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House-plant placement for indoor air purification and health benefits on asthmatics

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Objectives Some plants were placed in indoor locations frequented by asthmatics in order to evaluate the quality of indoor air and examine the health benefits to asthmatics.

Methods The present study classified the participants into two groups: households of continuation and households of withdrawal by a quasi-experimental design. The households of continuation spent the two observation terms with indoor plants, whereas the households of withdrawal passed the former observation terms with indoor plants and went through the latter observation term without any indoor plants.

Results The household of continuation showed a continual decrease in the indoor concentrations of volatile organic compounds (VOCs) during the entire observation period, but the household of withdrawal performed an increase in the indoor concentrations of VOCs, except formaldehyde and toluene during the latter observation term after the decrease during the former observation term. Peak expiratory flow rate (PEFR) increased in the households of continuation with the value of 13.9 L/min in the morning and 20.6 L/min in the evening, but decreased in the households of withdrawal with the value of -24.7 L/min in the morning and -30.2 L/min in the evening in the first experimental season. All of the households exhibited a decrease in the value of PEFR in the second experimental season.

Conclusions Limitations to the generalizability of findings regarding the presence of plants indoors can be seen as a more general expression of such a benefit of human-environment relations.

Keywords Asthma, Formaldehyde, Health, House-plant, Indoor air quality, Volatile organic compounds

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Introduction

As modern city dwellers showan increasing trend to spending most of their daily lives indoors, Son et al. [1] expressed deep concern that indoor air quality (IAQ) was one of the most influential factors on indoor residents' health. Similar descriptions have frequently been reported by many researchers, with the observation that indoor residents obtained substantial benefits from indoor air with good quality [2] and experienced serious problems in the presence of indoor air with poor quality [3,4].

According to former studies [5-7], indoor air was easily contaminated by certain air-borne substances, volatile organic compounds (VOCs) emitted from building materials or household goods [8,9] reported that indoor air contained about seven to ten times the amount of VOCs as outdoor air. It was firmly accepted that the VOCs causing the serious problems on indoor residents' health were chiefly constituted of formaldehyde and other chemical substances including benzene, toluene, ethylbenzene, and xylene (BTEX). These serious health problems could be asthma, dizziness, physical fatigue, and some irritations to the eyes, nose, and throat [9]. Among the problems identified, asthma was one of the most serious because it restricts patients' socially as well as their physical activities [10], due to the fact that it is a chronic inflamed disease of the respiratory tract with symptoms of dyspnea and the feeling of chest suppression [11]. Abbey et al. [12] asserted that VOCs were the limiting factor of asthma. Other researchers supported the assertion with their reports that the symptom severity of asthma was closely related to the amount of VOCs in indoor air [13,14].

With the awareness of the problem by IAQ, indoor residents conducted various trials to reduce the amount of VOCs in indoor air using frequent ventilation by opening windows, bake-out by raising indoor air temperature, pollution-source removal by exchanging building materials and household goods with environmentally-friendly goods, and air purification by applying an air purifier [2,15,16]. However, these trials required careful attention with much material outlay. For that reason, many researchers recommended indoor plant placement in indoor place as another possible method for improving IAQ [17]. It was widely accepted that indoor plants reduced the physical fatigue of indoor residents with environmentally-friendly methods [18-21], as well as providing some positive effects on their mental health [22]. Regarding the procedure of air purification by plants, many former researchers have confirmed that plants decompose air-borne substances during the course of respiration and photosynthesis by absorbing the substances through leaf surface, transporting to rhizosphere, and converting them into their energy with the help of microbes [23-27]. The present study evaluated the health condition of asthmatics by using the quality of life questionnaire for adult Korean asthmatics (QLQAKA). The QLQAKA was a recently devised asthma-specific questionnaire as a valid and reproducible clinical tool for monitoring and demonstrating the health state of asthmatics by the Korean Academy of Asthma, Allergy, and Clinical Immunology [13,28,29]. Additionally, this observation on the symptom changes of asthmatics followed the experimental procedure by quasi experimental design, which was recently conceived as a procedure to evaluate the symptom changes of a certain patient by analyzing the changes of environmental factors [30,31].

Materials and Methods

Indoor plants were placed in the households of asthmatics to evaluate the IAQ of the places and the symptom condition of the residents by the experimental design of case crossover in Seoul, South Korea for two experimental seasons in 2006 and 2007 [31]. The particulars of experimental procedure were as follows (Figure 1).

Participant Organization and Indoor Plant Placement

The Medical College of Yonsei University provided 17 participants who had been definitely-diagnosed as asthmatic by the Division of Allergy-Immunology, Department of Internal Medicine; these were selected for the present study from the outpatients in each experimental season. The participants were mainly constituted of housewives (1st experimental season, 16 individuals; 2nd experimental season, 14 individuals), who spend

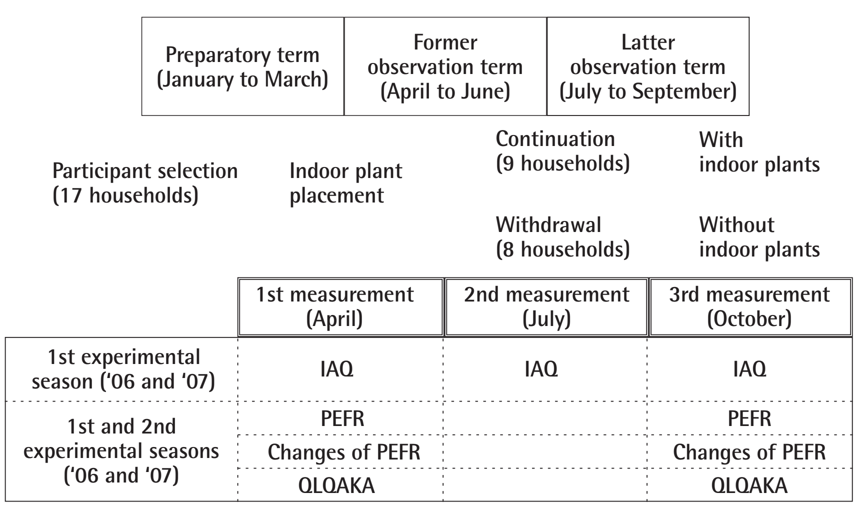

Figure 1. Experimental procedure by case crossover design for the present study. IAQ, indoor air quality; PEFR, peak expiratory flow rate; QLQAKA, quality of life questionnaire for adult Korean asthmatics.

most of their daily lives indoors in their own households; this was to prevent any confounders due to occupations. The individual characteristics were varied ages from 30s to 60s, with the mean value of 47.1 years for the first experimental season and 46.5 years for the second experimental season. Also, their residential area ranged from below 70 m^2 to above 130 m^2, with the mean value of 98.5 m^2 for the first experimental season and 100.3 m^2 for the second experimental season. Former results indicated that indoor residents perceived little difference in the symptom degree of sick building syndrome (SBS) by building ages [32] because the VOCs responsible for SBS of indoor residents were constantly emitted from various sources in indoor places [8] (Table 1).

The placement of indoor plants was performed in the households of participants, chiefly using foliage plants following the demonstration of previous studies [1]. Then, the present study provided the households the information on indoor plant management with the recommendations of the National Institute of Horticultural & Herbal Science, such as proper conditions for air temperature, relative humidity, and irrigation interval. In each household, indoor plants were placed as three couples of large pots (15 L) in the living room, one couple of small pots (7 L) in the kitchen, and two couples of small pots (7 L) in the bedroom. The indoor plants were asplenium, Satsuma mandarins, and gardenia in the living-room, pothos in the kitchen, and rosemary and gardenia in the bedroom during the first experimental season in 2006 and parlourplam, money trees, and peace lily in the living-room, pothos in the kitchen, and dumb cane and lady palm in the bedroom during the second experimental season in 2007 (Table 2).

In the present study, using a case crossover design, one experimental season was comprised of three terms: the preparatory term, the former observation term, and the latter observation term. The duration of each term was three months: the preparatory term was from January to March, the former observation term was from April to June, and the latter observation term was from July to September. The households of participants were divided into two groups, with the households of continuation including nine households and the households of withdrawal including eight households; this was according to the methods of indoor plant placement. The placement of indoor plants was practiced in all of the households during the entire preparatory term (from January to March). The households of continuation spent the two observation terms with indoor plant placement,

Table 1. Demographic information of the participants in this study

Item	Classification	1st experimental season ('06)		2nd experimental season ('07)	
		Continuation (n=9)	Withdrawal (n=8)	Continuation (n=9)	Withdrawal (n=8)
Gender	Female	8	8	8	6
	Male	1	N/A	1	2
Age	30s	5	N/A	3	3
	40s	1	2	1	2
	50s	2	6	5	2
	60s	1	N/A	N/A	1
	Mean (yr)	43.7	51.0	47.1	46.6
Resident area (m^2)	<70	2	2	2	3
	≥70	2	4	1	1
	>100	4	1	3	4
	>130	1	1	2	N/A
Year of building completion	1980s	2	3	2	2
	1990s	5	3	6	4
	2000s	2	2	1	2

Continuation, indoor plant placement during the entire season (April to September); Withdrawal, placement of indoor plants during the former observation term (April to June) and withdrawal during the latter observation term (July to September).
N/A, not applicable.

Table 2. Status of indoor plant placement for the present study

Site	1st experimental season ('06)			2nd experimental season ('07)		
	Kinds of plants	Quantity (n)	Size (L)	Kinds of plants	Quantity (n)	Size (L)
Living-room	Asplenium (*Aspleniumnidus*)	2	15	Parlour palm (*Chamaeadorea elegances*)	2	15
	Satsuma mandarins (*Citrus unshiu*)	2	15	Money tree (*Zamioculcas* spp.)	2	15
	Gardenia (*Gardenia jasminoides*)	2	15	Peace lily (*Spathiphyllum* spp.)	2	15
Kitchen	Pothos (*Epipremnum aureum*)	2	7	Pothos (*Epipremnum aureum*)	2	7
Bedroom	Rosemary (*Rosemarinusofficinalis*)	2	7	Dumb cane (*Dieffenbachia camilla*)	2	7
	Gardenia (*Gardenia jasminoides*)	2	7	Lady palm (*Rhapis Excelsa*)	2	7

and the households of withdrawal passed the former observation term with indoor plant placement and spent the latter observation term without indoor plant placement.

Measurement of Indoor Air Quality

IAQ was evaluated just after each term as the early days of April, July, and October in the first experimental season in 2006. For IAQ evaluation, certain VOCs were captured from the indoor air of participants' households and then quantitatively analyzed for formaldehyde and BTEX at the analytical laboratory of the Medical College in Yonsei University. Air capture was conducted for all of the households using airtight conditions after 30 minutes of ventilation with the official analysis method of the Act for IAQ Control in Public Use Facilities by the guide of Environmental Protection Agency in the US. A personal air sampler (MP-Σ30; Sibata Scientific Technology Ltd., Tokyo, Japan) was set up at a height of 1.5 m above floor level in the living-room. After a low-volume vacuum pump in the personal air sampler adsorbed formaldehyde into 2,4-dinitrophenylhydrazine (DNPH) cartridge (LpDNPH S10; Supelco, Bellefonte, PA, USA) and ozone scrubber (Sep-Pak W3018LL; Waters, Milford, MA, USA) for 60 minutes at the flow rate of 0.1 L/min, the amount of formaldehyde was analyzed with the use of high-performance liquid chromatography (Alliance Separation Module 2690 & Dual Absorbance Detector 2487; Waters) with a 60-m long capillary column with a 0.32-mm id and 1-μm thickness (HP-1; Agilent Technologies, Santa Clara, CA, USA). Another low-volume vacuum pump adsorbed BTEX into adsorbent tubes (PerkinElmer, Waltham, MA, USA) for 60 minutes at a flow rate of 0.2 L/min. BTEX was detached using a coupling thermal desorption system (TDS) (Aerotrap 6016; Tekmar, Mason, OH, USA) and quantitatively analyzed using gas chromatography (GC) (G-14-B; Shimadzu, Kyoto, Japan) with a 25-m long column with a 0.53-mm id and 0.32-μm thickness (19095W-123; Agilent Technologies) and a flame ionization detector. After the trap in TDS was thermally desorbed at 240°C for 3 minutes, the target substances were cryo-focused at -110°C on the internal trap (0.1-mm glass bead). The cold trap was rapidly heated up to 225°C to flush into the cryo-focusing module in TDS. The module transferred the target substances into GC. The initial oven temperature in GC was set to 50°C for 10 minutes and warmed up by 5°C every minute up to 200°C; the target substances were injected with the carrier gas of helium at a flow rate of 1 mL/min at 150°C.

This procedure was replicated five times to obtain good reliability. The calibration curve was established at 0.5% level for formaldehyde and BTEX. The desorbing efficiency for target substances was maintained at the range of 85 to 115%.

Clinical Examination

Health evaluation was practiced for all of the participants with the measurement of vital capacity by peak expiratory flow rate (PEFR) and the diagnosis of the symptom degree of asthma by QLQAKA before and after the observation terms as the early days of April and October in the first and the second experimental seasons in 2006 and 2007 (Figure 1).

All participants took a measurement of the PEFR using a peak flow meter (Clement Clarke Int., London, UK) twice a day (in the morning and in the evening) for seven days. PEFR could be applied to diagnose a person with an ordinary health condition as showing above 300 L/min or having asthma symptom as recording more than 20% decrease [35]. For a detailed diagnosis of the degree of asthma, QLQAKA, an asthma-specific questionnaire was applied to all of the participants as a regular form of a questionnaire with the advice of Korean Academy of Asthma, Allergy, and Clinical Immunology. The QLQAKA is constituted of 17 items in four domains dealing with activity, symptoms, emotion, and exposure to environmental stimuli. Participants answered each item with a five-point scale from the lowest degree (the severest symptom) being given one point to the best condition (the lightest or no symptom) with five points. An ordinary person showed a QLQAKA score of above 50 points and did not experience a decrease of more than six to nine points over six months [13,31].

Statistical Analysis

For all comparisons between groups in the present study, the Mann-Whitney test was applied with the probability level of 0.05 for significance and 0.01 for high significance.

Results

Although formaldehyde failed in performing various tendencies in its indoor concentration by indoor plant placement, BTEX succeeded in showing significant differences in their indoor concentrations according to placement. Formaldehyde followed a continual decrease in indoor concentrations with passing time during the entire experimental duration, regardless of indoor plant placement. The indoor concentration of formaldehyde decreased from 24.2 to 15.5 μg/m^3 in the households of continuation and decreased from 29.7 to 13.6 μg/m^3 in the households of withdrawal. On the other hand, the indoor concentrations of BTEX exhibited various tendencies by the meth-

Table 3. Changes of chemical substance concentration in indoor air according to indoor plant placement (μg/m^3)

Indoor plant placement	Measurement time	Form-aldehyde	*p*-value	Benzene	*p*-value	Toluene	*p*-value	Ethyl-benzene	*p*-value	Xylene	*p*-value
Continuation	April	24.2	0.03	6.35	0.001	79.05	0.01	3.56	0.01	13.43	0.01
	July	21.2		2.24		62.02		1.56		2.52	
	October	15.5		1.61		19.27		0.27		0.20	
Withdrawal	April	29.7	0.01	6.14	NS	90.26	0.05	3.62	NS	13.50	NS
	July	20.8		2.03		59.28		2.49		1.15	
	October	13.6		9.76		43.64		3.91		20.80	

Continuation, indoor plant placement during the entire season (April to September); Withdrawal, placement of indoor plants during the former observation term (April to June) and withdrawal during the latter observation term (July to September).
The *p*-values were calculated by Mann-Whitney test.
NS, non-significance.

ods of indoor plant placement. During the former observation term, all of the households showed significant decreases in the indoor concentrations of BTEX with passing time. During the latter observation term, the households of continuation maintained decreases in the indoor concentrations from 2.24 to 1.61 μg/m^3 for benzene, from 62.02 to 19.27 μg/m^3 for toluene, from 1.56 to 0.27 μg/m^3 for ethylbenzene, and from 2.52 to 0.20 μg/m^3 for xylene, but the households of withdrawal experienced various results in the indoor concentrations with increases from 2.03 to 9.76 μg/m^3 for benzene, from 2.49 to 3.91 μg/m^3 for ethylbenzene, and from 1.15 to 20.80 μg/m^3 for xylene and a decrease from 59.28 to 43.64 μg/m^3 for toluene (Table 3).

Although all the participants hardly recorded their PEFR as being above 500 L/min, which is the index for a healthy person, they kept their PEFR above 300 L/min, which is an index for a person with severe symptoms of asthma, regardless of the measurement time (in the morning or in the evening) during the entire experimental duration in both the first and the second experimental seasons. The variation in PEFR by measurement time indicated that the participants failed to show a certain tendency in April but succeeded in performing a regular trend in October, with higher values recorded in the evening than in the morning. In October, the participants recorded their PEFR as 405 L/min (1st) and 406 L/min (2nd) in the morning, and marked 416 L/min (1st) and 428 L/min (2nd) in the evening. On the other hand, participants saw an increase in their PEFR in the households of continuation with a level of 13.9 L/min^{-1} in the morning and 20.6 L/min in the evening, but this decreased in the households of withdrawal with a level of -24.7 L/min in the morning and -30.2 L/min in the evening in the first experimental season. All of the participants experienced decrease in their PEFR values in the second experimental season regardless of the measurement time or the methods of indoor plant placement (Figure 2).

A clinical examination with QLQAKA demonstrated little variation in the symptom degree of asthma for all of the participants in both experimental seasons. All participants maintained their symptom degree above 50 points, which is an index for an ordinary healthy condition, during the entire experimental duration, regardless of indoor plant placement in the first and the second experimental seasons. Although the participants saw a decrease in their QLQAKA scores with passing time regardless of the methods of indoor plant placement, they experienced less of a score decrease in the households of continuation than in the households of withdrawal, but with an absence of significance. On the other hand, it was noticeable that the participants perceived their QLQAKA score to be higher in the second experimental season than in the first experimental season (Figure 3).

Discussion

The present study used partially different plant species for installation in the houses. However, the National Institute of Horticultural & Herbal Science in South Korea recommends the kinds of houseplants in a list and their use in the 1st and 2nd experimental season. Some previous studies [24,34,35] have positively demonstrated that there was an induction of the metabolic VOC removal response in the potted-plant microcosm at TVOC levels to 100 ppb.

All of the households went through the indoor condition of little ventilation without indoor plant placement and managed their indoor air temperature high during the preparatory term (from June to March). Former studies reported that VOCs were constantly emitted from the abundant pollution sources in indoor places [8], and that emission was facilitated by high air temperature [16]. Therefore, the high VOC concentrations at the measurement time just after the preparatory term (in April) seemed to be caused by the co-working of the various indoor factors, chiefly including little ventilation and high indoor air temperature.

After three months' placement of indoor plants during the former observation term (from April to June), all of the households experienced a decrease in their VOC concentrations. This ten-

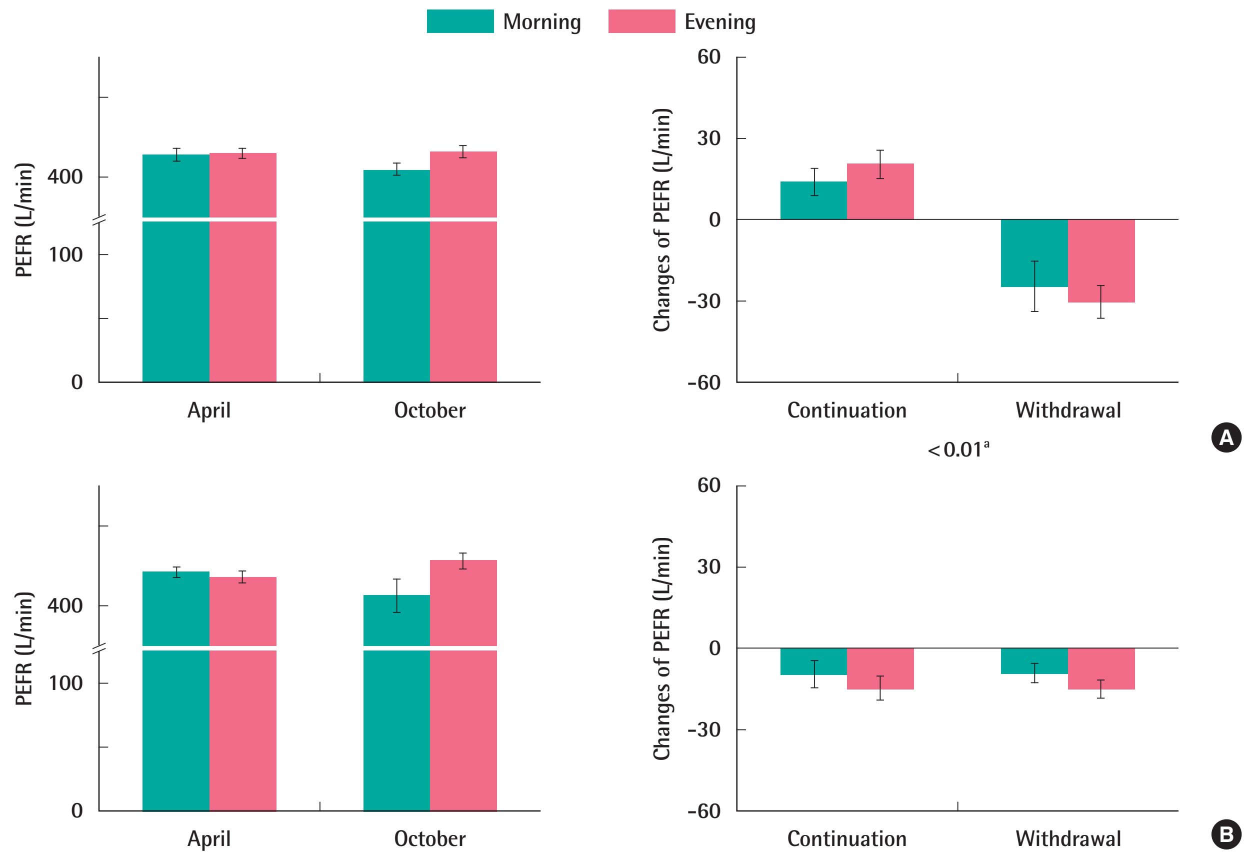

Figure 2. Clinical examination (A) 1st experimental season ('06) and (B) 2nd experimental season ('07) on peak expiratory flow rate (PEER) and changes of PEFR according to indoor plant placement. Continuation, indoor plant placement during the entire season (April to September); Withdrawal, placement of indoor plants during the former term (April to June) and withdrawal during the latter term (July to September). NS, non-significance.
[a]*p*-value by Mann-Whitney test.

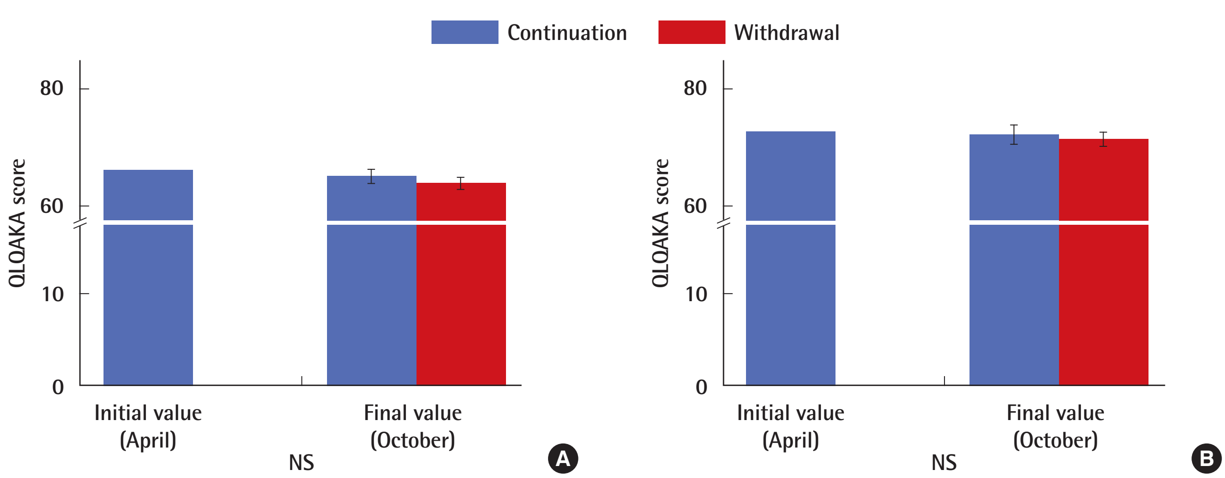

Figure 3. Clinical examination (A) 1st experimental season ('06) and (B) 2nd experimental season ('07) by disease specific quality of life questionnaire for adult Korean asthmatics (QLQAKA). Continuation, indoor plant placement during the entire season (April to September); Withdrawal, placement of indoor plants during the former term (April to June) and withdrawal during the latter term (July to September). NS, non-significance.

dency continued in the latter observation term (from July to September) for the households of continuation. There were many reports that recommended indoor plant placement as an efficient method to decrease VOC concentrations in indoor place [2,17,23]. Additionally, many researchers proved that plants could facilitate the decomposition of VOC particles [24, 26]. Considering the above, it could be stated that indoor plant placement was largely responsible for the decrease of VOC concentrations indoors.

In the latter observation term, the households of withdrawal performed increase again in the indoor concentrations of some VOC particles, but showed a continual decrease in those of other VOC particles. Park & Seong [26] observed that the indoor concentrations of air pollutants increased within two days of the removal of indoor plants. This observation could be applied to explain the change of indoor concentrations for benzene, ethylbenzene, and xylene, but could not be used to account for the variation in those for formaldehyde and toluene. Certain reports asserted that the indoor concentrations of some air pollutants were affected by various indoor factors especially by ventilation [24,36]. Hence, the continual decrease in indoor concentrations for certain VOC particles might be accepted as the result of ventilation.

Considering all of the above results, the indoor concentrations of VOCs might be controlled by various indoor conditions such as ventilation, air temperature, and indoor plant placement. Although indoor plant placement seemed to make little difference in the indoor concentrations for some particles of VOCs, the placement seemed to successfully control the indoor concentrations for certain VOC particles such as benzene, ethylbenzene, and xylene (Table 1).

Bringslimark et al. [37] suggested that the indoor environment is often not distinctly separate from the outdoor environment. The two most important issues are natural reduction and the presence of plants for VOCs. However, the occurrence and concentrations of HCHO and VOCs in homes can be affected by indoor sources, and HCHO and VOC levels indoor air were higher than those reported in previous studies [38,39], although the facilities, seasons and point of the studies were not the same. Therefore, this study aimed to investigate the removal of HCHO and VOC by plants along in an indoor environment.

The PEFR value of asthmatics increased in the households of continuation but showed a decrease in the households of withdrawal in the first experimental season. This trend did not follow in the second experimental season. Concerning the results, Abbey et al. [12] reported that air pollution worsened the PEFR value and other researchers accounted that plants could help to improve air quality [40]. However, the present study found little significance in comparing the variations of QLQAKA scores by indoor plant placement. As seen in Figures 2 and 3, the present study recruited the participants as the asthmatics not with severe symptom but with slight symptoms. Therefore, the health condition of participants seemed to play a role in the result to a certain degree.

In this study, the potential limitations to the generalizability of findings can be identified with regard to asthma-patient persons in a real-world [38]. In addition, limits on generalizability may arise from other forms of inter-individual variability confounders (gender, outdoor activity and ventilation etc.). Also, since asthma-patients do not stay in one place while at home, this study could not perform individual exposure assessments using home, workplace and outdoor exposure.

The presence of indoor plants for asthma is very important in the scale of this study. However, such a limitation was significant, with inverse associations reported between asthma symptoms and house-plants. It thus seems impossible to avoid the psychological benefits of house-plants [38]. This study cannot determine causal relationships because it was cross-sectional with different participants over two years and multiple confounding variables (climate, diet, outdoor environment and different plant varieties).

Considering all the above results, it could be stated that indoor plant placement decreased the indoor concentrations of VOCs and changed the health condition of asthmatics. However, the health condition of asthmatics could additionally be affected by other environmental conditions such as the kinds of or amount of indoor plants being placed, the indoor air temperature, and the symptom degree of participants.

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Conflict of Interest

The authors have no conflicts of interest with material presented in this paper.

References

1. Son KC, Lee SH, Seo SG, Song JE. Effects of foliage plants and potting soil on the absorption and adsorption of indoor air pollutants. J Korean Soc Hort Sci 2000;41(3):305-310 (Korean).
2. Myers GE, Nagaoka M. Emission of formaldehyde by particleboard: effect of ventilation rate and loading on air-contamination levels. For Prod J 1981;31(7):39-44.
3. Cho YS, Kim H, Lee JT, Hyun YJ, Kim YS. Relationship between exposure to air pollutants and aggravation of childhood asthma: a meta-analysis. J Korean Soc Atmos Environ 2001;17(5):425-437 (Korean).
4. Jones AP. Indoor air quality and health. Atmos Environ 1999; 33(28):4535-4564.
5. Carpenter DO. Human health effects of environmental pollutants:

new insights. Environ Monit Assess 1998;53(1):245-258.
6. Seo BR, Jeong MH, Jeon JM, Shin HS. The characteristics of aldehyde emissions in new apartment houses. J Korean Soc Indoor Environ 2006;3(2):158-169 (Korean).
7. Wolkoff P. Trends in Europe to reduce the indoor air pollution of VOCs. Indoor Air 2003;13 Suppl 6:5-11.
8. Spengler JD, Sexton K. Indoor air pollution: a public health perspective. Science 1983;221(4605):9-17.
9. Rehwagen M, Schlink U, Herbarth O. Seasonal cycle of VOCs in apartments. Indoor Air 2003;13(3):283-291.
10. Bousquet J, Knani J, Dhivert H, Richard A, Chicoye A, Ware JE Jr, et al. Quality of life in asthma. I. Internal consistency and validity of the SF-36 questionnaire. Am J Respir Crit Care Med 1994;149(2 Pt 1):371-375.
11. Kim YS, Byun MK, Jung WY, Jeong JH, Choi SB, Kang SM, et al. Validation of the Korean version of the St. George's respiratory questionnaire for patients with chronic respiratory disease. Tuberc Respir Dis 2006;61(2):121-128 (Korean).
12. Abbey DE, Petersen F, Mills PK, Beeson WL. Long-term ambient concentrations of total suspended particulates, ozone, and sulfur dioxide and respiratory symptoms in a nonsmoking population. Arch Environ Health 1993;48(1):33-46.
13. Jung JY, Son JY, Hong SJ, Lee YW, Sin YS, Park JW, et al. Comparison of the patient's global self-assessment scoring method with the quality of life questionnaire for adult Korean asthmatics. Korean J Asthma Allergy Clin Immunol 2008;28(2):134-142 (Korean).
14. Sheppard L, Levy D, Norris G, Larson TV, Koenig JQ. Effects of ambient air pollution on nonelderly asthma hospital admissions in Seattle, Washington, 1987-1994. Epidemiology 1999;10(1):23-30.
15. Guo H, Murray F, Lee SC. The development of low volatile organic compound emission house-a case study. Build Environ 2003; 38(12):1413-1422.
16. Kim S, Kim HJ. Comparison of formaldehyde emission from building finishing materials at various temperatures in under heating system; ONDOL. Indoor Air 2005;15(5):317-325.
17. Kim KJ, Kil MJ, Jeong MI, Kim HD, Yoo EH, Jeong SJ, et al. Determination of the efficiency of formaldehyde removal according to the percentage volume of pot plants occupying a room. Korean J Hort Sci Technol 2009;27(2):305-311 (Korean).
18. Hartig T, Mang M, Evans GW. Restorative effects of natural environment experiences. Environ Behav 1991;23(1):3-26.
19. Herzog TR, Black AM, Fountaine KA , Knotts DJ. Reflection and attentional recovery as distinctive benefits of restorative environments. J Environ Psychol 1997;17(2):165-170.
20. Kaplan S. Meditation, restoration, and the management of mental fatigue. Environ Behav 2001;33(4):480-506.
21. Shibata S, Suzuki N. Effects of the foliage plant on task performance and mood. J Environ Psychol 2002;22(3):265-272.
22. Lohr VI, Pearson-Mims CH. Particulate matter accumulation on horizontal surfaces in interiors: influence of foliage plants. Atmos Environ 1996;30(14):2565-2568.
23. Giese M, Bauer-Doranth U, Langebartels C, Sandermann H Jr. Detoxification of formaldehyde by the spider plant (Chlorophytum comosum L.) and by soybean (Glycine max L.) cell-suspension cultures. Plant Physiol 1994;104(4):1301-1309.
24. Lim YW, Kim HH, Yang JY, Kim KJ, Lee JY, Shin DC. Improvement of indoor air quality by houseplants in new-built apartment buildings. J Japanese Soc Hort Sci 2009;78(4):456-462.
25. Lohr VI, Pearson-Mims CH, Goodwin GK. Interior plants may improve worker productivity and reduce stress in a windowless environment. J Environ Hort 1996;14(2):97-100.
26. Park SY, Seong KJ. Plant effects on indoor formaldehyde concentration. J Environ Sci 2007;16(2):197-202 (Korean).
27. Park SY, Sung JS, Kim HD, Yamane K, Son KC. Effects of interior plantscapes on indoor environments and stress level of high school students. J Japanese Soc Hort Sci 2008;77(4):447-454.
28. Oh SW, Cho YS, Lim MK, Yoo B, Moon HB. Development of a quality of life questionnaire for Korean asthmatics. J Asthma Allergy Clin Immunol 1999;19(5):703-712 (Korean).
29. Park JW, Cho YS, Lee SY, Nahm DH, Kim YK, Kim DK, et al. Multi-center study for the utilization of quality of life questionnaire for adult Korean asthmatics (QLQAKA). J Asthma Allergy Clin Immunol 2000;20(3):467-480 (Korean).
30. Im HJ, Lee SY, Yun KJ, Ju YS, Kang DH, Cho SH. A case-crossover study between air pollution and hospital emergency room visits by asthma attack. Korean J Occup Environ Med 2000;12(2):249-257 (Korean).
31. Yang JY, Kim HH, Park JW, Kim KJ, Park CS, Shin DC, et al. The health effect of house-plant-focused on housekeepers and asthma patients. Indoor Environ Technol 2007; 4(1):1-13 (Korean).
32. Kim HH, Lee JY, Yang JY, Kim KJ, Lee YJ , Shin DC, et al. Evaluation of indoor air quality and health related parameters in office buildings with or without indoor plants. J Japanese Soc Hort Sci 2011;80(1):96-102.
33. Nolan D, White P. FEV1 and PEF in COPD management. Thorax 1999;54(5):468-469.
34. Wolverton BC, Wolverton JD. Plants and soil microorganisms: removal of formaldehyde, xylene and ammonia from the indoor environment. J Miss Acad Sci 1993;38(2):11-15.
35. Wood RA, Burchett MD, Alquezar R, Orwell RL, Tarran J, Torpy F. The potted-plant microcosm substantially reduces indoor air VOC pollution: 1. Office field-study. Water Air Soil Pollut 2006;175(1-4):163-180.
36. Kim HH, Park JW, Yang JY, Kim KJ, Lee JY, Shin DC, et al. Evaluating the relative health of residents in newly built apartment houses according to the presence of indoor plants. J Japanese Soc Hort Sci 2010;79(2):200-206.
37. Bringslimark T, Hartig T, Patil GG. The psychological benefits of indoor plants: a critical review of the experimental literature. J Environ Psychol 2009;29(4):422-433.
38. Barro R, Regueiro J, Llompart M, Garcia-Jares C. Analysis of industrial contaminants in indoor air: part 1. Volatile organic compounds, carbonyl compounds, polycyclic aromatic hydrocarbons and polychlorinated biphenyls. J Chromatogr A 2009;1216(3): 540-566.
39. Odabasi M. Halogenated volatile organic compounds from the use of chlorine-bleach-containing household products. Environ Sci Technol 2008;42(5):1445-1451.
40. Godish T, Guindon C. An assessment of botanical air purification as a formaldehyde mitigation measure under dynamic laboratory chamber conditions. Environ Pollut 1989;62(1):13-20.