Master of Medicine

The impact of lifestyle practices and environment on $PM_{2.5}$ in patient with COPD

만성폐쇄성폐질환 환자들의 초미세먼지($PM_{2.5}$)에의 노출에 영향을 줄 수 있는 생활습관과 주변환경

The Graduate School of the University of Ulsan

Department of Medicine

Hajeong Kim

The impact of lifestyle practices and environment on $PM_{2.5}$ in patient with COPD

Supervisor: Sei Won Lee

A Master's Thesis

Submitted to
the Graduate School of the University of Ulsan
For the Degree of

Master of Medicine
by
Hajeong Kim

Department of Medicine
University of Ulsan, Korea
August 2023

The impact of lifestyle practices and environment on $PM_{2.5}$ in patient with COPD

This certifies that the master's thesis of Hajeong Kim is approved

----

Committee Chairman Professor Yeon-Mok Oh

Committee Member Professor Soo-Jong Hong

Committee Member Professor Sei Won Lee

Department of Medicine

University of Ulsan, Korea

August 2023

Abstracts

Background & Aims: Exposure to particulate matter (PM) occurs is a global public health issue. In this study, we aimed to evaluate whether behavioral interventions to reduce PM exposure improve clinical outcomes in patients with chronic obstructive pulmonary disease (COPD).

Methods: We enrolled 104 patients with COPD aged 40 years or older from four hospitals in different areas of Korea. Internet of things-based sensors were installed at their homes to measure the indoor $PM_{2.5}$ concentration for a year, and they conducted detailed questionnaires twice (at enrollment and the end of the study). The relationship between $PM_{2.5}$ concentration, patients' lifestyles, and the impact on COPD exacerbation were analyzed.

Results: The $PM_{2.5}$ concentration was higher outdoors than indoors in most seasons, and, in particular, the difference was largest in winter (4.31±0.02 μg/m^3). Compared to the time of the enrollment, lifestyle practice scores of the participant were generally higher at the end of the research. The lifestyle practices that affect to lower indoor $PM_{2.5}$ concentration compared with the outdoors. And there was a difference between the seasonal items, the significant practices of winter were as follows: Operating indoor air filters (–4.69±1.12 μg/m^3, p=0.001), Ventilating the home by opening windows (–5.29±0.89 μg/m^3, p<0.001), Checking filters of air filters (–

4.00±1.01 μg/m^3, p=0.031), Refraining from going out when the outside $PM_{2.5}$ concentration was high (–3.80±1.26 μg/m^3, p=0.038), Choosing to go out in places with little traffic (–3.39±1.09 μg/m^3, p=0.020), and Closing windows while driving (–4.33±0.77 μg/m^3, p=0.002). The higher the educational level and economic status, the lower the indoor $PM_{2.5}$ concentration. Some lifestyle practices affect the reduction in small airway resistance, marked as R5–R20 accounted for impulse oscillometry, and scores of the St. George's Respiratory Questionnaire.

Conclusions: Some lifestyle practices and economic levels can reduce the indoor $PM_{2.5}$ concentration and can even affect clinical outcomes.

Keywords: chronic obstructive pulmonary disease; particulate matter; lifestyle practices; St George's Respiratory Questionnaire

Contents

List of Tables and Figures

Introduction

Air pollution is a global public health concern and cause 7 million deaths worldwide each year[1-3]. Among the various air pollutants, in particular, fine particulate matter sized less than 2.5 micrometers in diameter ($PM_{2.5}$) is known to increase morbidity and mortality[3-8]. The more exposed to the high concentration of $PM_{2.5}$, the higher the mortality, hospitalization and acute exacerbation of chronic obstructive pulmonary disease (COPD) patients[9-12]. Nevertheless, the concentration of air pollution is recorded far beyond the standards presented by the World Health Organization[2].

Distinction and removal of pollution sources is the best way to improve air pollution, but this is not easily resolved in most countries. In particular, it is difficult to analyze pollution sources in Korea, which is located between Asia, China, and the Pacific Ocean. These locational feature affected to PM concentration, which dynamically change over seasons due to fluctuations in air quality from domestic and foreign sources according to the wind direction[13,14]. Air pollution in transboundary countries cannot be improved through the only domestic control. There was no specific system to share information across jurisdictions between countries in Northeast Asia[15]. As a result, it may be difficult to reduce pollutants in the near future. Furthermore, personal efforts to reduce exposure are required. Especially, in East Asian countries like Korea, indoor source of PM make up a small portion while a higher outdoor PM concentration is showed, particularly in the winter season. Therefore, regulate of indoor PM concentration may be difficult. Therefore, we first studied that which practices can reduce PM concentration during the winter season. And then, considering the characteristics of Korea, where the seasons are relatively distinctly different, we investigated the lifestyle practices by expanding the range to four seasons.

Chronic respiratory diseases such as COPD at adulthood, the third leading cause of death from disease worldwide, is commonly affected by PM exposure[16,17]. Air pollution can also lead to aggravate symptoms, quality of life (QOL) and lung function in COPD patients[18,19]. Although harmful outcomes of PM exposure are recognized, systematic strategies for patient guidance are not enough. There is few research to support whether individual behavioral interventions to reduce PM exposure can improve clinical outcomes of COPD patients.

In some prior studies, the indoor PM concentration is affected by a life behavior pattern, and it can be reduced with lifestyle modification appropriately. The study found that a few lifestyle practices, including checking air quality forecast and using an air cleaner, were associated with reduced indoor $PM_{2.5}$ concentrations compared to outdoor concentrations[20,21]. These findings shows that the exposure of air pollution can be reduced by individual great efforts to modify their lifestyles. Considering the characteristics of Korea, which have relatively clear seasonal differences, the study was conducted to identify habits that can reduce PM even in seasons other than winter. Finally, guidance to reduce indoor $PM_{2.5}$ exposure effectively must be developed throughout the season. In this present study, we hypothesized that lifestyle behaviors were related to indoor $PM_{2.5}$ concentrations. In addition, modifications of behaviors appropriately can reduce the exposure to indoor $PM_{2.5}$ concentration. We analyzed the relationship between $PM_{2.5}$ concentration, life behavior, and the impact on COPD exacerbation by season for a year. Furthermore, we suggested lifestyle behaviors which improve indoor $PM_{2.5}$ concentrations, and finally we aimed to contribute to improving the health condition of COPD patients.

Methods

Participants

This study is a prospective panel study recruited patients with COPD patients from four representative areas of Korea. The inclusion criteria of the study were as follows: patients aged 40 years or older; COPD patients, defined as a postbronchodilator forced expiratory volume in one second (FEV1)/forced vital capacity (FVC) <0.7; and those with FEV1 <80% of the predicted value at enrollment. The exclusion criteria were as follows: patients without respiratory symptoms; patients who could not understand the details of questionnaires or instructions on using the air device. This study was approved by the Institutional Review Board of each study institution; Asan Medical Center (2019–0476), Ulsan University Hospital (2019-07-049), Gangneung Asan Hospital, and Gil Medical Center. was checked.

Study design and data collection

Clinical and demographic data, including data about age, sex, concurrent asthma, current place of residence and smoking history, were collected at enrollment. The patients completed the detailed questionnaire surveys. To measure indoor $PM_{2.5}$ concentrations, Internet of Things (IoT)-based sensors were installed in their homes and continuously monitored for 1 year. The exacerbation of COPD was checked every month. The detail of study protocol is published previously.[21]

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

The participants filled out questionnaires on their lifestyle and indoor/outdoor living environments(Table 2).

Table 2. Questionnaire about lifestyle practices to reduce PM exposure

The questionnaire started with "On a scale from 0 (never practiced) to 7 (practiced every day), how many days have you usually practiced the following items when the concentration of particulate matter was high (≥35 μg/m^3) or very high (≥75 μg/m^3) in the last year?"

Practice Item	Frequency Never practiced Practiced everyday ← →							
1. I frequently checked the forecast for fine dust and changes in its concentration.	(0)	(1)	(2)	(3)	(4)	(5)	(6)	(7)
2. I kept air purifiers on (if there was no air purifier, please choose the score (0)).	(0)	(1)	(2)	(3)	(4)	(5)	(6)	(7)
3. While the air purifier was on, I also regularly ventilated the room by opening windows (if there was no air purifier, please choose the score (0)).	(0)	(1)	(2)	(3)	(4)	(5)	(6)	(7)
4. While the air purifier was on, I also regularly checked and replaced the filters (if there was no air purifier, please choose the score (0)).	(0)	(1)	(2)	(3)	(4)	(5)	(6)	(7)
5. I turned on the kitchen ventilator (fan) while cooking and made sure that the room was ventilated afterward.	(0)	(1)	(2)	(3)	(4)	(5)	(6)	(7)
6. When cleaning indoors, I mopped instead of using a vacuum cleaner.	(0)	(1)	(2)	(3)	(4)	(5)	(6)	(7)
7. When cleaning indoors, I sprayed water before mopping.	(0)	(1)	(2)	(3)	(4)	(5)	(6)	(7)
8. I drank plenty of water to remove waste products from my body.	(0)	(1)	(2)	(3)	(4)	(5)	(6)	(7)
9. I ate a lot of vegetables and fruits with antioxidant properties.	(0)	(1)	(2)	(3)	(4)	(5)	(6)	(7)
10. I limited the frequency at which I went out or did outdoor activities.	(0)	(1)	(2)	(3)	(4)	(5)	(6)	(7)
11. I wore a health mask (FDA-certified) properly when I went out.	(0)	(1)	(2)	(3)	(4)	(5)	(6)	(7)

12. I minimized exposure of my body by wearing a hat, long sleeves, safety glasses, etc.	(0)	(1)	(2)	(3)	(4)	(5)	(6)	(7)
13. I refrained from going to places with high concentrations of fine dust, such as areas with heavy traffic, factories, etc., as much as possible.	(0)	(1)	(2)	(3)	(4)	(5)	(6)	(7)
14. I switched to indoor circulation mode with the windows closed while driving.	(0)	(1)	(2)	(3)	(4)	(5)	(6)	(7)
15. I reduced the duration or intensity of outdoor physical activities (for example, I chose to walk instead of run).	(0)	(1)	(2)	(3)	(4)	(5)	(6)	(7)
16. I washed myself after coming home (washing all over, especially hands, feet, eyes, and nose with running water, and brushing teeth).	(0)	(1)	(2)	(3)	(4)	(5)	(6)	(7)
17. I dusted off my clothes before entering the house.	(0)	(1)	(2)	(3)	(4)	(5)	(6)	(7)
18. I avoided secondhand smoke (in the case of a non-smoker)/I refrained from smoking (in the case of a smoker).	(0)	(1)	(2)	(3)	(4)	(5)	(6)	(7)
19. I purchased an emergency inhaler for symptom exacerbations and used it when necessary.	(0)	(1)	(2)	(3)	(4)	(5)	(6)	(7)
20. I used an inhaler regularly in the instructed way.	(0)	(1)	(2)	(3)	(4)	(5)	(6)	(7)

Measurements of individual PM exposure

Indoor $PM_{2.5}$ concentrations were measured using a sensor-based light scattering measurement device (CP-16-A5; Aircok Inc., Seoul, Korea). The device was located at the place where they spent most time in center of each patient's house. The data were sent to a server based on IoT throughout the study period. To correct for possible errors in the light scattering methods, gravimetric measurements were taken and accurate light scattering was measured using a mini-volume air sampler (Model KMS-4100; KEMIK Corp., Seongnam, Korea) and two dust spectrometers (11-D; Grimm Technologies and AM520; TSI, Shoreview, MN, USA), respectively. Indoor $PM_{2.5}$ concentrations reported by the IoT showed good linearity with the GRIMM reference, with a R^2 value of 0.923. Information about outdoor PM concentrations relating to the residential address was gathered from Air Korea, a national air pollution information system in South Korea (http://www.airkorea.or.kr).

Statistical analysis

Data are shown as means and standard deviations or as medians with interquartile ranges for continuous variables and as number (%) for categorical variables. For non-continuous variables such as practice scores, an analysis of variance was used to confirm the difference between indoor and outdoor $PM_{2.5}$ concentrations corresponding to the practice scores. In addition, data were compared using the t-test and variation analysis by classifying the frequency with which patients performed the practices into two categories: practiced or not practiced every day. Furthermore, logistic regression analysis was used to determine COPD exacerbations according to the difference between indoor and outdoor $PM_{2.5}$ concentrations. The statistical significance level was set to 0.05 unless otherwise specified. All statistical analyses were performed using SPSS software (version 22, IBM Corp., Armonk, NY, USA).

Results

3-1. Basic characteristics of the study patients

A total of 110 patients with COPD were enrolled for the panel study. Of these, six patients were excluded from the final analysis for missing data on indoor PM concentration. The mean age of patients was 67.4 ± 9.8 years, with 94 (90.4%) male patients. Current smokers were 23 (22.1%), and ex-smokers were 64 (64.5%) with 33.7 ± 23.3 pack-years. Thirty-eight had a history of acute exacerbation last year, accounting for 36.5% and all of them used inhalers. The mean COPD assessment test (CAT) score was 17.0 ± 8.7. The modified Medical Research Council (mMRC) was more than half (62, 59.6%) of them had grade 1, but about 30% had more than grade 3 (16 [15.4%] for Grade 3 and 14 [13.5%] for Grade 4) at enrollment. The mean score of the COPD-specific version of the St. George's Respiratory Questionnaire (SGRQ-

C) was 38.43±2.45 and mean R5 (resistance at 5 Hz)–R20 (resistance at 20 Hz) was 0.18±0.03 $cmH_2O/l/s$ (Table 1).

Table 1. Baseline characteristics of the study participants.

Characteristics	N
Age, years (SD)	67.4±9.8
Male, n (%)	94 (90.38)
Smoking status, n (%)	
Never smoker	17 (16.35)
Ex-smoker	64 (61.54)
Current-smoker	23 (22.12)
Smoking history (pack-year), mean (SD)	33.73±23.33
mMRC, n (%)	
Grade 1	62 (59.62)
Grade 2	12 (11.54)
Grade 3	16 (15.38)
Grade 4	14 (13.46)
Acute exacerbation history last year	38 (36.54)
Inhaler usage, n (%)	
ICS+LABA	21 (20.19)
LAMA+LABA	33 (31.73)
LAMA+LABA+ICS	39 (37.5)
LABA+LAMA+SABA	3(2.88)
ICS+LABA+LAMA+SABA	2(1.92)
LAMA+SABA	1(0.96)
LAMA	2(1.92)
ICS+LAMA	1(0.96)
Others	2(1.92)

Lung function, mean (SD)	
PreBD FEV_1, L (% predicted)	1.57±0.54 (52.69±17.11)
PreBD FVC, L (% predicted)	3.30±0.84 (79.64±16.27)
PostBD FEV_1, L (% predicted)	1.62±0.56 (54.53±16.64)
PostBD FVC, L (% predicted)	3.28±0.86 (80.52±14.48)
CAT score, mean (SD)	17.04±8.65
SGRQ total, mean (SD)	38.43±2.45
R5-R20 (SD)	0.18±0.03

SD, standard deviation; mMRC, Modified Medical Research Council; ICS, inhaled corticosteroid; LABA, long-acting beta 2 agonist; BD, bronchodilator; FEV_1, forced expiratory volume in one second; FVC, forced vital capacity; CAT, COPD assessment test; SGRQ, St. George's Respiratory Questionnaire; R5, Resistance at 5Hz; R20, Resistance at 20Hz

3-2. $PM_{2.5}$ concentrations and lifestyle practices to reduce PM exposure

The mean concentration of outdoor $PM_{2.5}$ was consistently higher than that of indoor $PM_{2.5}$ in most season except fall. The difference was greatest in winter (4.31±0.02 μg/m^3) (Figure 1). Comparing the survey results measured twice at the time of enrollment and at the end of the study, it was confirmed that the overall practice score of the subjects increased (Figure 2). There were lifestyle practices that can reduce PM concentration for each season, and among them, the number of items were the highest in winter, particularly. When patients operated indoor air filters(–4.69±1.12 μg/m^3, p=0.001) and checked filters of air filters(–4.00±1.01 μg/m^3, p=0.031), ventilated the home by opening windows(–5.29±0.89 μg/m^3, p<0.001), and closed windows while driving with internal circulation mode(–4.33±0.77 μg/m^3, p=0.002), refrained from going out when the outside $PM_{2.5}$ concentration was high (–3.80±1.26 μg/m^3, p=0.038), chose to go out in places with little traffic (–3.39±1.09 μg/m^3, p=0.020) (Figure 3). Other lifestyle practices that reduced the indoor PM2.5 concentration compared with the outdoor PM2.5 concentration in specific seasons included mopping indoors (spring and summer), choosing to go out in places with little traffic (spring and winter), and refraining from going out when the outside PM2.5 concentration was high (winter, Figure 3). There was no significant relationship between the difference in indoor and outdoor PM2.5 concentrations and lifestyle practices. The more air filters were used, the lower the indoor PM2.5 concentration tends to be throughout the year (Figure 4)

Figure 1.

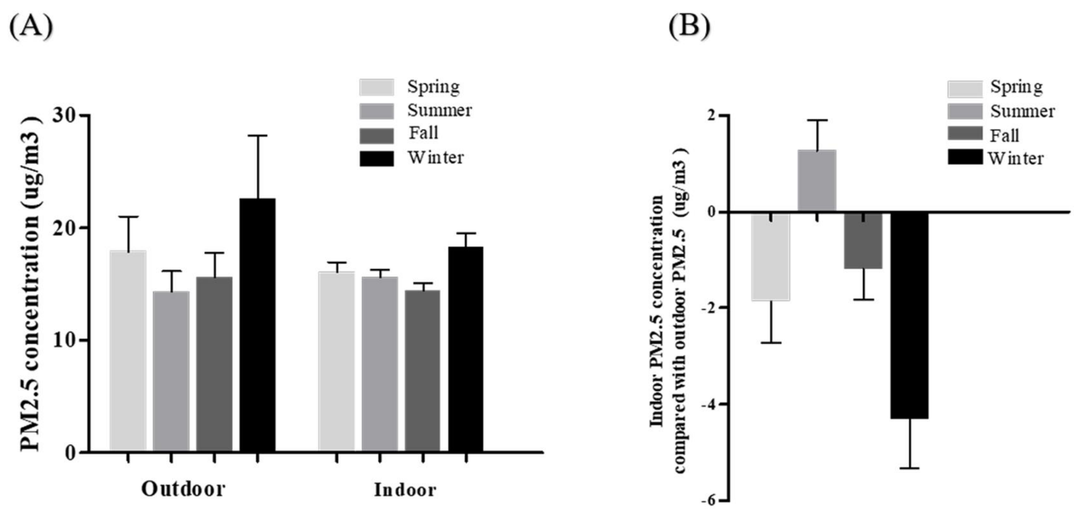
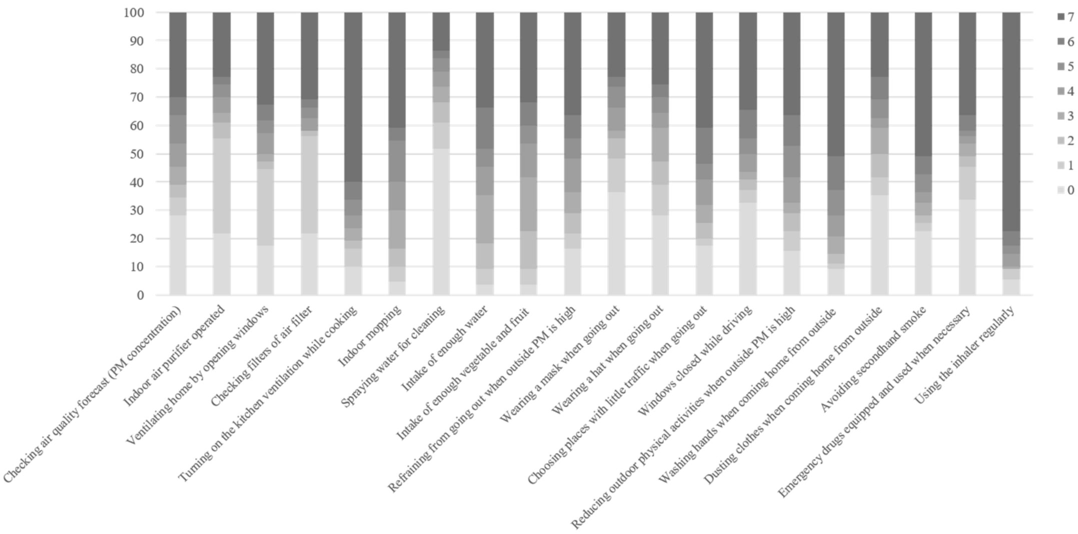


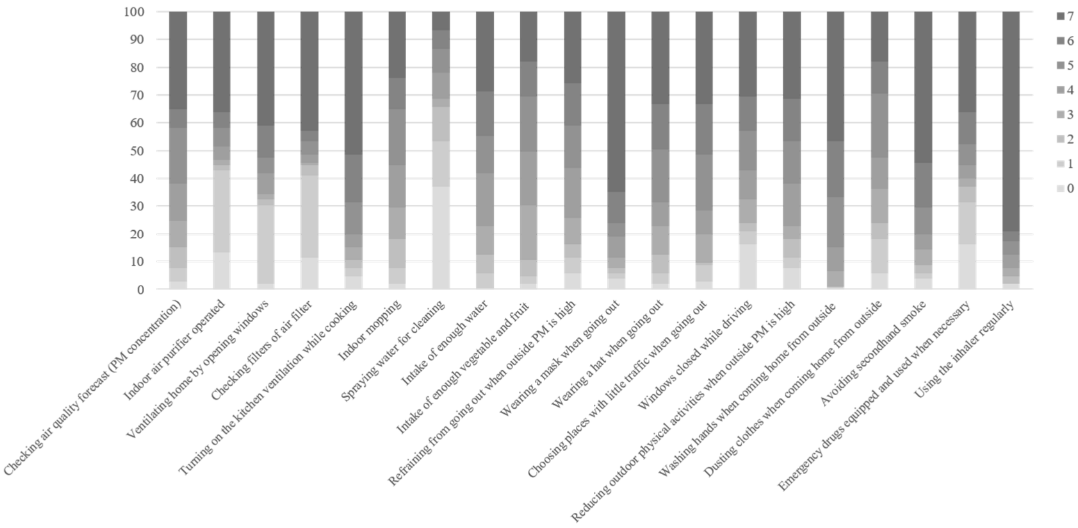
Figure 2.

A



100
90
80
70
60
50
40
30
20
10
0
Checking air quality forecast (PM concentration)
Indoor air purifier operated
Ventilating home by opening windows
Checking filters of air filter
Turning on the kitchen ventilation while cooking
Indoor mopping
Spraying water for cleaning
Intake of enough water
Intake of enough vegetable and fruit
Refraining from going out when outside PM is high
Wearing a mask when going out
Wearing a hat when going out
Choosing places with little traffic when going out
Windows closed while driving
Reducing outdoor physical activities when outside PM is high
Washing hands when coming home from outside
Dusting clothes when coming home from outside
Avoiding secondhand smoke
Emergency drugs equipped and used when necessary
Using the inhaler regularly
7
6
5
4
3
2
1
0

B



100
90
80
70
60
50
40
30
20
10
0
Checking air quality forecast (PM concentration)
Indoor air purifier operated
Ventilating home by opening windows
Checking filters of air filter
Turning on the kitchen ventilation while cooking
Indoor mopping
Spraying water for cleaning
Intake of enough water
Intake of enough vegetable and fruit
Refraining from going out when outside PM is high
Wearing a mask when going out
Wearing a hat when going out
Choosing places with little traffic when going out
Windows closed while driving
Reducing outdoor physical activities when outside PM is high
Washing hands when coming home from outside
Dusting clothes when coming home from outside
Avoiding secondhand smoke
Emergency drugs equipped and used when necessary
Using the inhaler regularly
7
6
5
4
3
2
1
0

Figure 3.

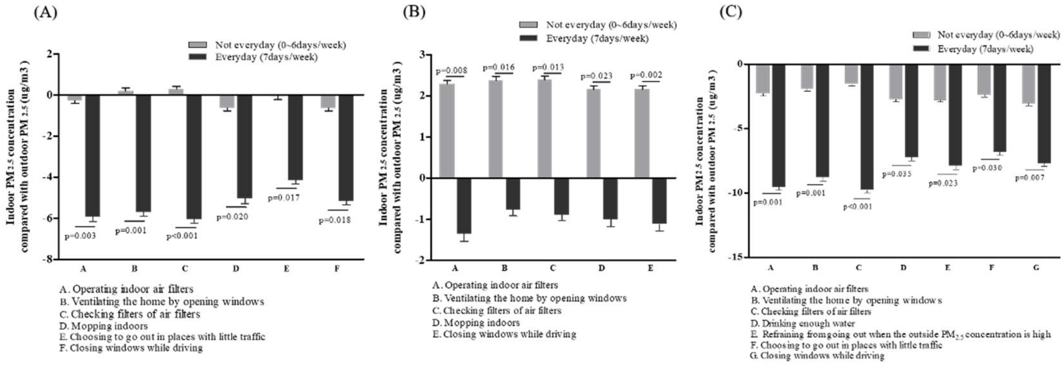
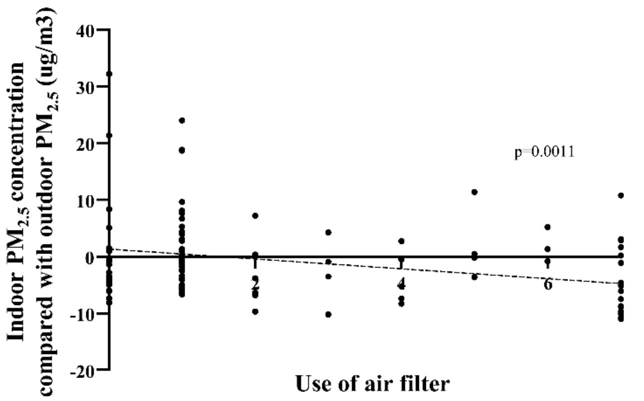


Figure 4.



3-3. Relationship between Indoor and outdoor $PM_{2.5}$ concentrations and participants' social environment

We analyzed social environment of participants, including their economic status and educational level. The higher educational level and the economic status, the more the difference between indoor and outdoor $PM_{2.5}$ concentrations. We divided economic status into three groups (High, Average, Low), and educational level into three groups (College or higher level, High school graduation, Below middle school). The higher the economic status, the more the difference between annual indoor and outdoor $PM_{2.5}$ concentrations (high, –4.71±1.12 μg/m^3; average, +0.17±1.40 μg/m^3; and low, –1.93±0.92 μg/m^3; p=0.086, Figure 5). These differences between each group were more pronounced in some lifestyle practices, including checking air quality forecasts (p=0.012), checking filters of air filters (p=0.023), wearing a mask when going out (p=0.073), closing windows while driving (p=0.042), and being equipped with emergency drugs and using them when necessary (p=0.099, Figure 5). The higher the educational level, the more the difference between indoor and outdoor $PM_{2.5}$ concentrations (higher than college graduation, –6.00±1.14 μg/m^3; high school graduation, –1.98±0.88 μg/m^3; and less than middle school graduation, +0.32±1.40 μg/m^3; p=0.034, Figure 6).

Figure 5.

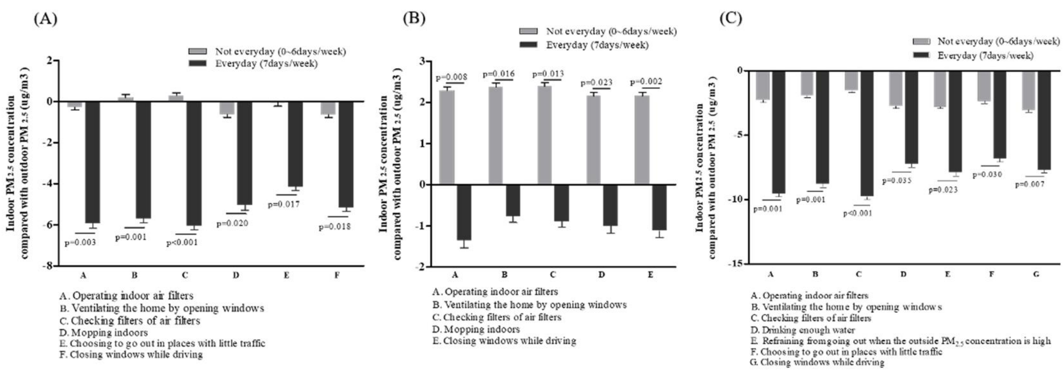
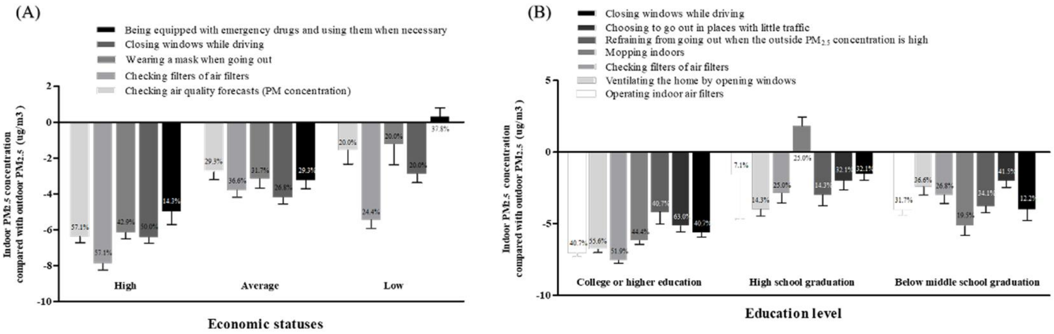


Figure 6.



3-4. Lifestyle practices and acute COPD exacerbations according to Indoor $PM_{2.5}$ concentrations

The relationship between lifestyle practices, COPD acute exacerbation and $PM_{2.5}$ concentration was analyzed. Some lifestyle practices were significantly reduced acute exacerbation of COPD(Table 3). The R5–R20 was significantly lower for patients whose everyday lifestyle practices included checking air quality forecasts (0.12±0.02 cmH_2O/l/s, p=0.038) and wearing a mask when going out (0.11±0.03 cmH_2O/l/s, p=0.080, Figure 7-A). The SGRQ-C score was also lower for patients whose everyday lifestyle practices including mopping indoors (29.21±4.29, p=0.046), closing windows while driving (27.37±3.17, p=0.004), dusting clothes when coming home from outside(16.73±2.16, p<0.001) (Figure 7-B).

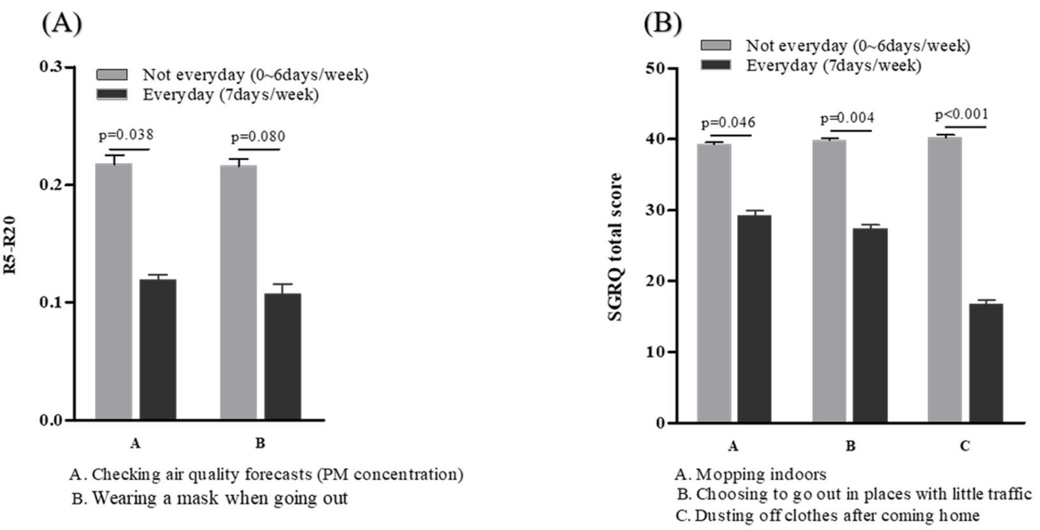
Table 3. Relative risk of difference between acute exacerbations of COPD when Performed every day and not performed every day.

	Relative risk (95% confidence interval)	p value
Checking air quality forecast (PM concentration)	1.31 (0.35,4.83)	0.69
Indoor air purifier operated	4.73 (1.00,22.40)	0.05*
Ventilating home by opening windows	1.33 (0.28,6.34)	0.72
Checking filters of air filter	0.32 (0.07,1.47)	0.14
Turning on the kitchen ventilation while cooking	2.66 (0.84,8.45)	0.10
Indoor mopping	0.83 (0.22,3.13)	0.79
Spraying water for cleaning	3.10 (0.29,32.55)	0.35
Intake of enough water	0.93 (0.29,2.99)	0.91
Intake of enough vegetable and fruit	1.29 (0.32,5.14)	0.72
Refraining from going out when outside PM is high	0.43 (0.10,1.78)	0.24
Wearing a mask when going out	0.30 (0.06,1.41)	0.13
Wearing a hat when going out	1.59 (0.48,5.20)	0.45
Choosing places with little traffic when going out	0.71 (0.15,3.41)	0.67

Windows closed while driving	0.64 (0.20,2.12)	0.47
Reducing outdoor physical activities when outside PM is high	4.91 (1.20,20.26)	0.03**
Washing hands when coming home from outside	0.45 (0.14,1.44)	0.18
Dusting clothes when coming home from outside	0.37 (0.08,1.70)	0.20
Avoiding secondhand smoke	1.39 (0.41,4.64)	0.60
Emergency drugs equipped and used when necessary	2.29 (0.72,7.27)	0.16
Using the inhaler regularly	3.99 (0.89,17.83)	0.07*

**P<0.05, *P,<0.1

Figure 7.



Discussion

This prospective panel study showed that $PM_{2.5}$ concentration would be affected by individual lifestyle practices and social environment. Although there were seasonal differences, some lifestyle practices were related with a significantly lower indoor $PM_{2.5}$ concentration compared with the outdoor $PM_{2.5}$ concentration substantially. These items included that operating indoor air filters, ventilating the home by opening windows, checking filters of air filters, and closing windows while driving. The higher the economic status and educational level, the greater the difference between indoor and outdoor $PM_{2.5}$ concentrations. Some lifestyle practices including mopping indoor and choosing to go out in places with little traffic effected to lower SGRQ-C scores and small airway resistance. These results suggest that exposure to $PM_{2.5}$ can be reduced by conducting these practices.

Many studies that Air filters are intervention to improve indoor $PM_{2.5}$ concentration have already been. Among them, a meta-analysis about air filter interventions for COPD patients, air filters continuously improved indoor $PM_{2.5}$ concentrations[22]. One randomized controlled trial found that improvements of respiratory symptoms and acute exacerbations by an air filter intervention were associated with reduced indoor $PM_{2.5}$ concentrations[23]. In a study, a classroom-based air filter intervention effect to significant reduction of $PM_{2.5}$ and black carbon concentrations[24]. Using indoor air filters also led to significant reduction of indoor $PM_{2.5}$ concentrations and its major components such as NO^{3-}, SO_4^{2-}, Zn^{2+}, Pb^{2+}, and K^+ [25]. In a pilot study, children exposed to secondhand smoke, air filters reduced the airborne particles and also improved clinical outcomes such as visiting unscheduled hospital due to asthma[26]. In a study on college students, intervention with a short-term indoor air filter improved various cardiovascular biomarkers[27]. Everyday operate air filters is suggested to improve indoor $PM_{2.5}$ concentrations, and checking filters of air filters is also helpful[20,28]. In our study, everyday operate air filters reduced indoor $PM_{2.5}$ concentrations.

To reduce indoor air pollution, maintenance of a clean indoor environment is a important strategy. In our study there is a interesting result that the indoor mopping reduce significantly the indoor $PM_{2.5}$ concentration compared with the outdoor $PM_{2.5}$ concentration in spring and summer. This is similar to the prior recommendation for wet mopping to lower indoor pollution[29]. The previous finding that dry sweeping increases $PM_{2.5}$ concentrations more than wet sweeping supports the recommendation for wet mopping[30]. Another valuable recommendation for the indoor environment is to use a vacuum with a high-efficiency particulate-absorbing (HEPA) filter. Using a vacuum without filter can stir up particles and deep dust. However, using a vacuum with a HEPA filter reduced the exposure of dust and helped to control asthma [31,32].

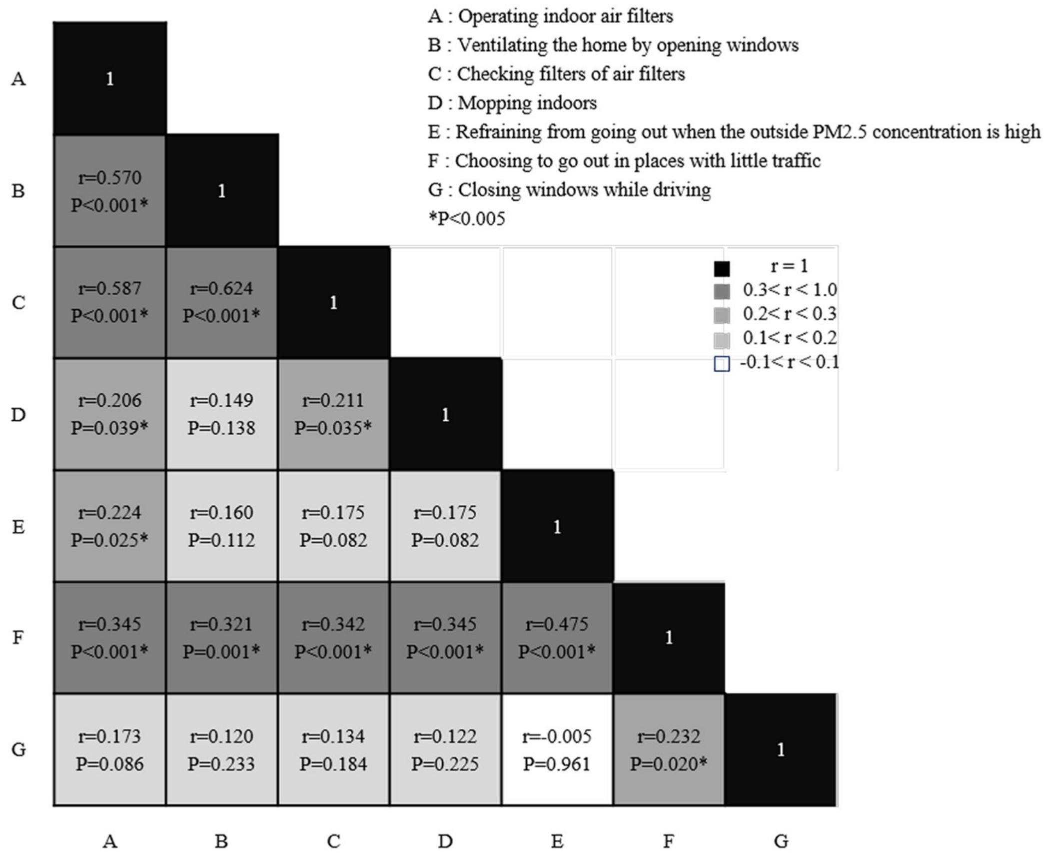
Unlike other seasons, there was no significant association between $PM_{2.5}$ concentration and lifestyle practices in fall. This can be explained by the results of our study that the difference in indoor and outdoor PM concentrations was the smallest in fall. A national database also noted that the mean outdoor PM concentration is lowest in the fall[33]. In contrast, a relatively strong association was found in the winter, when the difference in PM2.5 concentration between indoor and outdoor was the largest. Studies have shown that chronic obstructive pulmonary disease has a seasonal variation of hospitalization rate and more exacerbation occurs in winter[34,35]. Acute exacerbation of COPD was also related with cooler temperatures[36,37]. This signify that lifestyle modification can reduce the risk of COPD more effectively in winter, when patients are more hazardous.

Choosing to go out in places with little traffic and refraining from going out when the outside $PM_{2.5}$ concentration was high were also effective, but they are not be directly related to the indoor $PM_{2.5}$ concentrations. Furthermore, prior study recommended that refraining from outdoor physical activities and staying indoor when outdoor PM concentrations are very high can reduce exposure to $PM_{2.5}$ concentrations[38]. The U.S. Air Quality Index suggests to stay inside in the place with operating air filters and avoid outdoor activities when outdoor PM concentration is high[29]. These lifestyle practices help people to refrain from breathing deeply and rapidly and also avoid inhalation of $PM_{2.5}$. This suggestion also applicable to COPD patients[39]. It is uncertain how these lifestyle practices also have beneficial impacts on indoor $PM_{2.5}$ concentrations. It can be assumed that it is because people who perform these lifestyle practices well do other lifestyles well. As a result, that have significantly beneficial impacts on indoor $PM_{2.5}$ concentrations. In our study, participants who had a lifestyle of going out to places with less traffic were also doing well in other lifestyle practices(Figure 8). And also, a group of participants tended to perform several lifestyle practices simultaneously to reduce PM exposure. Through our study, we explained that reduction of $PM_{2.5}$ was possible to through lifestyle practices. Thus, we expect that intervention of lifestyle of patients with COPD and encourage them to do meaningful habits, we would finally improve their quality of life.

Environmental inequality is a global issue that affects both developing and developed countries. So far, many studies have found that low socioeconomic status(SES) leads to a high risk of exposure to air pollutants[40]. Low educational attainment generally correspond to an individual's income, which is associated with SES, such as the residential environment[41]. In previous study, a high PM hazard were effected by a low educational level[42]. Our study also showed that a high education level and economic status showed a great difference between indoor and outdoor PM concentrations. This difference was significant in the highest income (≥$5250/month) and those with a college degree or higher. In Korea, educational level was closely related to household income[43]. However, in a European previous analysis, they found that non-linear trends which both higher and lower income groups had higher PM concentration than middle-income groups[44]. This finding suggest that the association with income, educational level and environment can have various patterns due to region, society, country and how they cope with the environmental problem.

Our study had some strengths and limitation. The lifestyle questionnaire was based on patient's memories, and that can sometimes has biases. Nonetheless, there were some important implications. First, despite the impact of PM on the occurrence of COPD, there was little research on detailed lifestyles. This study reported the detailed lifestyle practices of COPD patients and analyze their relationship. It also showed a relationship between $PM_{2.5}$ concentrations and acute COPD exacerbations. Second, this research collected data over 1 year and showed variable changes in $PM_{2.5}$ concentration by the season. Applying this research design, it could be possible to determine the impact of each lifestyle practices for each season. Third, IoT-based $PM_{2.5}$-measuring sensors used in our study were installed in patients' home, and we monitored continuously indoor PM concentrations. This study provides evidence with more accurate data.

Figure 8.



Conclusion

Lifestyle practices have association with indoor PM concentration and can even affect small airway resistance and exacerbation of COPD patients. Furthermore, indoor PM concentration can be affected by social environment including the level of economic and education of COPD patients. Some lifestyle practices lead to reduce $PM_{2.5}$ concentrations as follows: operating air filters and ventilating the home by opening windows. Finally, these can be scientific guideline to reduce exposure of patients with COPD to $PM_{2.5}$ concentration.

Abbreviations

COPD, chronic obstructive pulmonary disease; FEV_1, forced expiratory volume in 1 second; FVC, forced vital capacity; HEPA, high-efficiency particulate-absorbing; IoT, Internet of Things; PM, particulate matter; $PM_{2.5}$, particulate matter with a diameter smaller than 2.5 µm; SGRQ-C, COPD-specific version of the St. George's Respiratory Questionnaire; R5, Resistance at 5Hz; R20, Resistance at 20Hz.

Acknwledgement

This study was supported by the Korea Centers for Disease Control and Prevention (Grant Nos. 2019ER671100 and 2019ER671101) and the Korea Disease Control and Prevention Agency (Grant No. 2021ER120900). The authors would like to thank all the members of our research group at the University of Ulsan College of Medicine, Asan Medical Center, Gangneung Asan Hospital, Ulsan University Hospital, Gachon University Gil Medical Center, and Inha University who contributed to this study, and all the participants involved to support this study.

References

1. Brook RD, Rajagopalan S, Pope CA, 3rd, et al. Particulate matter air pollution and cardiovascular disease: An update to the scientific statement from the American Heart Association. Circulation 2010;121:2331-78.

2. The L. WHO's global air-quality guidelines. The Lancet 2006;368:1302.

3. Wang Y, Kloog I, Coull BA, Kosheleva A, Zanobetti A, Schwartz JD. Estimating Causal Effects of Long-Term PM2.5 Exposure on Mortality in New Jersey. Environmental health perspectives 2016;124:1182-8.

4. Crouse DL, Peters PA, Hystad P, et al. Ambient PM2.5, O_3, and NO_2 Exposures and Associations with Mortality over 16 Years of Follow-Up in the Canadian Census Health and Environment Cohort (CanCHEC). Environmental health perspectives 2015;123:1180-6.

5. Cohen AJ, Brauer M, Burnett R, et al. Estimates and 25-year trends of the global burden of disease attributable to ambient air pollution: an analysis of data from the Global Burden of Diseases Study 2015. Lancet (London, England) 2017;389:1907-18.

6. Samet JM, Dominici F, Curriero FC, Coursac I, Zeger SL. Fine particulate air pollution and mortality in 20 U.S. cities, 1987-1994. The New England journal of medicine 2000;343:1742-9.

7. Pope CA, 3rd, Ezzati M, Dockery DW. Fine-particulate air pollution and life expectancy in the United States. The New England journal of medicine 2009;360:376-86.

8. Lelieveld J, Evans JS, Fnais M, Giannadaki D, Pozzer A. The contribution of outdoor air pollution sources to premature mortality on a global scale. Nature 2015;525:367-71.

9. Liu S, Zhou Y, Liu S, et al. Association between exposure to ambient particulate matter and chronic obstructive pulmonary disease: results from a cross-sectional study in China. Thorax 2017;72:788-95.

10. Hansel NN, McCormack MC, Kim V. The Effects of Air Pollution and Temperature on COPD. Copd 2016;13:372-9.

11. Zhu R, Chen Y, Wu S, Deng F, Liu Y, Yao W. The relationship between particulate matter (PM10) and hospitalizations and mortality of chronic obstructive pulmonary disease: a meta-analysis. Copd 2013;10:307-15.

12. Hansel NN, McCormack MC, Belli AJ, et al. In-home air pollution is linked to respiratory morbidity in former smokers with chronic obstructive pulmonary disease. American journal of respiratory and critical care medicine 2013;187:1085-90.

13. Jung W. Environmental Challenges and Cooperation in Northeast Asia. Institute for Security & Development Policy 16 March 2016.

14. Zhu W, Xu X, Zheng J, Yan P, Wang Y, Cai W. The characteristics of abnormal wintertime pollution events in the Jing-Jin-Ji region and its relationships with meteorological factors. The Science of the total environment 2018;626:887-98.

15. OECD. <Policy Brief-NE Asia_Air pollution.pdf>.

16. Halpin DMG, Criner GJ, Papi A, et al. Global Initiative for the Diagnosis, Management, and Prevention of Chronic Obstructive Lung Disease. The 2020 GOLD Science Committee Report on COVID-19 and Chronic Obstructive Pulmonary Disease. American journal of respiratory and critical care medicine 2021;203:24-36.

17. World Health Organization. https://www.who.int/news-room/fact-sheets/detail/chronic-obstructive-pulmonary-disease-(copd). August 24, 2021.

18. Pothirat C, Chaiwong W, Liwsrisakun C, et al. Influence of Particulate Matter during Seasonal Smog on Quality of Life and Lung Function in Patients with Chronic Obstructive Pulmonary Disease. International journal of environmental research and public health 2019;16.

19. Lamichhane DK, Leem JH, Kim HC. Associations between Ambient Particulate Matter and Nitrogen Dioxide and Chronic Obstructive Pulmonary Diseases in Adults and Effect Modification by Demographic and Lifestyle Factors. International journal of environmental research and public health 2018;15.

20. Kim H, Na G, Park S, et al. The impact of life behavior and environment on particulate matter in chronic obstructive pulmonary disease. Environmental research 2021;198:111265.

21. Kang J, Jung JY, Huh JY, Ji HW, Kim HC, Lee SW. Behavioral interventions to reduce particulate matter exposure in patients with COPD. Medicine 2021;100:e28119.

22. Park HJ, Lee HY, Suh CH, et al. The Effect of Particulate Matter Reduction by Indoor Air Filter Use on Respiratory Symptoms and Lung Function: A Systematic Review and Meta-analysis. Allergy, asthma & immunology research 2021;13:719-32.

23. Hansel NN, Putcha N, Woo H, et al. Randomized Clinical Trial of Air Cleaners to Improve Indoor Air Quality and Chronic Obstructive Pulmonary Disease Health: Results of the CLEAN AIR Study. American journal of respiratory and critical care medicine 2022;205:421-30.

24. Jhun I, Gaffin JM, Coull BA, et al. School Environmental Intervention to Reduce Particulate Pollutant Exposures for Children with Asthma. The journal of allergy and clinical immunology In practice 2017;5:154-9.e3.

25. Shao D, Du Y, Liu S, et al. Cardiorespiratory responses of air filtration: A randomized crossover intervention trial in seniors living in Beijing: Beijing Indoor Air Purifier StudY, BIAPSY. The Science of the total environment 2017;603-604:541-9.

26. Lanphear BP, Hornung RW, Khoury J, Yolton K, Lierl M, Kalkbrenner A. Effects of HEPA air cleaners on unscheduled asthma visits and asthma symptoms for children exposed to secondhand tobacco smoke. Pediatrics 2011;127:93-101.

27. Chen R, Zhao A, Chen H, et al. Cardiopulmonary benefits of reducing indoor particles of outdoor origin: a randomized, double-blind crossover trial of air purifiers. Journal of the American College of Cardiology 2015;65:2279-87.

28. Prevention CfDCa. Improving Ventilation in Your Home, https://www.cdc.gov/coronavirus/2019-ncov/prevent-getting-sick/improving-ventilation-home.html. CDC June 29, 2022.

29. Extremely High Levels of PM2.5: Steps to Reduce Your Exposure. https://www.airnow.gov/aqi/aqi-basics/extremely-high-levels-of-pm25/. August 4, 2022.

30. Lin Y, Zou J, Yang W, Li CQ. A Review of Recent Advances in Research on PM(2.5) in China. International journal of environmental research and public health 2018;15.

31. Roberts JW, Wallace LA, Camann DE, et al. Monitoring and reducing exposure of infants to pollutants in house dust. Rev Environ Contam Toxicol 2009;201:1-39.

32. Castner J, Barnett R, Moskos LH, Folz RJ, Polivka B. Home environment allergen exposure scale in older adult cohort with asthma. Canadian journal of public health = Revue canadienne de sante publique 2021;112:97-106.

33. Airkorea, monthly/annual report on air conditionimg, https://www.airkorea.or.kr/index. 2020.

34. Bryden C, Bird W, Titley HA, Halpin DM, Levy ML. Stratification of COPD patients by previous admission for targeting of preventative care. Respiratory medicine 2009;103:558-65.

35. Jenkins CR, Celli B, Anderson JA, et al. Seasonality and determinants of moderate and severe COPD exacerbations in the TORCH study. The European respiratory journal 2012;39:38-45.

36. Dowell SF, Ho MS. Seasonality of infectious diseases and severe acute respiratory syndrome-what we don't know can hurt us. The Lancet Infectious diseases 2004;4:704-8.

37. Kim Y-M, Kim J, Cheong H-K, Jeon B-H, Ahn K. Exposure to phthalates aggravates pulmonary function and airway inflammation in asthmatic children. PLOS ONE 2018;13:e0208553.

38. Improving Ventilation in Your Home, https://www.cdc.gov/coronavirus/2019-ncov/prevent-getting-sick/improving-ventilation-home.html. June 29,2022.

39. Choi J, Oh JY, Lee YS, et al. Harmful impact of air pollution on severe acute exacerbation of chronic obstructive pulmonary disease: particulate matter is hazardous. International journal of chronic obstructive pulmonary disease 2018;13:1053-9.

40. Hajat A, Hsia C, O'Neill MS. Socioeconomic Disparities and Air Pollution Exposure: a Global Review. Current Environmental Health Reports 2015;2:440-50.

41. Jerrett M, Burnett RT, Brook J, et al. Do socioeconomic characteristics modify the short term association between air pollution and mortality? Evidence from a zonal time series in Hamilton, Canada. Journal of epidemiology and community health 2004;58:31-40.

42. Cakmak S, Dales RE, Rubio MA, Vidal CB. The risk of dying on days of higher air pollution among the socially disadvantaged elderly. Environmental research 2011;111:388-93.

43. Byun S-y, Kim K-k. Educational inequality in South Korea: The widening socioeconomic gap in student achievement. In: Hannum E, Park H, Goto Butler Y, eds.

Globalization, Changing Demographics, and Educational Challenges in East Asia: Emerald Group Publishing Limited; 2010:155-82.

44. Havard S, Deguen S, Zmirou-Navier D, Schillinger C, Bard D. Traffic-related air pollution and socioeconomic status: a spatial autocorrelation study to assess environmental equity on a small-area scale. Epidemiology (Cambridge, Mass) 2009;20:223-30.

국문요약

연구배경 및 목적: 미세먼지에 대한 노출은 전 세계적인 공중 보건 문제이다.

이 연구에서는 COPD 환자들에게서 미세먼지 노출을 줄이기 위한 행동 중재가 임상 결과를 개선할 수 있는지 여부를 평가하는 것을 목표로 하였다.

방법: 우리는 한국의 다른 지역에 있는 4 개의 병원에서 40 세 이상의 COPD 환자 104 명을 대상으로 조사를 하였다. 실내 $PM_{2.5}$ 농도를 측정하기 위해 IoT 기반 센서를 집에 설치하여 1 년동안 모니터링 하였고, 세부 설문조사는 환자들 방문시에 두 번(등록 및 연구 종료) 실시했다. 이를 이용하여 $PM_{2.5}$ 농도와 환자의 생활습관, COPD 악화에 미치는 영향과의 관계를 분석하였다.

결과: $PM_{2.5}$ 농도는 대부분의 계절에서 실내보다 실외에서 더 높았으며, 특히 겨울철에 그 차이가 가장 컸다(4.31±0.02 μg/m^3). 환자들의 생활습관 실천점수는 입적당시와 비교할 때 연구가 끝날 때 더 높았다. 실외에 비해 실내 $PM_{2.5}$ 농도를 낮추는데 영향을 미치는 생활습관들은 계절에 따라 항목에 차이가 있었다. 그 중 겨울철에 유의한 생활습관 항목수가 가장 많았고, 그 항목들은 다음과 같다: 실내 공기 청정기 작동 (-4.69±1.12 μg/m^3, $p=0.001$), 창문열어 환기 (-5.29±0.89 μg/m^3, $p<0.001$), 공기청정기 필터점검 (-4.00±1.01 μg/m^3, $p=0.031$), 실외 미세먼지 농도 높을 때 외출 삼가기 (3.80±1.26 μg/m^3, $p=0.038$), 교통량이 적은 곳으로 외출하기 (-3.39±1.09 μg/m^3, $p=0.020$), 운전시 창문 닫기 (-4.33±0.77 μg/m^3, $p=0.002$). 교육수준과 경제수준이 높을수록 실내 $PM_{2.5}$ 농도가 낮게 나타났다. 일부 생활습관은 임펄스 오실로메트리(IOS)를 통해 측정한 R5-R20 값으로 표기된 소기도 저항을 감소시키는데 영향을 미치며, SGRQ 점수를 낮추는 데에도 영향을 미친다.

결론: 일부 생활습관과 생활환경은 실내 $PM_{2.5}$ 농도를 감소시키는데 영향을 줄 수 있고, 그 결과 COPD 환자들의 임상결과에도 영향을 미칠 수 있다.

중심단어: 만성 폐쇄성 폐질환; 미세먼지; 생활 습관; 세인트 조지 호흡기 설문지