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Reduction in Indoor Airborne Endotoxin Concentration by the Use of Air Purifier and Its Relationship with Respiratory Health: A Randomized Crossover Intervention Study

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Abstract: Endotoxins are biological components of particulate matter that cause adverse respiratory system effects. Recently, air purifiers have been widely used; however, their effects on endotoxins are not fully understood. We conducted a randomized crossover intervention study to evaluate the effects of air purifiers on indoor endotoxins and occupants' respiratory health. Thirty-two healthy subjects were randomly assigned to two groups; each group spent four weeks using either a true or sham (filter removed) air purifier. Subsequently, the subjects spent an additional four weeks using the alternative air purifier. The indoor endotoxins in fine ($PM_{2.5}$) and coarse ($PM_{10–2.5}$) particulate matter were continuously collected, and pulmonary function was tested repeatedly during the study period. Household characteristics were assessed using a questionnaire. The geometric mean of the $PM_{2.5}$ endotoxin concentrations was 0.13 EU/m^3, which was significantly lower with true purifiers compared with sham purifiers, after adjusting for household characteristics (0.17 EU/m^3). In addition, the $PM_{2.5}$ endotoxin concentrations were significantly greater in reinforced concrete houses than in wooden houses. The $PM_{10–2.5}$ endotoxin concentrations were significantly greater in homes with two or more household members, and in those with pets. No association was found between endotoxin concentration and respiratory health among the subjects.

Keywords: indoor air pollution; air purifier; endotoxin; household characteristics; pulmonary function; fractional exhaled nitric oxide

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1. Introduction

Indoor air pollution is a serious problem. Therefore, air purifiers are widely used to improve indoor air quality. Air purifiers equipped with filters reduce indoor particulate matter (PM) concentrations [1–5]. Air purification has also been reported to benefit cardiovascular health, reduce stress hormone levels, and reduce asthma and allergy symptoms [6–9]. Endotoxins are lipopolysaccharides from Gram-negative bacteria [10] and are known to cause airway inflammation, which induces the production of cytokines and proteins [11,12]. Endotoxins are suspended as components of airborne PM [13]. Consequently, many studies have been conducted to clarify the effects of endotoxins on human health. Exposure to airborne endotoxins is associated with an increased prevalence of asthma [14] and exacerbation of asthma symptoms [15–18]. In contrast, an additional study reported that exposure to endotoxins was related to a decreased risk of atopy sensitization, and had a protective effect [19]. Numerous studies have reported exposure to endotoxins in occupational environments, such as in the livestock industry [20–22] and textile factories [23,24].

A study in Taiwan reported that the range of indoor airborne endotoxin concentrations was 0.02–8.13 EU/m^3 [14]. In Danish homes, the range of indoor endotoxin concentrations was 0.078–8.32 EU/m^3 [25]. On the other hand, a study conducted in California found that the range of indoor endotoxin concentrations was 0.063–7.5 EU/m^3 [26]. In this way, indoor endotoxin concentrations vary depending on the region and home characteristics. Regarding the aerodynamic diameter of PM, in our previous study [27], the indoor endotoxin concentrations were higher in $PM_{2.5}$ than in $PM_{10–2.5}$. The use of air purifiers may effectively reduce indoor PM concentrations [28–31]. However, the effectiveness of air purifiers on indoor concentrations of endotoxins is not well documented. In our previous observational study, we found that $PM_{2.5}$ endotoxin concentrations were significantly lower in homes using air purifiers [27]. However, the air purifier model and usage patterns were not specified in the study. In addition, the relationship between the use of an air purifier and the health condition of the occupants was not identified. Currently, the association between indoor endotoxin concentrations and the respiratory systems of healthy subjects is relatively unknown.

Therefore, we performed a crossover intervention study to evaluate the relationship between air purifier usage, indoor endotoxin concentrations in ordinary homes, and the respiratory function of healthy adults residing in those homes. We previously reported the effects of air purifiers on indoor air pollutant concentrations and the respiratory health of occupants in each household [32]. In the present study, we focused on indoor endotoxin concentrations and clarified the effects of endotoxin concentration using an air purifier.

2. Materials and Methods

2.1. Study Design and Subjects

This crossover intervention study was conducted to evaluate the effectiveness of the use of air purifiers for indoor air pollution. The details of this study have been reported in the previous paper showing the relationship between the indoor environment and air purifiers [32]. In summary, the study was conducted between November 2018 and February 2019 in ordinary homes in the Hanshin area of Western Japan (Figure 1). A total of 32 healthy subjects were randomly assigned to one of two groups. All the subjects used the same model of air purifiers. This air purifier is equipped with a dust collection and deodorizing filter, but does not have other functions, such as adsorption, plasma or photocatalytic oxidation. During the study period, the deodorizing function was not used, and only the dust collection function was used. The air flow rate was fixed at 0.5 m^3/min during the study period. The airflow of the air purifier was the same with and without the filter, and we consider that there was no difference in air movement in the home and dispersion of PM endotoxins. The air purifier was placed in a living room where the subject spent a lot of time, and the size of the living room was 10 m^2 × 36 m^2. One group used a true air purifier (EP-NZ30, Hitachi, Tokyo, Japan) and the second group used a sham air purifier that operated with the filter removed. The subjects spent four weeks of the first intervention using one of each air purifier in the living room. Subsequently, both groups spent four weeks of daily life without an air purifier as a washout period. For the next four weeks, each group used the alternate air purifier to the one that was used in the first four weeks. At the study baseline, household characteristics, such as the number of household members and structure of the house, were obtained using a questionnaire. This study adopted a single-blind method. The Ethics Review Board of Hyogo College of Medicine approved the study protocol (registration No. 2898), and all subjects provided written informed consent according to the Declaration of Helsinki. This study protocol was registered in the University Hospital Medical Information Network (UMIN), which is a network organization of 42 national university hospitals nationwide in Japan (number: UMIN000031902).

Figure 1. Location of Hanshin area in Japan. The map was obtained from the internet (https://nureyon.com/japanese_archipelago-1?pattern=12 (accessed on 27 September 2021)).

2.2. Indoor Endotoxin Measurements

The airborne endotoxins were extracted from PM in the indoor air. The airborne PM was collected on a quartz filter weekly using a small vacuum pump (MP-∑300N IIT; Sibata Scientific Technology, Soka, Japan) adjusted to a flow rate of 1.5 L/min. As our previous study showed that endotoxins were detected in both $PM_{2.5}$ and $PM_{10–2.5}$ collected from indoor air [27], we used an impactor (ATPS-20H; Sibata Scientific Technology, Soka, Japan) to differentiate the PM into one of the following two categories: the first, PM with a mean aerodynamic diameter less than 2.5 μm ($PM_{2.5}$), and the second, PM with mean aerodynamic diameter between 2.5 and 10 μm ($PM_{10–2.5}$). The quartz fiber filters (Whatman Inc., Florham Partk, NJ) used for the collection were sterilized by dry heat at 250 °C for 2 h prior to use and stored at −30 °C until analysis. We analyzed endotoxins using the kinetic Limulus amebocyte lysate assay (Pyrostar ES-F test, Wako Pure Chemical Industries, Ltd., Osaka, Japan). This procedure involved the use of a toxinometer (ET-6000, Wako Pure Chemical Industries, Ltd., Osaka, Japan) in our previous study [27]. Blank filters were used during each intervention period. The endotoxin concentrations were expressed in endotoxin units (EU/m^3) per cubic meter of collected air. The detection limit was 0.001 EU/mL, which corresponded to a 0.0022 EU/filter.

We also measured the mass concentrations of $PM_{2.5}$ and $PM_{10–2.5}$, to evaluate endotoxin concentrations per milligram of $PM_{2.5}$ and $PM_{10–2.5}$. We collected $PM_{2.5}$ and $PM_{10–2.5}$ on a Teflon-coated glass fiber filter with the same methods as endotoxin, and measured them using an electronic microbalance with a sensitivity of 0.1 μg (UMX-2, Mettler-Toledo Inc., Columbus, OH, USA). The temperature and humidity in homes were measured using a HOBO data logger (Onset Computer Corp., Bourne, MA, USA). Data were recovered from the data loggers at the end of each intervention period. The average value for each week was then calculated.

2.3. Spirometry and Exhaled Nitric Oxide Measurements

Pulmonary function and fractional exhaled nitric oxide (FeNO) levels were measured weekly when the subjects arrived at the laboratory to replace the endotoxin collection pump. Pulmonary function tests were conducted using a spirometer (Microspiro HI-205T. Chest, M.I., Inc., Tokyo, Japan), which was calibrated to a volume of 3 L using a syringe.

Forced vital capacity (FVC), forced expiratory volume in one second ($FEV_{1.0}$), $FEV_{1.0}$/FVC, maximal mid-expiratory flow (MMEF), peak expiratory flow rate (PEF), and the ratio of the maximum expiratory flow rate at 50% of the FVC to the maximum expiratory flow rate at 25% of the FVC ($\dot{V}50/\dot{V}25$) were used as the parameters to quantify pulmonary function.

We also measured FeNO, which is a biomarker of airway inflammation [33–35], using NObreath (Bedfont Scientific, Maidstone, UK). The measuring instrument was calibrated to zero monthly according to the manufacturer's specifications. This instrument is designed to operate in environments containing NO concentrations less than 350 ppb NO; consequently, FeNO measurements were conducted after measuring the concentration of NO in the indoor air in the laboratory.

These tests were performed by qualified inspectors in accordance with the American Thoracic Society guidelines [36–38].

2.4. Statistical Analysis

Because the data for endotoxins, PM concentrations, and FeNO were roughly lognormally distributed, the values were converted to common logarithms for statistical analysis. The log-transformed data were confirmed to be normally distributed by Kolmogorov–Smirnov test. Endotoxin and PM concentrations were expressed as geometric means with 95% confidence intervals (CIs). Characteristics of the subjects and parameters of pulmonary function were calculated as arithmetic mean ± standard deviation. The endotoxin concentrations per milligram of $PM_{2.5}$ and $PM_{10–2.5}$ were expressed as EU/mg. The t-test was used to compare differences in indoor endotoxin concentrations between the true and sham air purifiers. Mixed-effects models with a compound symmetry covariance structure were used to quantify the relationship between endotoxin concentrations and household characteristics. We considered and analyzed the use of air purifiers, household members, the presence of pets, the structure of the house, architectural style, floor type, temperature, and humidity as fixed effects. The relationships between endotoxin concentrations in homes and the respiratory function parameters were analyzed using a mixed-effects model with unstructured covariance matrix, which is suitable for repeated measures, to evaluate endotoxin concentration measurements for the week prior to a pulmonary function test. This analysis was adjusted for age, sex, body mass index, intervention period, temperature, and humidity.

SPSS 22 software (IBM Co., Armonk, NY, USA) was used for all analyses. Statistical significance was assessed using a p-value of <0.05.

3. Results

For one of the 32 subjects, the endotoxin concentrations could not be measured because the pump had multiple errors at all times. Consequently, 31 participants completed the study. There were 9 men and 22 women, with ages ranging from 31 to 60 years. The average age was 41.1 ± 7.6 years, and the average body mass index (BMI) was 21.8 ± 3.2 kg/m^2 (Table 1). For the household characteristics of the subjects, according to the questionnaire, ten subjects lived alone and five kept pets.

Table 1. Study subject characteristics.

Characteristics		(n = 31)
Sex		
	male	9
	female	22
Age (years)		
	mean ± SD	41.1 ± 7.6
	range	31–60
BMI (kg/m^2)		
	mean ± SD	21.8 ± 3.2
	range	16.6–31.6

Table 1. *Cont.*

Characteristics		(n = 31)
Household members		
	One	10
	Two or more	21
Presence of pet		
	Yes	5
	No	26
Structure of house		
	Reinforced concrete	25
	Wood	6
Architectural style		
	Apartment	21
	Detached house	10
Type of floor		
	Wooden flooring	21
	Others	10

SD, standard deviation; BMI, body mass index.

A total of 248 endotoxin samples were collected for $PM_{2.5}$ and $PM_{10–2.5}$. These samples were from 31 homes, each of which received weekly sampling during the study period. Of the collected filters, 14 samples in $PM_{2.5}$ and 11 samples in $PM_{10–2.5}$ were excluded from the analysis because of pump errors or filter contamination. Endotoxin concentrations were not detected in any of the blank filters. The geometric mean of the $PM_{2.5}$ endotoxin concentrations was 0.13 EU/m^3 for the true air purifiers. This value was significantly less than the corresponding value, 0.17 EU/m^3, for the sham air purifiers (p = 0.002, Table 2). In contrast, the $PM_{10–2.5}$ endotoxin concentrations decreased slightly during the use of the true air purifier; however, the difference was not significant. Similarly, the $PM_{2.5}$ mass concentrations when using the true air purifier were significantly less than the same while using the sham air purifier; however, there were no differences observed for the $PM_{10–2.5}$ mass concentrations. For the endotoxin concentrations per milligram of particulate matter, both the $PM_{2.5}$ and $PM_{10–2.5}$ endotoxin concentrations decreased slightly while using the true air purifier, but no significant difference was found.

Table 2. Comparison of measurement results of each concentration using the true and sham air purifiers.

	True Air Purifiers		Sham Air Purifiers		
	n	**GM (95% CI)**	***n***	**GM (95% CI)**	***p***
Endotoxin (EU/m^3)		data		data	
$PM_{2.5}$	115	0.13 (0.12, 0.15)	119	0.17 (0.15, 0.19)	0.002
$PM_{10–2.5}$	118	0.09 (0.07, 0.10)	119	0.10 (0.09, 0.12)	0.297
Endotoxin (EU/mg PM)					
$PM_{2.5}$	109	18.5 (16.7, 20.4)	117	19.1 (17.2, 21.1)	0.663
$PM_{10–2.5}$	110	44.2 (37.6, 51.8)	116	46.8 (39.6, 55.4)	0.619

GM, geometric mean; CI, confidence interval; *p*, *p*-value.

Table 3 presents the relative percentage change in endotoxin concentrations, corresponding to differences in household characteristics and meteorological factors. The $PM_{2.5}$ endotoxin concentrations during the use of the true air purifier were significantly less than those observed while using the sham air purifier (−14.0% (95% CI: −18.8, −9.3). Regarding the structure of the house, the $PM_{2.5}$ endotoxin concentrations were significantly higher in reinforced concrete houses than in wooden houses (34.1% (95% CI: 6.9, 61.2)). The $PM_{10–2.5}$ endotoxin concentrations were slightly lower with the use of the true air purifier, but

no significant difference was observed. The $PM_{10–2.5}$ endotoxin concentrations were also significantly lower in single-person households than in houses with two or more household members. In addition, the $PM_{10–2.5}$ endotoxin concentrations were significantly higher in homes with pets than in those without pets. Neither the $PM_{2.5}$ nor $PM_{10–2.5}$ endotoxin concentrations were observed to be related to indoor temperature and humidity during the intervention period.

Table 3. The percent changes in endotoxin concentrations related to household characteristics and meteorological factors.

	$PM_{2.5}$ Endotoxin		**$PM_{10-2.5}$ Endotoxin**	
	Percent Change (95%CI)	***p***	**Percent Change (95%CI)**	***p***
Air purifier (true/sham)	−14.0 (−18.8, −9.3)	<0.001	−3.8 (−9.4, 1.7)	0.177
Household members (one/two or more)	−2.8 (−20.7, 15.0)	0.748	−29.2 (−52.2, −6.1)	0.015
Presence of pet (yes/no)	6.4 (−19.1, 31.8)	0.611	41.6 (12.4, 70.7)	0.007
Structure of house (reinforced concrete/wood)	34.1 (6.9, 61.2)	0.016	1.6 (−31.6, 34.9)	0.920
Architectural style (apartment/house)	−12.9 (−40.6, 14.8)	0.348	14.4 (−19.8, 48.6)	0.395
Type of floor (others/wooden flooring)	−4.4 (−20.1, 11.4)	0.576	6.9 (−11.7, 25.6)	0.453
Temperature (°C)	0.7 (−0.9, 2.2)	0.394	−0.3 (−2.1, 1.5)	0.759
Relative humidity (%)	0.3 (−0.2, 0.9)	0.190	0.4 (−0.2, 1.0)	0.188

CI, confidence interval; *p*, *p*-value.

The results of pulmonary function and FeNO measurements are shown in Table 4. The FeNO levels were higher in males than in females during both intervention periods. For the parameters of pulmonary function, $\dot{V}50/\dot{V}25$ was higher in females than in males during both intervention periods, but all the other parameters were higher in males (Table 4).

Table 4. Summary of pulmonary function and exhaled nitric oxide measurement (mean ± SD).

	1st Term		**2nd Term**	
	Male	**Female**	**Male**	**Female**
FVC (L)	3.79 ± 0.38	3.02 ± 0.34	3.85 ± 0.43	3.01 ± 0.33
$FEV_{1.0}$ (L)	3.17 ± 0.44	2.46 ± 0.29	3.21 ± 0.43	2.45 ± 0.29
$FEV_{1.0}$/FVC (%)	83.4 ± 6.0	82.0 ± 7.1	83.3 ± 4.8	81.6 ± 7.0
MMEF (L/s)	3.43 ± 1.01	2.71 ± 0.80	3.52 ± 1.03	2.73 ± 0.88
PEF (L/s)	7.95 ± 2.56	5.13 ± 1.22	8.72 ± 2.15	5.29 ± 1.19
$\dot{V}50/\dot{V}25$	2.75 ± 0.89	3.70 ± 2.98	2.82 ± 0.89	3.48 ± 1.26
FeNO (ppb) *	13.0 ± 2.5	10.3 ± 2.1	14.5 ± 2.5	10.6 ± 2.6

* Geometric mean. SD, standard deviation; $FEV_{1.0}$, forced expiratory volume in one second; FVC, forced vital capacity; $FEV_{1.0}$/FVC, forced expiratory volume in one second/forced vital capacity; MMEF, maximal mid-expiratory flow; PEF, peak expiratory flow rate; $\dot{V}50/\dot{V}25$, maximal expiratory flow rate at 50%/25% of the average vital capacity; FeNO, fractional exhaled nitric oxide.

Table 5 presents the correlations between endotoxin concentrations, changes in pulmonary function parameters, and FeNO levels. The FVC decreased slightly when the $PM_{2.5}$ and $PM_{10–2.5}$ endotoxin concentrations increased (−0.02 (95% CI: −0.11, 0.07), −0.02 (95% CI: −0.07, 0.04) per increase of 1 log endotoxin (EU/m^3), respectively). However, the difference was not statistically significant. Similarly, $FEV_{1.0}$, $\dot{V}50/\dot{V}25$, and FeNO decreased slightly with an increase in the $PM_{2.5}$ and $PM_{10–2.5}$ endotoxin concentrations; however, a significant difference was not found. In addition, $FEV_{1.0}$/FVC and MMEF showed a slight

increase when subjected to an increase for each endotoxin concentration, but the difference was not statistically significant. Consequently, the endotoxin concentrations in indoor $PM_{2.5}$ and $PM_{10–2.5}$ did not show any statistically significant differences in pulmonary function and FeNO levels.

Table 5. Associations between $PM_{2.5}$ and $PM_{10–2.5}$ endotoxin concentrations, changes in pulmonary function parameters, and FeNO concentration levels.

	$PM_{2.5}$ Endotoxin		**$PM_{10-2.5}$ Endotoxin**	
	Percent Change (95%CI)	***p***	**Percent Change (95%CI)**	***p***
FVC (L)	−0.02 (−0.11, 0.07)	0.671	−0.02 (−0.07, 0.04)	0.509
$FEV_{1.0}$ (L)	−0.04 (−0.11, 0.03)	0.297	−0.01 (−0.06, 0.03)	0.607
$FEV_{1.0}$/FVC (%)	1.58 (−0.45, 3.16)	0.127	0.16 (−1.05, 1.38)	0.788
MMEF (L/s)	0.12 (−0.12, 0.35)	0.325	0.01 (−0.13, 0.16)	0.840
PEF (L/s)	0.27 (−0.25, 0.79)	0.307	−0.21 (−0.58, 0.16)	0.263
$\dot{V}50/\dot{V}25$	−0.16 (−0.64, 0.32)	0.516	−0.24 (−0.51, 0.03)	0.078
LogFeNO	−0.12 (−0.27, 0.03)	0.123	−0.07 (−0.19, 0.04)	0.216

The percent relative change in each parameter corresponding to a 1 log endotoxin increase.

4. Discussion

This study aimed to evaluate the reduction in indoor endotoxin concentrations in ordinary homes using an air purifier, and the effect of endotoxins on the respiratory functions of occupants therein. The results indicated that the $PM_{2.5}$ and $PM_{10–2.5}$ endotoxin concentrations decreased when an air purifier was used. This reduction was statistically significant for the $PM_{2.5}$ endotoxin concentrations. However, no significant relationship was found between endotoxin concentrations, pulmonary function, and FeNO concentration among the occupants.

Several studies have demonstrated that endotoxin concentrations depend on suspended particle diameter [39,40]. In our previous study, the $PM_{2.5}$ endotoxin concentrations in homes were greater than the $PM_{10–2.5}$ endotoxin concentrations [27]. This is consistent with the results of the present study. Padhi et al. also reported that the $PM_{2.5}$ endotoxin concentrations in homes were higher than the PM_{10} endotoxin concentrations [41]. Our study showed that the use of an air purifier reduced the endotoxin concentrations for both the $PM_{2.5}$ and $PM_{10–2.5}$ components; however, the difference was only significant for the $PM_{2.5}$ component. This finding may indicate that endotoxin concentrations and air purifier effects depend on particle size.

We observed that the $PM_{2.5}$ endotoxin concentrations decreased significantly with the use of an air purifier. Although the difference was as small as 0.04 EU/m^3, it was shown that the $PM_{2.5}$ endotoxin concentrations, which had been considerably low in the home, were further reduced by using an air purifier. This result is compatible with our previous observational study, in which the $PM_{2.5}$ endotoxin concentrations decreased with the use of an air purifier; however, there was no significant effect of air purifier usage on $PM_{10–2.5}$ endotoxin concentrations. In contrast, Niu et al. reported that endotoxin concentrations varied prior to and after filter cleaning, and that filter replacement may reduce the increase in endotoxins of large sizes, but not smaller sizes [42]. From these results, the relationship between endotoxin concentrations and the use of an air purifier has not been consistently found; consequently, additional studies are needed to clarify this relationship.

In the present study, the $PM_{2.5}$ endotoxin concentrations were greater in reinforced concrete houses than in wooden houses. Tran et al. reported that endotoxin concentrations depend on the material comprising houses in Ho Chi Minh City, Vietnam [43]. This suggests that the structure of the house may affect the endotoxin concentrations. Presumably, the difference in endotoxin concentrations, which depend on the structure of the house, was attributed to the absence of air exchange between the indoor and outdoor environment. Regarding household members, the $PM_{10–2.5}$ endotoxin concentrations were significantly

less in single-person households. This result is similar to that of our previous study [27], in which the $PM_{10–2.5}$ endotoxin concentrations were significantly greater in homes with two or more children. These results suggest that $PM_{10–2.5}$ endotoxin concentrations are related to human activity. In a previous study [27], the $PM_{2.5}$ endotoxin concentrations were significantly greater in homes with pets, but for the $PM_{10–2.5}$ endotoxin concentrations, this effect was not significant. Conversely, the present results indicated that the $PM_{10–2.5}$ endotoxin concentrations were significantly greater in homes with pets, even when considering the use of an air purifier. Several studies have investigated the presence of pets as an endotoxin source [44,45]. This is consistent with this study's results.

Endotoxins have been reported to cause adverse effects in the respiratory system. However, the present study found no relationship between endotoxin concentration and the subject's respiratory system. Rooij et al. noted that increasing endotoxin levels emitted from livestock farmers caused the prevalence of respiratory symptoms in neighboring populations; however, the endotoxin levels were not significantly associated with lung function [22]. Nonnenmann et al. observed no association between exposure to endotoxins via personal inhalation, lung function, and FeNO among dairy workers [21]. Our results concur with these results. High personal endotoxin exposure levels have been reported to decrease FEV_1 among children with asthma [46]. As children are known to be more susceptible to air pollution than adults [47], they may also be more sensitive to endotoxin exposure. However, healthy adults may be less susceptible to infection. The reason for no effect being observed may be that the endotoxin concentrations in this study were considerably lower than those in the previous study. The low concentrations are observed regardless of the use of the true or sham air purifier. Recent studies have shown that indoor endotoxin concentrations are not associated with lung function in schoolchildren; however, indoor O_3 and PM_{10} concentrations alter the association between airborne endotoxin and lung function in schoolchildren [48]. This finding may indicate that the interaction between airborne endotoxins and air pollutants affects the lung function of children, so it is necessary to analyze not only the endotoxin concentrations, but also the other air pollutants present in indoor environments.

The limitations of this study are as follows: Firstly, the sample size was relatively small. If the number of samples was larger, the statistical detection would increase. However, such an intervention study would be expensive and effort intensive, as it would require preparing air purifiers, setting up environmental measuring instruments, and measuring pulmonary function. Secondly, we measured the endotoxin concentrations once a week for a total of two months during the winter season. As airborne endotoxin concentrations vary seasonally [49], further study should be conducted throughout the year. Thirdly, because the size of the living room where the air purifier was installed was different in each home, the effectiveness of air purification also varied. However, it is impossible to prepare a space with the same conditions when conducting an intervention study for ordinary households. By contrast, a positive attribute of this study is that the subjects were healthy adults. Furthermore, because we repeated the endotoxin measurement and the respiratory function test, we could accurately evaluate the relationship between the effect of the air purifier and respiratory function. Therefore, we believe that the results of this study can be generalized.

5. Conclusions

Recently, the use of air purifiers in ordinary homes has increased. The use of an air purifier is effective for reducing indoor air pollutants in the living rooms or bedrooms where people generally reside. Our results showed that the indoor endotoxin concentrations were not very large, but the use of an air purifier further reduced the indoor endotoxin concentrations. However, the respiratory function of the subjects remained unaffected when using an air purifier.

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Informed Consent Statement: Informed consent was obtained from all the subjects involved in the study.

Data Availability Statement: The data set is available from the corresponding author, upon reasonable request.

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Abbreviations

PM	particulate matter
$PM_{2.5}$	fine particulate matter $\leq$2.5 μm in aerodynamic diameter
$PM_{10–2.5}$	coarse particulate matter between 2.5 and 10 μm in aerodynamic diameter
$FEV_{1.0}$	forced expiratory volume in one second
FVC	forced vital capacity
MMEF	maximal mid-expiratory flow
PEF	peak expiratory flow rate
$\dot{V}50/\dot{V}25$	the ratio of the maximum expiratory flow rate at 50% of the FVC to the maximum expiratory flow rate at 25% of the FVC
FeNO	fractional exhaled nitric oxide
GM	geometric mean
SD	standard deviation
BMI	body mass index
CI	confidence interval

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