phone call after 7 days was performed to have confirmation that the clinical conditions had not worsened after discharge.

The most severe score assessed in each infant during the bronchiolitis episode was considered for the analyses.

The study was approved by the ethical committee of the Fondazione IRCCS Ca' Granda Ospedale Maggiore Policlinico, Milan, Italy. Informed consent was obtained by the parents of the infants.

### 2.2 | Data collection and classification

For each infant, the following information was collected: age, sex, birth weight and length, body weight and height at enrollment, ethnicity, residential address, delivery mode, current breastfeeding, history of antibiotics intake, allergy, daycare attendance, number of siblings and the presence of pets at home.

Moreover, age, educational level, current smoking, the presence of any chronic disease, treatment or allergy of both parents were registered and information on smoking during pregnancy, assumption of antibiotics during pregnancy or during breastfeeding and the result of Group B Streptococcus in vaginal swab at the end of the pregnancy was obtained from the mother.

### 2.3 | Particulate matter exposure assessment

PM<sub>2.5</sub> and PM<sub>10</sub> (i.e., particulate matter with a particle size <2.5 or <10 μm, respectively), exposure levels were obtained from the Open Data Lombardy Region (<https://www.dati.lombardia.it>) database, which contains daily mean estimates of municipal aggregate values calculated by the Regional Environmental Protection Agency (ARPA Lombardy). The assessment of the pollutant concentrations was based on the ARIA Regional Modeling ([www.aria-net.it](http://www.aria-net.it)), which is a chemical-physical model of air quality that simulates the dispersion and chemical reactions of atmospheric pollutants. It integrates the data measured from the monitoring stations of the ARPA Lombardy air quality network as well as meteorological data,

emissions, concentrations at the beginning of the simulation period, and trends in adjacent areas, covering the whole Lombard territory with a grid of  $1 \times 1 \text{ km}^2$  cells and providing daily mean estimates available from the website at municipality resolution. Each subject was assigned the daily  $\text{PM}_{10}$  and  $\text{PM}_{2.5}$  concentrations of the municipality of residence in the 29 days (day-1 to day-29) preceding the severity score retained for the analysis and of the Municipality of Milan for the day of recruitment (day-0) or during hospitalization.

## 2.4 | Laboratory analysis

Viral RNA was extracted from nasal swabs using the QIAamp Viral RNA Mini kit (Qiagen), according to the manufacturer's instructions. The purified RNA was eluted in  $50 \mu\text{l}$  and immediately stored at  $-80^\circ\text{C}$ . For the quantification of RSV-RNA levels, a commercial real-time RT-qPCR kit was used (PrimerDesign™ genesig; PrimerDesign Ltd., Southampton, Hants, UK) and the qPCR were conducted using a QuantStudio3 real-time PCR system (Applied Biosystem). A standard curve and template negative controls (sterile water) were included on each plate.

## 2.5 | Statistical analysis

Summary statistics of study subjects' characteristics were reported in terms of frequency and percentage for categorical variables and in terms of mean and standard deviation or median and first quartile–third quartile as appropriate for continuous variables. The normal distribution of continuous variables was tested by graphical inspection and by Kolmogorov–Smirnov test.

With regards to the effect of  $\text{PM}_{10}$  and  $\text{PM}_{2.5}$  on bronchiolitis severity, univariate and multivariable ordinal logistic regression models were fitted. The response variable was the score, using 7 ordinal categories. To evaluate short-term PM exposure, pollutant levels were retrieved as daily means up to 2 days before the day of the enrollment and as averages over 1 week, 2 weeks, 3 weeks and 1 month; we also calculated the average of PM levels in the first, second, third and fourth week. Multivariable analyses were adjusted for age, sex, ethnicity, use of antibiotics during pregnancy and use of antibiotics in the last month. Potential confounders were included in the multivariate model after verifying the presence of an association in a univariate model.

Estimated effects are reported as  $\beta$  and 95% confidence intervals (CI) associated with an increase of  $1 \mu\text{g}/\text{m}^3$  in PM exposure. Statistical analyses were performed with SAS software (version 9.4; SAS Institute Inc.). A two-sided  $p$ -value of .05 was considered statistically significant.

## 3 | RESULTS

A total of 161 infants with bronchiolitis visited the pediatric emergency department of Fondazione IRCCS Ca' Ospedale Maggiore

Policlinico, Milan, Italy, during the study period. Thirty-seven were not eligible due to underlying conditions potentially associated with a worse clinical course of bronchiolitis and 14 did not accept to participate. Hence, a total of 110 infants (mean age  $6.3 \pm 5.5$  months, 61% males) with bronchiolitis were finally included. The baseline characteristics of these subjects are given in Table 1. RSV was detected in 64 (58%) of the 110 infants. The bronchiolitis severity score was mild in 75 (68%), moderate in 34 (31%) and severe in one (0.6%) subject. Among infants with RSV, bronchiolitis was mild in 39 (61%) and moderate in 25 (39%) (Figure 1). Data regarding the mother and the father of the included subjects are reported in Table 2. The mean levels of  $\text{PM}_{10}$  and  $\text{PM}_{2.5}$  for each time lag preceding the severity peak are given in Table S1.

Results from univariate analyses of variables associated with bronchiolitis severity scores are given in the supplementary online

**TABLE 1** Characteristics of the study participants ( $N = 110$ ). For some variables, percentage total slightly differs from 100% due to rounding effect

Characteristics	
Age, months mean $\pm$ SD	6.3 $\pm$ 5.5
Sex, N (%)	
Males	67 (61)
Females	43 (39)
Birth weight, kg mean $\pm$ SD	3.204 $\pm$ 0.550
Birth length, cm mean $\pm$ SD	49.6 $\pm$ 2.2
Gestational age, median [Q1–Q3]	38 [38–40]
Weight, kg mean $\pm$ SD	7.2 $\pm$ 2.2
Length, cm mean $\pm$ SD	64.8 $\pm$ 10.0
Living area, N (%)	
City of Milan	73 (66)
Province of Milan, outside city area	35 (32)
Other provinces	2 (1.8)
Ethnicity, N (%)	
Caucasian	87 (79)
African	6 (5.4)
Asian	11 (10)
Multi-ethnic	6 (5.4)
Delivery mode, N (%)	
Vaginal delivery	68 (62)
Vacuum	5 (4.6)
Elective cesarean section	25 (23)
Emergency cesarean section	12 (11)
Systemic antibiotic after birth, N (%)	
Yes	25 (23)
No	85 (77)
Systemic antibiotic in the last month, N (%)	
Yes	6 (5.4)

(Continues)

TABLE 1 (Continued)

Characteristics	
No	104 (95)
Allergy, N (%)	
Yes	3 (2.8)
No	107 (97)
Daycare attendance, N (%)	
Yes	26 (24)
No	84 (76)
Siblings, N (%)	
Yes	80 (73)
No	30 (27)
Number of siblings, N (%)	
0	31 (28)
1	50 (45)
2	23 (21)
3	6 (5.5)
Siblings attending daycare/school, N (%)	
Yes	83 (75)
No	27 (25)
Pets at home, N (%)	
Yes	25 (23)
No	85 (77)
Current breastfeeding, N (%)	
Characteristics	
Yes	69 (63)
No	41 (37)

tables (Tables S2 and S3).  $PM_{2.5}$  was positively associated with the bronchiolitis severity score on day-2 ( $\beta$  0.0214, 95% CI 0.0011–0.0417,  $p = .0386$ ), on day-5 ( $\beta$  0.0313, 95% CI 0.0054–0.0572,  $p = .0179$ ), on day-14 ( $\beta$  0.0284, 95% CI 0.0078–0.0490,  $p = .0069$ ), on day-15 ( $\beta$  0.0496, 95% CI 0.0242–0.0750,  $p = .0001$ ) and on day-16 ( $\beta$  0.0327, 95% CI 0.0080–0.0574,  $p = .0093$ ).  $PM_{10}$  was positively associated with the bronchiolitis severity score on day-2 ( $\beta$  0.0171, 95% CI 0.0015–0.0326,  $p = .0317$ ), on day-5 ( $\beta$  0.0268, 95% CI 0.0067–0.0469,  $p = .0091$ ), on day-14 ( $\beta$  0.0220, 95% CI 0.0062–0.0379,  $p = .0065$ ), on day-15 ( $\beta$  0.0356, 95% CI 0.0167–0.0545,  $p = .0002$ ) and on day-16 ( $\beta$  0.0230, 95% CI 0.0049–0.0412,  $p = .0128$ ).

Adjusted models returned very similar results (Table 3). A significant association with the  $PM_{2.5}$  and  $PM_{10}$  mean levels during the third week before the assessment and the bronchiolitis severity score was observed ( $\beta$  0.0426, 95% CI 0.0173–0.0679,  $p = .0010$ ;  $\beta$  0.0478, 95% CI 0.0159–0.0797,  $p = .0034$ , respectively). Similar figures were observed considering only  $PM_{2.5}$  and  $PM_{10}$  exposure and bronchiolitis severity score of infants with bronchiolitis due to RSV infection (Table S4).

#### 4 | DISCUSSION

Bronchiolitis is the main cause of hospitalization in infants. Although a few risk factors (e.g., pre-existing pulmonary diseases) are recognized, most cases occur in previously healthy infants without predisposing risk factors.<sup>17</sup> This prospective cohort study showed for the first time a significant association between  $PM_{2.5}$  and  $PM_{10}$  levels and the severity of bronchiolitis.

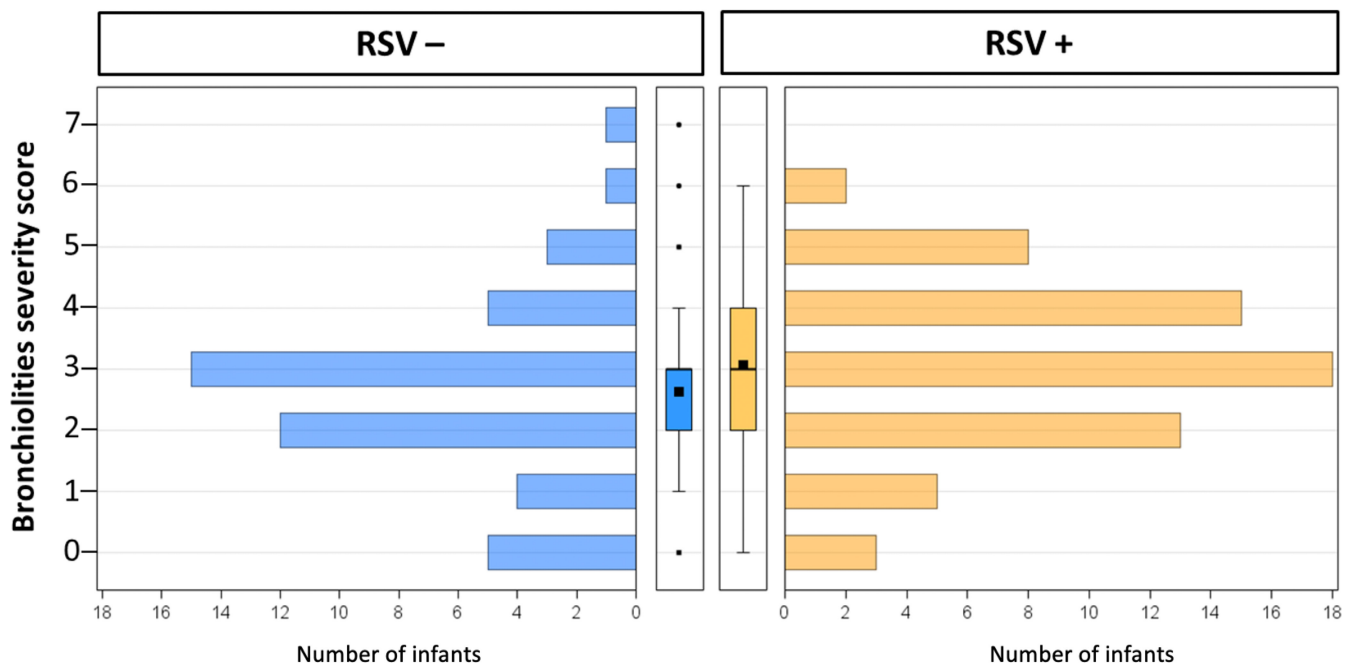


FIGURE 1 Bronchiolitis severity score in infants with and without respiratory syncytial virus (RSV)

**TABLE 2** Characteristics of parents of the study participants ( $N = 110$ ). For some variables, percentage total slightly differs from 100% due to rounding effect

	Mothers	Fathers
Age, years, mean $\pm$ SD	34.8 $\pm$ 5.6	37.1 $\pm$ 6.3
Education, N (%)		
Elementary school	5 (4.6)	1 (0.9)
Junior high school	14 (13)	18 (16)
High school	29 (27)	38 (35)
University	62 (56)	53 (48)
Smoking, N (%)		
Yes	10 (9.2)	41 (37)
No	100 (91)	69 (63)
Maternal smoking during pregnancy, N (%)		
Yes	7 (6.4)	—
No	103 (94)	—
Chronic diseases, N (%)		
Yes	31 (28)	13 (12)
No	79 (72)	97 (88)
Allergy, N (%)		
Yes	43 (39)	30 (27)
No	67 (61)	80 (73)
Systemic antibiotics during pregnancy, N (%)		
Yes	27 (25)	—
No	83 (75)	—
Systemic antibiotics during breastfeeding, N (%)		
Yes	12 (11)	—
No	98 (89)	—
Vaginal swab for Group B Streptococcus, N (%)		
Positive	14 (14)	—
Negative	89 <sup>a</sup> (86)	—

<sup>a</sup>Information was not available for 7 mothers.

Previous retrospective studies investigating the association between the risk of hospitalization or number of clinical encounter for infants with bronchiolitis and exposure to PM ended with inconsistent results. A study performed in the United States on ~20,000 infants found very limited support for a link between the acute increase of PM<sub>2.5</sub> and bronchiolitis hospitalization.<sup>18</sup> A further study conducted in Canada on approximately 11,000 infants found that exposure to PM<sub>10</sub> and PM<sub>2.5</sub> had no association with inpatient or outpatient clinical encounter for bronchiolitis.<sup>19</sup> On the other hand, studies conducted in Italy, Israel and France found a positive association between the risk of hospitalization and exposure to PM  $\leq 10 \mu\text{m}$  in infants with bronchiolitis.<sup>6,20–22</sup> This association was also observed in a study conducted in Hong Kong on >29,000 subjects.<sup>23</sup> Finally, a study conducted on about 12,000 infants hospitalized for RSV bronchiolitis found that exposure to PM<sub>2.5</sub> and PM<sub>10</sub>, together with other air pollutants might explain >20% of the hospitalizations.<sup>24</sup> In this study, which includes individual data of all infants visiting the pediatric emergency department, we were able to observe

a positive association between the exposure to PM<sub>2.5</sub> and PM<sub>10</sub> and bronchiolitis severity thus confirming the potential role of PM in bronchiolitis. Moreover, such association was observed in the few days before the severity score assessment or about 2 to 3 weeks before. These observations deserve some consideration.

It has been speculated that the air pollutants and especially PM might play a key role in the viral spread and transmission.<sup>25,26</sup>

It is known that after the infection, bronchiolitis symptoms peak occurs roughly within 2 weeks.<sup>6,27</sup> The positive association between the levels of PM<sub>2.5</sub> and PM<sub>10</sub> about 2 weeks preceding the symptoms peak corroborates the hypothesis that high levels of PM might increase the viral load reaching the patient's airways.<sup>25,26</sup> Growing evidence points out that PM<sub>2.5</sub> and PM<sub>10</sub> cause airways inflammation<sup>28,29</sup> by stimulating the release of pro-inflammatory cytokines (e.g., IL-1, IL-6, IL-8 and IL-33).<sup>29–31</sup> High levels of airways inflammation are associated with severe bronchiolitis, in turn.<sup>32,33</sup> These data might explain the positive association found in this study between the severity of bronchiolitis and the levels of PM<sub>2.5</sub> and PM<sub>10</sub> exposure also in the few days preceding the severity peak. Overall, this study suggests a mediating role of PM in different stages of bronchiolitis (Figure 2).

Based on our data, we speculate that personalized preventive measures might be developed for infants at risk of severe bronchiolitis. In particular, strategies to limit the spread of respiratory viruses (e.g., limiting the time spent in potentially contagious settings) or to reduce airways inflammation (e.g., preventively using inhaled anti-inflammatory molecules) might be performed in the days following high levels of PM<sub>2.5</sub> and PM<sub>10</sub> exposure. These hypotheses should be tested in future prospective studies.

It is recognized that climate has an impact on air pollutant concentrations.<sup>34</sup> Recent observations suggest that climate change and especially increased temperatures are associated with PM peaks in the atmosphere.<sup>35,36</sup> The results of this study and the current context of global warming point out that increasing efforts should be addressed to raise awareness among parents, healthcare providers and public authorities on the possible role of PM on infant health and to limit its production.

This study has some limitations: first, it included only infants with bronchiolitis visiting the emergency department. Therefore, infants managed by primary care physicians or by pediatricians in private practice were not considered. Second, the study included a limited number of patients from a single center. Finally, we did not evaluate the possible role of chronic exposure to PM<sub>2.5</sub> and PM<sub>10</sub>. Yet, the study has important strengths. All clinical data were prospectively collected. Several confounding factors for bronchiolitis severity were controlled. Furthermore, the study was conducted immediately before the COVID-19 outbreak in Italy and therefore there was no potential confounding effect of exceptional preventive measures (e.g., homebound, social distancing, use of facial masks or school closure) applied during the first wave of the pandemic.<sup>37</sup>

In conclusion, this study shows a direct association between PM<sub>2.5</sub> and PM<sub>10</sub> levels and the severity of bronchiolitis. Levels of

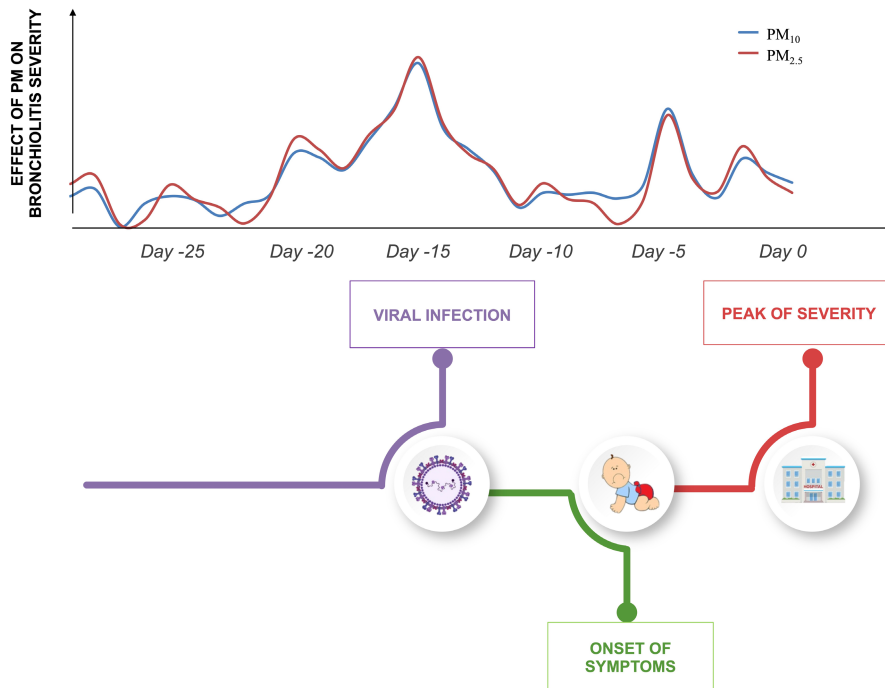
TABLE 3 Association between exposure to PM<sub>2.5</sub> and PM<sub>10</sub> and bronchiolitis severity score (N = 110 case of bronchiolitis)

PM <sub>10</sub>	$\beta$	SE	95% CI	p-value	PM <sub>2.5</sub>	$\beta$	SE	95% CI	p-value
Day 0	0.0099	0.0090	-0.0077	0.0275	Day 0	0.0067	0.0110	-0.0148	0.0283
Day -1	0.0131	0.0078	-0.0022	0.0283	Day -1	0.0116	0.0092	-0.0065	0.0297
Day -2	<b>0.0175</b>	<b>0.0083</b>	<b>0.0013</b>	<b>0.0338</b>	Day -2	<b>0.0214</b>	<b>0.0104</b>	<b>0.0011</b>	<b>0.0417</b>
Day -3	0.0051	0.0074	-0.0094	0.0197	Day -3	0.0070	0.0099	-0.0124	0.0263
Day -4	0.0125	0.0086	-0.0044	0.0295	Day -4	0.0112	0.0100	-0.0083	0.0308
Day -5	<b>0.0333</b>	<b>0.0114</b>	<b>0.0109</b>	<b>0.0557</b>	Day -5	<b>0.0313</b>	<b>0.0132</b>	<b>0.0054</b>	<b>0.0572</b>
Day -6	0.0088	0.0094	-0.0097	0.0272	Day -6	0.0040	0.0115	-0.0185	0.0265
Day -7	0.0049	0.0096	-0.0139	0.0237	Day -7	-0.0032	0.0120	-0.0267	0.0204
Day -8	0.0067	0.0095	-0.0119	0.0252	Day -8	0.0035	0.0109	-0.0180	0.0249
Day -9	0.0061	0.0096	-0.0128	0.0249	Day -9	0.0047	0.0122	-0.0192	0.0285
Day -10	0.0067	0.0087	-0.0103	0.0237	Day -10	0.0097	0.0106	-0.0110	0.0304
Day -11	0.0021	0.0075	-0.0126	0.0168	Day -11	0.0029	0.0097	-0.0162	0.0220
Day -12	0.0136	0.0082	-0.0025	0.0297	Day -12	0.0143	0.0100	-0.0053	0.0339
Day -13	<b>0.0205</b>	<b>0.0095</b>	<b>0.0018</b>	<b>0.0392</b>	Day -13	0.0190	0.0114	-0.0034	0.0414
Day -14	<b>0.0268</b>	<b>0.0089</b>	<b>0.0093</b>	<b>0.0443</b>	Day -14	<b>0.0284</b>	<b>0.0105</b>	<b>0.0078</b>	<b>0.0490</b>
Day -15	<b>0.0477</b>	<b>0.0107</b>	<b>0.0268</b>	<b>0.0686</b>	Day -15	<b>0.0496</b>	<b>0.0130</b>	<b>0.0242</b>	<b>0.0750</b>
Day -16	<b>0.0336</b>	<b>0.0101</b>	<b>0.0139</b>	<b>0.0534</b>	Day -16	<b>0.0327</b>	<b>0.0126</b>	<b>0.0080</b>	<b>0.0574</b>
Day -17	<b>0.0234</b>	<b>0.0109</b>	<b>0.0021</b>	<b>0.0447</b>	Day -17	0.0250	0.0137	-0.0019	0.0518
Day -18	0.0139	0.0088	-0.0034	0.0311	Day -18	0.0145	0.0110	-0.0071	0.0361
Day -19	0.0179	0.0104	-0.0025	0.0383	Day -19	0.0204	0.0130	-0.0051	0.0459
Day -20	0.0193	0.0103	-0.0010	0.0395	Day -20	0.0238	0.0134	-0.0024	0.0500
Day -21	0.0059	0.0097	-0.0130	0.0249	Day -21	0.0049	0.0125	-0.0196	0.0293
Day -22	0.0033	0.0091	-0.0144	0.0211	Day -22	-0.0030	0.0124	-0.0273	0.0213
Day -23	-0.0006	0.0092	-0.0186	0.0175	Day -23	0.0021	0.0122	-0.0219	0.0260
Day -24	0.0044	0.0093	-0.0139	0.0227	Day -24	0.0046	0.0118	-0.0185	0.0278
Day -25	0.0056	0.0090	-0.0120	0.0232	Day -25	0.0092	0.0113	-0.0129	0.0313
Day -26	0.0033	0.0086	-0.0135	0.0202	Day -26	-0.0019	0.0109	-0.0232	0.0195
Day -27	-0.0041	0.0089	-0.0215	0.0134	Day -27	-0.0033	0.0111	-0.0251	0.0185
Day -28	0.0079	0.0080	-0.0077	0.0235	Day -28	0.0122	0.0105	-0.0085	0.0329
Day -29	0.0056	0.0091	-0.0122	0.0234	Day -29	0.0095	0.0114	-0.0129	0.0319
-1st week AVG (Day 0-6)	<b>0.0235</b>	<b>0.0117</b>	<b>0.0005</b>	<b>0.0466</b>	-1st week AVG (Day 0-6)	0.0235	0.0143	-0.0046	0.0516
-2nd week AVG (Day -7 -13)	0.0151	0.0119	-0.0082	0.0384	-2nd week AVG (Day -7 -13)	0.0150	0.0147	-0.0138	0.0438
-3rd week AVG (Day -14 -20)	<b>0.0426</b>	<b>0.0129</b>	<b>0.0173</b>	<b>0.0679</b>	-3rd week AVG (Day -14 -20)	<b>0.0478</b>	<b>0.0163</b>	<b>0.0159</b>	<b>0.0797</b>
-4th week AVG (Day -21 -27)	0.0032	0.0110	-0.0184	0.0248	-4th week AVG (Day -21 -27)	0.0030	0.0143	-0.0251	0.0311
-2 week AVG (Day 0-13)	<b>0.0284</b>	<b>0.0143</b>	<b>0.0003</b>	<b>0.0565</b>	-2 week AVG (Day 0-13)	0.0289	0.0177	-0.0058	0.0635
-3 week AVG (Day 0-20)	<b>0.0425</b>	<b>0.0154</b>	<b>0.0122</b>	<b>0.0728</b>	-3 week AVG (Day 0-20)	0.0051	0.0094	-0.0133	0.0234
-4 week AVG (Day 0-27)	<b>0.0318</b>	<b>0.0151</b>	<b>0.0023</b>	<b>0.0614</b>	-4 week AVG (Day 0-27)	0.0336	0.0191	-0.0038	0.0709

Note:  $\beta$  (95% CIs) at different time lags (from the day of the nasal swab to the previous 30 days) and for different 7-day moving average are calculated for a 1  $\mu\text{g}/\text{m}^3$  increase in PM. Beta regression coefficients were estimated from multivariate continuous ordinal regression models adjusted for age, sex, ethnicity, assumption of systemic antibiotics during pregnancy and assumption of systemic antibiotics in the last month.

Significant associations are reported in bold.

**FIGURE 2** Hypothesis linking PM exposure and bronchiolitis severity



PM might modulate the viral load and the airways inflammation. Future studies should investigate whether preventive strategies, applied to very high-risk infants in the days following high levels of  $PM_{2.5}$  and  $PM_{10}$  exposure might reduce the burden of this disease.

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#### CONFLICT OF INTEREST

None.

#### ORCID

Gregorio P. Milani  <https://orcid.org/0000-0003-3829-4254>

#### REFERENCES

- Pfeffer PE, Mudway IS, Grigg J. Air pollution and asthma: mechanisms of harm and considerations for clinical interventions. *Chest*. 2021;159(4):1346-1355.
- Bontinck A, Maes T, Joos G. Asthma and air pollution: recent insights in pathogenesis and clinical implications. *Curr Opin Pulm Med*. 2020;26(1):10-19.
- Baek J, Kash BA, Xu X, Benden M, Roberts J, Carrillo G. Association between ambient air pollution and hospital length of stay among children with asthma in South Texas. *Int J Environ Res Public Health*. 2020;17(11):3812.
- Gass K, Klein M, Sarnat SE, et al. Associations between ambient air pollutant mixtures and pediatric asthma emergency department visits in three cities: a classification and regression tree approach. *Environ Health*. 2015;14:58.
- Min KD, Yi SJ, Kim HC, et al. Association between exposure to traffic-related air pollution and pediatric allergic diseases based on modeled air pollution concentrations and traffic measures in Seoul, Korea: a comparative analysis. *Environ Health*. 2020;19(1):6.
- Carugno M, Dentali F, Mathieu G, et al.  $PM_{10}$  exposure is associated with increased hospitalizations for respiratory syncytial virus bronchiolitis among infants in Lombardy. *Italy Environ Res*. 2018;166:452-457.
- Girguis MS, Strickland MJ, Hu X, et al. Chronic  $PM_{2.5}$  exposure and risk of infant bronchiolitis and otitis media clinical encounters. *Int J Hyg Environ Health*. 2017;220(6):1055-1063.
- Mishra R, Krishnamoorthy P, Gangamma S, Raut AA, Kumar H. Particulate matter ( $PM_{10}$ ) enhances RNA virus infection through modulation of innate immune responses. *Environ Pollut*. 2020;266(Pt 1):115148.
- Domingo JL, Rovira J. Effects of air pollutants on the transmission and severity of respiratory viral infections. *Environ Res*. 2020;187:109650.
- King C, Kirkham J, Hawcutt D, Sinha I. The effect of outdoor air pollution on the risk of hospitalisation for bronchiolitis in infants: a systematic review. *PeerJ*. 2018;6:e5352.
- Girguis MS, Strickland MJ, Hu X, et al. Exposure to acute air pollution and risk of bronchiolitis and otitis media for preterm and term infants. *J Expo Sci Environ Epidemiol*. 2018;28(4):348-357.
- Milani GP, Plebani AM, Arturi E, et al. Using a high-flow nasal cannula provided superior results to low-flow oxygen delivery in moderate to severe bronchiolitis. *Acta Paediatr*. 2016;105(8):E368-E372.
- Azzari C, Baraldi E, Bonanni P, et al. Epidemiology and prevention of respiratory syncytial virus infections in children in Italy. *Ital J Pediatr*. 2021;47(1):198.
- Milani GP, Rocchi A, Teatini T, et al. Hyponatremia in infants with new onset moderate-severe bronchiolitis: a cross-sectional study. *Respir Med*. 2017;133:48-50.
- Milani GP, Bollati V, Ruggiero L, et al. Bronchiolitis and SARS-CoV-2. *Arch Dis Child*. 2021;106(10):999-1001.
- Mazzoni MB, Milani GP, Bernardi S, et al. Hyponatremia in infants with community-acquired infections on hospital admission. *PLoS One*. 2019;14(7):e0219299.
- Florin TA, Plint AC, Zorc JJ. Viral bronchiolitis. *Lancet*. 2017;389(10065):211-224.

18. Karr C, Lumley T, Shepherd K, et al. A case-crossover study of wintertime ambient air pollution and infant bronchiolitis. *Environ Health Perspect*. 2006;114(2):277-281.
19. Karr CJ, Demers PA, Koehoorn MW, Lencar CC, Tamburic L, Brauer M. Influence of ambient air pollutant sources on clinical encounters for infant bronchiolitis. *Am J Respir Crit Care Med*. 2009;180(10):995-1001.
20. 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.
21. Yitshak-Sade M, Yudovitch D, Novack V, Tal A, Kloog I, Goldbart A. Air pollution and hospitalization for bronchiolitis among young children. *Ann Am Thorac Soc*. 2017;14(12):1796-1802.
22. Ségala C, Poizeau D, Mesbah M, Willems S, Maidenberg M. Winter air pollution and infant bronchiolitis in Paris. *Environ Res*. 2008;106(1):96-100.
23. Leung SY, Lau SYF, Kwok KL, Mohammad KN, Chan PKS, Chong KC. Short-term association among meteorological variation, outdoor air pollution and acute bronchiolitis in children in a subtropical setting. *Thorax*. 2021;76(4):360-369.
24. Wrotek A, Badyda A, Czechowski PO, Owczarek T, Dąbrowiecki P, Jackowska T. Air Pollutants' concentrations are associated with increased number of RSV hospitalizations in polish children. *J Clin Med*. 2021;10(15):3224.
25. Feng C, Li J, Sun W, Zhang Y, Wang Q. Impact of ambient fine particulate matter (PM<sub>2.5</sub>) exposure on the risk of influenza-like-illness: a time-series analysis in Beijing, China. *Environ Health*. 2016;15:17.
26. Setti L, Passarini F, De Gennaro G, et al. Potential role of particulate matter in the spreading of COVID-19 in northern Italy: first observational study based on initial epidemic diffusion. *BMJ Open*. 2020;10(9):e039338.
27. Eiland LS. Respiratory syncytial virus: diagnosis, treatment and prevention. *J Pediatr Pharmacol Ther*. 2009;14(2):75-85.
28. Choi J, Sim JK, Oh JY, et al. Relationship between particulate matter (PM<sub>10</sub>) and airway inflammation measured with exhaled nitric oxide test in Seoul, Korea. *Can Respir J*. 2020;2020:1823405-1823407.
29. Arias-Pérez RD, Tabora NA, Gómez DM, Narvaez JF, Porras J, Hernandez JC. Inflammatory effects of particulate matter air pollution. *Environ Sci Pollut Res Int*. 2020;27(34):42390-42404.
30. De Grove KC, Provoost S, Brusselle GG, Joos GF, Maes T. Insights in particulate matter-induced allergic airway inflammation: focus on the epithelium. *Clin Exp Allergy*. 2018;48(7):773-786.
31. Yang X, Zhang Y, Zhan X, et al. Particulate matter exposure is highly correlated to pediatric asthma exacerbation. *Aging (Albany NY)*. 2021;13(13):17818-17829.
32. Pickles RJ, DeVincenzo JP. Respiratory syncytial virus (RSV) and its propensity for causing bronchiolitis. *J Pathol*. 2015;235(2):266-276.
33. Vázquez Y, González L, Noguera L, et al. Cytokines in the respiratory airway as biomarkers of severity and prognosis for respiratory syncytial virus infection: an update. *Front Immunol*. 2019;10:1154.
34. Kinney PL. Interactions of climate change, air pollution, and human health. *Curr Environ Health Rep*. 2018;5(1):179-186.
35. Kalisa E, Fadlallah S, Amani M, Nahayo L, Habiyaremye G. Temperature and air pollution relationship during heatwaves in Birmingham. *UK Sustainable Cities and Society*. 2018;43:111-120.
36. Leão MLP, Zhang L, da Silva Júnior FMR. Effect of particulate matter (PM<sub>2.5</sub>) and PM<sub>10</sub> on health indicators: climate change scenarios in a Brazilian metropolis. *Environ Geochem Health*. 2022;1-12. doi:10.1007/s10653-022-01331-8. Online ahead of print.
37. Van Brusselen D, De Troeyer K, Ter Haar E, et al. Bronchiolitis in COVID-19 times: a nearly absent disease? *Eur J Pediatr*. 2021;180(6):1969-1973.

#### SUPPORTING INFORMATION

Additional supporting information can be found online in the Supporting Information section at the end of this article.

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