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Association between exposure to specific PM_{2.5} constituents and environment, lifestyle, and clinical parameters in patients with COPD

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ABSTRACT

This study investigated the correlation between the individual chemical constituents of particulate matter 2.5 μm (PM_{2.5}) and respiratory parameters as well as the living environment and daily behaviors in patients with chronic obstructive pulmonary disease (COPD). Data were obtained from prospective COPD panel conducted in South Korea. Following collection via a microPEM, 18 metallic elements were determined using energy-dispersive X-ray fluorescence spectroscopy. All participants completed detailed questionnaires on living environments and lifestyle practices. Eighty-nine stable COPD patients (mean age 68.1 years; 94.4% male) were analyzed. Several constituents (titanium, aluminum, bromine, and silicone) were significantly associated with respiratory outcomes. Copper and manganese concentrations were significantly associated with the living environment. Increased ventilation time and air purifier operation were associated with lower concentrations of copper, silicone, barium, and titanium. These findings suggest varying relationships between PM_{2.5} constituents and clinical parameters in COPD patients, providing a basis for personalized interventions and future research.

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KEYWORDS

Air pollution; particulate matter; constituents; chronic obstructive pulmonary disease

Introduction

Air pollution is a major global health concern (Committee of the Environmental and Occupational Health Assembly of the American Thoracic Society 1996, GBD 2015 Risk Factors Collaborators

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2016). Among the various documented air pollutants, fine particulate matter sized less than 2.5 micrometers in diameter ($PM_{2.5}$) is well known to increase mortality and morbidity (Pope et al. 2009; Lelieveld et al. 2015; Cohen et al. 2017). High $PM_{2.5}$ levels also pose a significant threat to patients with chronic obstructive pulmonary disease (COPD) and several studies have reported that short-term or long-term exposures to $PM_{2.5}$ are associated with increased mortality, hospitalization, and acute exacerbation in these patients (Dominici et al. 2006; Hansel et al. 2013, 2016; Zhu et al. 2013).

While the overall concentration of $PM_{2.5}$ is linked to adverse health effects, recognizing that ambient $PM_{2.5}$ consists of diverse particles from various sources is crucial (Korsiak et al. 2022). Identifying the chemical constituents of $PM_{2.5}$ offers valuable insights into the primary sources of air pollution in a given environment. Constituents such as vanadium or arsenic are more easily traced to their sources owing to their distinct origins, facilitating targeted regulatory or preventive measures. Similarly, metals such as copper and zinc, associated with metal brake and tire wear emissions, serve as identifiable markers of distinct pollution sources (Councell et al. 2004; Hulskotte et al. 2007, Thurston, Awe, Ostro and Sanchez-Triana). However, despite previous studies primarily focusing on the total concentration of $PM_{2.5}$, studies examining the health effects of its specific constituents are currently lacking.

In assessing $PM_{2.5}$ exposure, the outdoor and indoor sources of air pollution should be considered (Hansel et al. 2022). Indoor $PM_{2.5}$ constituents can change significantly owing to the living environment and individual behaviors. Environmental factors or behaviors that significantly influence concentrations of constituents associated with respiratory outcomes could serve as viable targets for lifestyle interventions. A previous study demonstrated that behaviors such as operating air purifiers or ventilating homes through window openings significantly reduced indoor total $PM_{2.5}$ concentrations in patients with COPD (Kim et al. 2021). Clarifying the associations between the living environment, daily behaviors, and specific $PM_{2.5}$ constituents is crucial for developing effective interventions to mitigate the adverse effects of $PM_{2.5}$. Therefore, this study aimed to investigate the associations between individual chemical constituents of $PM_{2.5}$ and respiratory outcomes within a COPD cohort. Additionally, we aim to explore the potential associations between the living environment, daily life behaviors, and specific $PM_{2.5}$ constituents among the study patients.

Materials and methods

Participants

This study used data from a prospective panel study that recruited patients with COPD from three hospitals in the capital region of the Republic of Korea. The inclusion criteria were (1) adults aged 40 years or older; (2) diagnosis of COPD, defined as post-bronchodilator forced expiratory volume in 1 second (FEV_1)/forced vital capacity (FVC) < 0.7; and (3) predicted FEV_1 less than 80% of the predicted value at enrollment. The exclusion criteria were (1) patients without respiratory symptoms and (2) patients who could not understand the questionnaires used in the study or instructions about how to use the air sampler device. The study protocol was approved by the Institutional Review Boards of Asan Medical Center (2021–0701), Inje University Ilsan Paik Hospital (2021-05-042), and Yonsei University Severance Hospital (04–2021–0607).

Study design

The prospective panel study from which the data were derived was designed to investigate the association between $PM_{2.5}$ and COPD outcomes. The detailed study protocol has been previously published (Kang et al. 2021). In brief, the study was conducted between July 2021 and November 2022. Patients' demographic and clinical data were obtained at baseline, including data about age, sex, current address, and history of smoking, were

collected at enrollment after obtaining written informed consent. In addition, the participants completed detailed questionnaire surveys of their living environment and lifestyle behaviors.

Patients were regularly monitored at their respective hospitals every three months. During each visit, assessments were conducted to evaluate patients' lung function, respiratory symptoms, and health-related quality of life. The development of acute exacerbations was tracked monthly. Before the scheduled hospital visit, a team responsible for PM_{2.5} measurements visited the patients' homes to set up PM_{2.5} collection devices, which remained in operation for 24 h.

In this study, we utilized the data on PM_{2.5} and its constituents collected at three months to analyze the relationship between the concentrations of each constituent and the living environment, daily life behaviors, and respiratory outcomes. Respiratory outcomes, including impulse oscillometry (IOS), health-related quality of life, and respiratory symptoms, were collected one day after measuring PM_{2.5} and its constituents.

Questionnaires on the living environment and daily life behaviors of the study participants

The participants completed detailed questionnaires on their indoor/outdoor living environments and lifestyle. The living environment assessments included the distance from their home to the road, average traffic volume, width of the road near the home, floor level of the residence, presence of an indoor ventilating system, and presence of certain household appliances including an air purifier. The distance from the patient's home to the nearest main road was considered short or long based on a 100-meter benchmark. The width of the road was checked to determine whether it had 1, 2, 4, 6, 8 lanes or more. The level of traffic in the vicinity of the patients' residences was classified as low- or high-volume. Questions regarding lifestyle included the methods and durations of indoor ventilation, air purifier operation times, and methods and frequency of cleaning. Ventilation times were represented as mean hours per week. Air purifier operation times were separately calculated on days with low, moderate, and heavy dust also as mean hours per week. The frequencies of cleaning the kitchen ventilator and vacuum cleaner use were represented as mean numbers per week.

Clinical data collection

Respiratory symptoms and health-related quality of life were evaluated using the modified Medical Research Council (mMRC) grade, the COPD Assessment Test (CAT), and the St. George's Respiratory Questionnaire for patients with COPD (SGRQ-C). Spirometry was performed according to the European Respiratory Society/American Thoracic Society guidelines (Miller et al. 2005). IOS parameters were collected using the MasterLab IOS System (Erich Jaeger, Würzburg, Germany).

Measurements of the concentrations and chemical constituents of PM_{2.5}

Both real-time and gravimetric PM_{2.5} concentrations were collected for 24 h using MicroPEM placed in the house where each participant spent the most time. The MicroPEM device also analyzes PM_{2.5} on a 25 mm PTFE filter for chemical speciation analyses (Cho et al. 2016). After collecting samples, the following metallic elements were determined using energy-dispersive X-ray fluorescence spectroscopy (EDXRF) (ARLTM QUANT'X EDXRF Spectrometer; Thermo Scientific, Rodano, Italy): sulfur (S), silicon (Si), potassium (K), iron (Fe), calcium (Ca), chlorine (Cl), aluminum (Al), zinc (Zn), magnesium (Mg), copper (Cu), barium (Ba), lead (Pb), manganese (Mn), bromine (Br), titanium (Ti), chromium (Cr), cesium (Cs), and nickel (Ni). Detailed descriptions of these analytical methods can be found in previous studies (Ye et al. 2020).

Statistical analysis

The study data are presented as means and standard deviations or as medians with interquartile ranges for continuous variables. For categorical variables, numbers (%) are presented. The correlations between individual constituent concentrations of the indoor PM_{2.5} measured at three months and the respiratory outcomes, living environments, and daily life behaviors of the study participants were analyzed. The Shapiro – Wilk test was used to assess the normal distribution of continuous data. Correlation analyses were conducted using Spearman's rank-order correlation, considering the non-normal distribution of continuous variables. A point biserial correlation was used when a variable was categorical. The correlation degree was categorized using a correlation coefficient as follows: >0.6 as strong, 0.3–0.6 as moderate, and < 0.3 as weak. All p-values were two-tailed, with $p < 0.05$ considered statistically significant. Statistical analyses were conducted using Statistical Package for the Social Sciences software, version 25.0 (SPSS Inc., Chicago, IL).

Results

Characteristics of the study participants

The clinical characteristics of the 89 participating patients with stable COPD are presented in Table 1. The mean age of this cohort was 68.1 years and 94.4% of the subjects were men. The mean body mass index was 23.9 kg/m². The mean post-bronchodilator FEV₁ and FVC at baseline were 56.2 and 82.7% of the predicted value, respectively. The mean CAT score was 15.5. Nine patients (10.1%) reported at least one exacerbation during the three months of follow-up. Of these cases, six patients (6.7%) had moderate to severe exacerbations. Supplementary Table S1 provides details of the living environment and daily behaviors. Approximately 28.1% of participants reported living within 50 meters of a road, and 44.9% lived in high-traffic areas. The most prevalent indoor ventilation method was opening windows or doors (97.8%), and 62.9% reported owning an air purifier.

PM_{2.5} constituent analysis

The median indoor PM_{2.5} concentration was 11.3 µg/m³ (interquartile range: 8.5–14.3 µg/m³). A total of 33 constituents were detected and are presented in order of the highest median concentration in Table 2. Sulfur showed the highest median concentration (0.496 µg/m³) followed by Si (0.137 µg/m³). Br and Ti showed relatively lower concentrations among the analyzed constituents. Correlations between the constituents are shown in Supplementary Figure S1 some of which were very strong i.e. Si and Al ($r = 0.925$; $p < 0.001$), Fe and Mn ($r = 0.880$; $p < 0.001$), Fe and Ti ($r = 0.818$; $p < 0.001$), Ca and Mg ($r = 0.883$; $p < 0.001$), and Zn and Mn ($r = 0.837$; $p < 0.001$). In contrast, K did not show high correlations with most of the other constituents.

Correlations between PM_{2.5} constituent levels and the clinical parameters of the study participants

The results of correlation analysis between the chemical constituents of PM_{2.5} and various respiratory outcomes are presented in Figure 1. Several chemical constituents showed significant positive correlations with IOS parameters. Moderate correlations were shown between R5%pred.) and Ti ($r = 0.325$; $p = 0.018$); and between X5%pred.) and Pb ($r = 0.308$; $p = 0.025$) and Ti ($r = 0.310$; $p = 0.024$). Weak correlations were found between R20%pred.) and Br ($r = 0.287$; $p = 0.023$) and Ti ($r = 0.291$; $p = 0.035$); and between R5-R20 and Ti ($r = 0.289$; $p = 0.036$). An increased risk of moderate to severe exacerbation was associated with exposure to a higher concentration of Al ($r = 0.237$; $p = 0.026$), Br ($r = 0.238$; $p = 0.025$), and Si ($r = 0.241$; $p = 0.023$). Exposure to Br was also positively correlated with higher scores for the total SGRQ-C ($r = 0.228$; $p = 0.040$) and the impact domain of SGRQ-C ($r = 0.261$; $p = 0.018$). K,

Table 1. Clinical characteristics of the study participants.

Characteristics	
Age, years, mean $\pm$ SD	68.1 $\pm$ 6.5
Male, n (%)	84 (94.4)
Smoking status, n (%)	
Never smoker	4 (4.5)
Ex-smoker	70 (78.7)
Current smoker	15 (16.9)
Smoking history (pack-year), mean (SD)	36.1 $\pm$ 16.9
Body mass index, mean $\pm$ SD	23.9 $\pm$ 3.7
Obesity*, n (%)	3 (3.4)
Lung function, % of the predicted value, mean (SD)	
Pre-bronchodilator FEV ₁	53.6 $\pm$ 14.3
Pre-bronchodilator FVC	80.2 $\pm$ 15.6
Post-bronchodilator FEV ₁	56.2 $\pm$ 14.8
Post-bronchodilator FVC	82.7 $\pm$ 14.0
Inhaler treatment administered, n (%)	
LABA+LAMA	44 (49.4)
ICS+LABA+LAMA	34 (38.2)
LABA or LAMA	6 (6.7)
ICS+LABA	5 (5.6)
mMRC, n (%)	
Grade 0	2 (2.2)
Grade 1	21 (23.6)
Grade 2	21 (23.6)
Grade 3	28 (31.5)
Grade 4	17 (19.1)
CAT score, mean $\pm$ SD	15.5 $\pm$ 8.5
SGRQ total, mean $\pm$ SD	35.7 $\pm$ 19.1
R5-R20, median [IQR]	0.1 [0.0–0.2]
Acute exacerbation during the 3-month follow-up, n (%)	9 (10.1)
Moderate to severe acute exacerbation, n (%)	6 (6.7)

*Obesity was defined as a body mass index of 30 kg/m² or greater.

Abbreviation: IQR, interquartile range; SD, standard deviation; mMRC, modified Medical Research Council; FEV₁, forced expiratory volume in one second; FVC, forced vital capacity; LABA, long-acting beta-2 agonist; LAMA, long-acting muscarinic antagonist; ICS, inhaled corticosteroid; CAT, COPD assessment test; SGRQ, St. George's Respiratory Questionnaire; R5, Resistance at 5 Hz; R20, Resistance at 20 Hz.

Pb, and Zn showed positive correlations with the CAT score, whereas Br, K, Pb were positively correlated with the mMRC grade of dyspnea.

Correlations between PM_{2.5} constituents and the living environments

Figure 2 lists the correlations between the constituents of PM_{2.5} and characteristics of the study participants' living environments. A significant negative correlation was observed between the concentration of Cu and living distance from the road ($r = -0.263$; $p = 0.013$). Cu also showed a negative correlation with a floor level of the subject's residence ($r = -0.252$; $p = 0.018$). A higher concentration of Mn was associated with a greater traffic level ($r = 0.251$; $p = 0.018$). A greater width of the road nearest the residence showed a trend towards an association with a higher concentration of Ca ($r = 0.207$; $p = 0.052$).

Correlations between PM_{2.5} constituents and daily life behaviors

Several daily life behaviors were shown to have negative correlations with exposures to certain PM_{2.5} constituents (Figure 3). The ventilation time through the use of open windows in the home correlated negatively with lower concentrations of Cu ($r = -0.233$; $p = 0.028$), Si ($r = -0.223$; $p = 0.036$), and Zn

Table 2. Identity and concentration of the chemical constituents of PM_{2.5}.

Chemical constituents of PM _{2.5}	Median concentration [interquartile range] (x10 ⁻² µg/m ³)
Sulfur (S)	49.60 [35.00;83.15]
Silicon (Si)	13.70 [9.45;24.00]
Potassium (K)	12.00 [7.15;22.20]
Iron (Fe)	9.10 [5.40;13.60]
Calcium (Ca)	5.20 [3.10;9.55]
Chloride (Cl)	3.20 [2.00;5.90]
Aluminum (Al)	2.70 [1.20;6.20]
Zinc (Zn)	2.30 [1.40;3.80]
Magnesium (Mg)	2.00 [1.20;4.10]
Copper (Cu)	0.70 [0.30;1.10]
Barium (Ba)	0.70 [0.35;1.00]
Lead (Pb)	0.60 [0.10;1.00]
Manganese (Mn)	0.50 [0.30;0.90]
Bromine (Br)	0.30 [0.10;0.55]
Titanium (Ti)	0.30 [0.10;0.60]
Chromium (Cr)	0.20 [0.10;0.25]
Cesium (Cs)	0.20 [0.00;0.30]
Nickel (Ni)	0.10 [0.00;0.20]

Abbreviation: PM_{2.5}, particulate matter sized less than 2.5 micrometers in diameter.

($r=-0.208$; $p=0.050$). The duration of air purifier operation on days with a high PM_{2.5} concentration was found to be negatively correlated with the Ba ($r=-0.234$; $p=0.027$) and Ti ($r=-0.267$; $p=0.011$) levels. Fe and Mn were negatively correlated with the frequency of cleaning the kitchen ventilator ($r=-0.213$; $p=0.046$ and $r=-0.225$; $p=0.035$, respectively). Mg tended to have a negative correlation with the frequency of vacuum cleaner use ($r=-0.188$; $p=0.078$).

Correlation between clinical parameters and daily life behaviors

The correlations between daily life behaviors and clinical parameters were also investigated, to explore if any specific PM_{2.5} constituents appeared to mediate these associations. Among the various daily life behaviors, a lower X5%pred.) showed a significant association with a longer duration of air purifier use on a low dust day ($r=-0.297$, $p=0.031$), and Mn showed an association tendency with both the X5%pred.) and air purifier operation time (Figures 1 and 3). When comparing PM_{2.5} constituent concentrations based on the air purifier operation time, Mn levels were lower in the group with longer air purifier operation time (Supplementary Table S2). To examine whether the association between X5%pred.) and air purifier operation time on low dust days was mediated by Mn, this correlation was further analyzed in accordance with the Mn concentration, which was classified as high and low based on the median value (Supplementary Figure S2). There was no significant association in the high Mn concentration group, but the X5% pred.) and air purifier operation time tended to show a negative correlation in the low Mn concentration group ($r=-0.314$, $p=0.071$).

Discussion

In our present analysis of exposures to the chemical components of indoor PM_{2.5} in a COPD cohort, several associations with living environment, lifestyle and clinical parameters were identified. The concentration of Ti showed a significant association with small airway resistance and those of Br, K, Pb, and Zn showed correlations with COPD symptoms and/or the subjects’ quality of life. Higher concentrations of Al and Br had an association with more frequent acute exacerbations of COPD. In terms of the living environment, the higher concentrations of Cu were related to a shorter distance from the home to a road and a lower floor level of the residence. Several lifestyles such as ventilation times, duration of air purifier use, and frequency of cleaning the kitchen

	Ventilation time	Air purifier operation time			Frequency of cleaning kitchen ventilator	Frequency of vacuum cleaner use
		Low dust day	Intermediate dust day	Heavy dust day		
Al						
Ba				-0.234**		
Br						
Ca					-0.189*	
Cu	-0.233**					
Fe				-0.188*	-0.213**	
K						
Mg						-0.188*
Mn		-0.191*	-0.193*	-0.178*	-0.225**	
Pb						
Si	-0.223**					
Ti			-0.188*	-0.267**	-0.198*	
Zn	-0.208*	-0.178*	-0.177*	-0.194*	-0.189*	

Figure 1. Correlation analysis between the chemical constituents of PM_{2.5} and respiratory outcome parameters. Only correlation coefficients with a P-value <0.10 are shown. **p* < 0.10, ***p* < 0.05. The extent of a positive or negative correlation is represented by the intensity of the red and blue shading, respectively. Abbreviations: IOS, impulse oscillometry; AE, acute exacerbation; SGRQ-C; St. George’s Respiratory Questionnaire for patients with COPD; CAT, COPD assessment test; mMRC, modified Medical Research Council; Al, aluminum; Ba, barium; Br, bromine; Ca, calcium; Cu, copper; Fe, iron; K, potassium; Mg, magnesium; Mn, manganese; Pb, lead; Si, silicon; Ti, titanium; Zn, zinc.

ventilator were also associated with lower exposure concentrations of Cu, Si, Zn, barium, Ti, Fe, and Mn. All these associations suggested that the impact of PM_{2.5} can be different depending on its components, and that lifestyle interventions to reduce the impact of PM_{2.5} exposure can be individualized in accordance with the patient’s environment and clinical status.

Most prior studies on the health effects of PM_{2.5} involved the total concentrations of this air pollutant even though it is a complex mixture of heterogeneous particles, and its composition can vary across locations depending on meteorological conditions and emission sources (Thangavel et al. 2022). Differences in PM_{2.5} compositions may also affect its overall toxicity (Korsiak et al. 2022, Thurston, Awe, Ostro and Sanchez-Triana). There is limited evidence however on which PM_{2.5} constituents are associated with the greatest risk of aggravating a respiratory disease and what the underlying mechanisms of this are. In our current study, several chemical constituents of PM_{2.5} correlated with poorer respiratory outcomes and some had associations across multiple outcomes (Br, Ca, Fe, Mn, Pb, Si, and Zn). Although exposure to metal dust or fumes can cause serious cardiopulmonary complications (Merget et al. 2002; Zhou et al. 2018), these chemicals as particulate matters may have different mechanisms involved in their hazardous effects. The adverse health effects of PM_{2.5} exposure are considered to be mediated by oxidative stress through the generation of reactive oxygen species,

	Living distance from road	Width of road	Traffic level	Floor level of residence
Al				
Ba				
Br				
Ca		0.207 *		
Cu	-0.263 **			-0.252 **
Fe				
K				
Mg				
Mn			0.251 **	
Pb				
Si				
Ti				
Zn			0.193 *	

Figure 2. Correlation analysis between the indicated PM_{2.5} chemical constituents and the living environment of the study participants. Only correlation coefficients with a P-value <0.10 are shown. **p* < 0.10, ***p* < 0.05. The extent of a positive or negative correlation is represented by the intensity of the red and blue shading, respectively. Abbreviations: Al, aluminum; Ba, barium; Br, bromine; Ca, calcium; Cu, copper; Fe, iron; K, potassium; Mg, magnesium; Mn, manganese; Pb, lead; Si, silicon; Ti, titanium; Zn, zinc.

inflammation, and mitochondrial damage (Thangavel et al. 2022), with some PM_{2.5} constituents sharing similar mechanisms. In a previous study by Shang et al., the constituents of PM_{2.5} were measured before and after air quality control in Beijing and biological responses to PM_{2.5} and its components were analyzed in murine alveolar macrophages (Shang et al. 2013). Metals including Fe and Ba were found to be associated with increased granulocyte-macrophage colony-stimulating factor and interleukin-10 levels, whereas Zn showed a significant association with cell viability. These findings suggest that various chemical constituents of PM_{2.5} contribute differently to pro-inflammatory responses and cytotoxicity. Therefore, further research is needed to elucidate the physiological mechanisms and health implications of these constituents.

The residential environments of our current study participants were also observed to be associated with certain PM_{2.5} constituents. Road traffic is a well-known factor affecting the profile of air pollutants that can even have mortality impacts (Beelen et al. 2008; Wang et al. 2021). In our present study, Mn was found to be associated with the road traffic levels, and Cu with both distance from the road to the home and the floor level of the residence, which can be closely correlated. The respiratory impacts of the living distance from major roads has been well-studied, but that of the floor level of the residence has not (Jung et al. 2011). Other than mining areas, a major source of Cu is the burning of fossil fuels including motor oils, in addition to ash, and other waste from industrial incinerators. A prior population-based study

	IOS				AE	SGRQ-C				CAT	mMRC
	R5 %pred.	R20 %pred.	X5 %pred.	R5-R20		Total	Symptom	Activity	Impact		
Al					0.237**						
Ba											
Br		0.287**			0.238**	0.228**		0.215*	0.261**	0.184*	0.255**
Ca		0.239*					0.186*			0.194*	
Cu	0.230*		0.270*								
Fe			0.267*							0.183*	
K						0.183*			0.198*	0.286**	0.270**
Mg											
Mn			0.249*							0.190*	
Pb			0.308**				0.214*			0.291**	0.218**
Si		0.246*	0.229*	0.264*	0.241**						
Ti	0.325**	0.291**	0.310**	0.289**							
Zn			0.267*							0.237**	

Figure 3. Correlation analysis between the indicated PM_{2.5} chemical constituents and daily life behaviors of the study participants. Only correlation coefficients with a P-value <0.10 are shown. *p < 0.10, **p < 0.05. The extent of a positive or negative correlation is represented by the intensity of the red and blue shading. Abbreviations: Al, aluminum; Ba, barium; Br, bromine; Ca, calcium; Cu, copper; Fe, iron; K, potassium; Mg, magnesium; Mn, manganese; Pb, lead; Si, silicon; Ti, titanium; Zn, zinc.

has reported that Cu as an air pollutant can increase cardiovascular mortality (Zhang et al. 2021) and even alter neurologic function (Pujol et al. 2016). Our current study has found that the Cu concentration and airway resistance parameters are related with marginal significance. One of the interesting things we observed in our present analysis was the association between an increased ventilation time and a reduced Cu concentration. As a lifestyle parameter, the ventilation time was also observed to be associated with reduced concentrations of Si and Zn. Although outdoor air pollution is the main source of indoor PM_{2.5}, indoor sources such as aerosols, fireworks, smoking, mixed dust are not negligible (Matthaios et al. 2021). These aforementioned data suggest that adequate ventilation times are no less important than controlling outdoor air pollution for respiratory disorders.

Some lifestyle parameters in our present analyses were found to be associated with lower concentrations of PM_{2.5} components. A longer duration of air purifier use on heavy dust days was significantly associated with lower indoor exposure concentrations of Ba and Ti. Ti was found to be associated with small airway resistance, suggesting that an air purifier could be an individualized intervention for patients with an airway disease. Indeed, this is a well-established intervention to reduce the indoor PM_{2.5} concentration and improve peak expiratory flow (Park et al. 2021). This consistent finding for airway resistance in relation to air purifier use suggests that some PM_{2.5} constituents such as Ti may be involved in this association (Zhan et al. 2018). Air purification is also effective in reducing the concentrations of PM_{2.5} components, as well as the overall PM_{2.5} levels (Zhan et al. 2018). We further observed that lower concentrations of Fe and Mn were noted if a kitchen ventilator was cleaned frequently. The Fe constituent of PM_{2.5} is considered to come mostly from anthropogenic sources such as brake wear and exhaust products, and Mn mainly from steel industries, but their indoor sources are not as well defined. Fe and Mn are utilized in a variety of kitchen tools, but it has not yet been studied whether these metals can be released into the air from those sources and affect air pollution. Mud floors and the burning of plastic can affect the indoor heavy metal concentrations (Nakora et al. 2020), but they are not common in households in Korea. Cooking activities are the major source of indoor PM_{2.5} in Korean residences with open kitchens (Kim et al. 2018; Kang et al. 2019), and can increase the levels of various PM_{2.5} components (Zhang et al. 2016). Our present study findings suggest that effective ventilation in the kitchen can contribute to the control of these indoor sources of air pollutants.

Higher zinc levels were associated with high traffic volume, while lower zinc levels were associated with increased ventilation time. This suggests that prolonged ventilation in heavy traffic areas may not be effective, as the reduction in zinc levels is counteracted by high traffic volume. Alternative ventilation methods may be preferable in situations where open windows could let outdoor particulate matter inside. Additionally, air purifier runtime significantly reduced PM_{2.5} constituents more on heavy dust days with lower or intermediate dust levels. This highlights the significance of air purifier use for patients with COPD, particularly during elevated particulate matter levels.

There were some limitations of this study of note. First, we only examined the correlations between concentrations of PM_{2.5} constituents and clinical parameters, the exact causal relationships could not be confirmed. Furthermore, the effect of particular PM_{2.5} constituents in mediating the influence of living environments or behaviors on respiratory outcomes was not explored in this study. Further investigations are needed to investigate these underlying mechanisms. However, previous studies on the chemical constituents of PM_{2.5} have not been conducted in patients with chronic respiratory diseases. Our current analyses, which included essential clinical parameters of COPD patients, thus provide an insight into possible individualized interventions for PM_{2.5} exposure in accordance with its constituents. Second, the generalizability of our study to populations with different sex distributions may be limited, as 94.4% of our cohort were men. Although our study inadvertently included a higher percentage of male participants, it is important to acknowledge that sex-linked COPD prevalence varies depending

on geographic location and associated risk factors. Considering the influence of sex on lifestyles and daily behaviors, additional research is needed in populations with different sex distributions. Third, the major indoor sources of each PM_{2.5} constituent are not yet defined and the capacity to make environmental improvements to reduce these corresponding constituents is thus limited. Nonetheless, our current study presents some interesting findings that provide insights for future studies to identify the indoor sources of these constituents. For instance, the highly correlated nature of some constituents e.g. Si and Al suggests that they may be of similar or even the same origin. By contrast, PM_{2.5} constituents that did not show high correlations with others may be less-specific markers. Since our present study findings suggest that there may be indoor sources of chemical constituents related to clinical outcomes in COPD, more research into the indoor sources of these pollutants is required for meaningful and individualized interventions in the future. Finally, given the potential influence of a variety of external factors, including meteorological conditions, on PM_{2.5} concentrations and constituents, an extended duration of the PM_{2.5} collection could have offered valuable insights into result stability. Unfortunately, resource constraints limited the collection period to 24 h in our study. Further research is therefore warranted to validate and confirm the robustness of our results.

PM_{2.5} comprises various chemical constituents that have different relationships with the clinical parameters of patients with COPD. Such constituents can be affected by environmental factors and lifestyles, and more sophisticated individualized interventions may well be possible upon the identification of their residential sources in future studies.

Disclosure statement

No potential conflict of interest was reported by the author(s).

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Data availability statement

The datasets used and/or analyzed during the current study are available from the corresponding author upon reasonable request.

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