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The effect of low-volatile organic compounds, water-based paint on aggravation of allergic disease in schoolchildren

Abstract Whether indoor painting aggravates preexisting allergic diseases remains unclear. We aimed to evaluate the impact of new classroom painting on aggravation of asthma, allergic rhinitis (AR), and atopic dermatitis (AD) in children. Studied school was previously painted with conventional water-based paint 20 years ago and had natural ventilation system. We identified a total of 172 children aged 10–12 years with allergic diseases in 17 classrooms, which were allocated to newly painted rooms with low-volatile organic compounds (VOC), water-based paint, or existing rooms. After painting, there was no intervention or internal airflow to influence indoor air environment in both classrooms. We prospectively assessed the symptom severity and serious events of allergic diseases between both classrooms at baseline and after one and eight weeks after painting. At one and eight weeks, there were no significant changes in the Childhood Asthma Control Test scores, the fractional nitric oxide levels, lung function in asthmatic children in either classroom. There were also no significant changes in the severity score of AR or AD, or serious events in all allergic diseases. These findings suggest classroom painting with this new paint at the levels encountered in this study might not be a major aggravating factor for school-aged children with allergic diseases.

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Key words: Paint; Asthma; Allergic rhinitis; Atopic dermatitis; Indoor air.

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Practical Implications

There is little evidence of the direct effect of indoor painting on preexisting allergic diseases. Our study revealed that new painting classrooms with low-VOC, water-based paint had no significant effect on the aggravation and the prevalence of serious adverse events of allergic diseases in school-aged children, including asthma, AR, and AD. These findings suggest that switching from conventional paint to this new indoor paint at the levels encountered in this study could be an option for decorating school classrooms without imposing any substantial hazards. Further research with more rigorous exposure measurement of indoor painting and adjustment of various confounders is needed to figure out how new paints with improved composition could affect subjects with allergic disease, especially in children.

Introduction

Chronic allergic diseases, including asthma, allergic rhinitis (AR), and atopic dermatitis (AD), are serious health problems worldwide (ISAAC Steering Committee, 1998). They cause physical discomfort and interfere with many aspects of daily life (Lozano et al., 1999; Gupta et al., 2004; Kim et al., 2011). Therefore, maintaining control and preventing exacerbation are the main therapeutic goals. Indoor air pollution is considered as one of the major risk factors associated with adverse effects of allergic diseases (Franklin, 2007). There are various sources of indoor air pollution, including smoking, cleaning product chemicals, and off-gassing of flooring and furniture (Nielsen et al., 2007; Chan-Yeung and Dimich-Ward, 2003).

Indoor paint used during home renovation or redecoration is another source of indoor chemicals.

Newly applied paints can emit various chemicals, including volatile organic compounds (VOC) and formaldehyde, during drying (Chang et al., 1999; Wieslander et al., 1997a). Several studies have examined whether indoor painting including VOC has adverse effects on asthma or allergic disease (Cakmak et al., 2014; Rumchev et al., 2004; Wieslander et al., 1997a). A recent systemic review of the effects of indoor paints on asthma (Canova et al., 2013), however, reported difficulty confirming the causal relationship between paint exposure and asthma aggravation in adults and children because most studies were observational epidemiologic reports rather than experimental studies. This weak association might be related to heterogeneity in study design, population, exposure level, and paints used. With growing concerns over the harmful effects of volatile solvents, indoor paints with no or minimal VOC concentrations have become popular. While acute exposure to VOC-free paint showed some symptomatic benefit compared with conventional paints in adults with asthma in the United Kingdom (Beach et al., 1997), it remains to be determined whether new paint exposure, even if VOC-free, would be safe for those with asthma and allergic diseases, especially children.

In school-aged children, the role of school environment on respiratory health and allergic symptoms has been underlined (Mendell and Heath, 2005; Shendell et al., 2004). In this experimental study, we examined whether painting classroom with low-VOC, water-based paint affected the exacerbation of allergic diseases in children with asthma, AR, or AD by assessing symptoms and adverse events, along with lung function measurements and airway inflammation. We evaluated acute effects in children at one week and subacute effects at eight weeks, after painting of school classrooms in urban Korea.

Materials and methods

Study design and subjects

This study was planned to evaluate the effects of school classroom newly painted with low-VOC, water-based paint on aggravation of allergic disease in children. We contacted the Seongdong District of Education, located in Seoul, Korea, to recommend an elementary school scheduled for new classroom painting. One elementary school was recommended and selected as the study school. This school had old classrooms painted with conventional water-based paint about 20 years ago and was scheduled to be painted regardless of study participation. The School Steering Committee agreed to participate in this study. The study protocol was approved by the Institutional Review Board of Hanyang University Hospital, Seoul, Korea (protocol #2012500).

The study design is shown in Figure 1. The study was carried out from September to November 2012. Schoolchildren in 4th–6th grades, 10–12 years of age, were enrolled, and their parents or guardians of the subjects gave written informed consent. Among 456 children, we screened for asthma, AR, and AD using a modified Korean version of the questionnaire prepared by the International Study of Asthma and Allergies in Childhood (ISAAC) (Lee et al., 2001). The children's parents or guardians completed this questionnaire at home. Overall, 430 parents (94.3%) provided valid questionnaire answers. The prevalence of each disease based on the questionnaire is summarized in Table 1. Asthma was defined as a previous diagnosis by a physician and/or wheezing in the previous 12 months. The

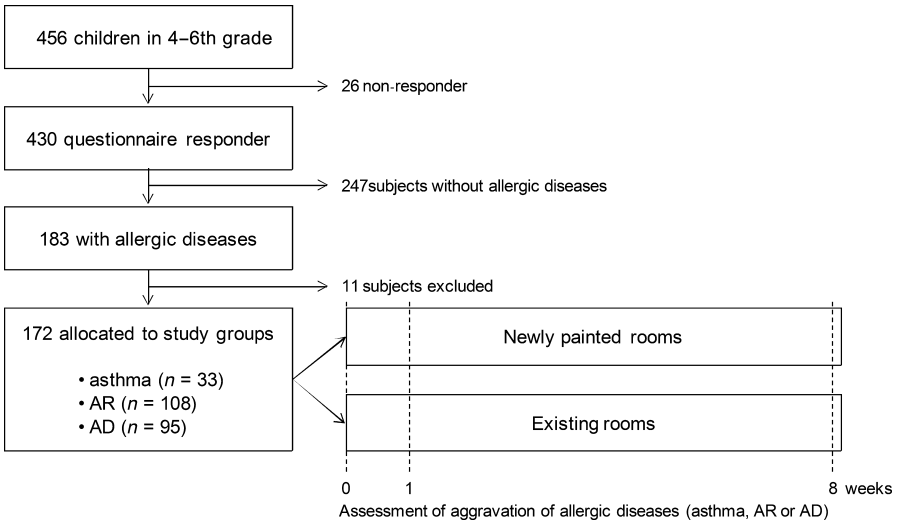

Fig. 1 Study design

Table 1 Prevalence of asthma, allergic rhinitis, and atopic dermatitis ($n = 430$)

Disease	Questions	*n* (%)
Asthma	Wheeze, ever	43 (10.0)
	Wheeze, last 12 months	17 (4.0)
	Diagnosis, ever	25 (5.8)
	Treatment, last 12 months	6 (1.4)
Allergic rhinitis	Symptom, ever	165 (38.4)
	Symptom, last 12 months	148 (34.4)
	Diagnosis, ever	117 (27.2)
	Treatment, last 12 months	88 (20.5)
Atopic dermatitis	Itchy rash, ever	89 (20.7)
	Flexural rash, last 12 months	59 (13.7)
	Diagnosis, ever	101 (23.3)
	Treatment, last 12 months	43 (10.0)

presence of AR and AD was identified by previous diagnosis by a physician. Subjects with current exacerbation of their allergic diseases, acute infection, or other concurrent diseases were excluded from the study. Baseline information regarding demographic and clinical characteristics of the subjects and severity of allergic diseases was obtained before painting classroom.

School classroom painting and new painting material

To compare the effect of new painting with low-VOC, water-based paint, the classrooms were painted in two steps. During the study period, the only subjects in newly painted rooms were exposed to this new paint, while those in existing rooms previously painted with conventional paint were not. The rest of classrooms including existing rooms were painted after the study period. The study was carried out in a single school building with natural ventilation system including window and door opening. We tried to prevent unnecessary exposure to this new paint among the subjects in the existing rooms. The school building comprised four stories. At the center of the school building, there was a central staircase separating the classrooms into left and right side. We enrolled all 4th–6th grade schoolchildren in a total of 17 classrooms on two floors in the school building. Among them, subjects with asthma, AR, and AD were identified according to the above questionnaire. Eight classrooms on the left side of central staircase were allocated to newly painted rooms, and the remaining nine on the right side of central staircase were allocated to existing rooms. There was no mechanical ventilation system to circulate internal airflow between newly painted and existing rooms. Moving classes for cocurricular activities among enrolled subjects were limited, and, if needed, progressed at classrooms not included in this study.

We used new low-VOC, water-based paint (The Classy™, Samwha, Korea), which contains only minimal amount of VOC including propylene glycol and acrylate/methacrylate. Formaldehyde, toluene, and acetone generally included as major VOC in conventional water-based paints were removed in indoor paints used in this study. With regard to non-VOC components, silicon dioxide (SiO_2), aluminum hydroxide, talc (non-asbestos form), titanium dioxide, and kaolin were used in new indoor paint as surface-modified fillers. Painting was undertaken with a paintbrush in enrolled classrooms with all four walls and ceiling. There were no direct measurements of VOC in enrolled classrooms. Unlike in experimental study design such as chamber test, realistic behaviors and characteristics of VOC emission in clinical study of painting rooms should be considered (Xiong et al., 2013). In this study, we did not estimate the amount of exposure to this new paint. However, we intended to assess the direct impact of new painting classrooms on allergic health in practical life of school environment. Thus, we determined that indoor chemicals including VOC and other substances from this new paint were needed to be maintained at a consistent realistic level that would not exceed the usual exposure level and evenly affected all subjects in newly painted rooms. We painted classrooms over the weekend, and fully ventilated them via opening windows for at least 24 h in the absence of all subjects. All enrolled schoolchildren attended class as usual and spent for at least six hours per weekday in their classrooms during the study period. After painting, there was no intervention (such as frequent opening windows) to deserve to have an impact on ventilation system in both classrooms.

Assessment of asthma, allergic rhinitis, and atopic dermatitis

Symptom severity of asthma, AR and AD was assessed at baseline and after one and eight weeks after painting. For the assessment of asthma, we used the Childhood Asthma Control Test (C-ACT), a seven-item self-administered questionnaire. Fractional exhaled nitric oxide (FeNO) and lung function were also measured to evaluate airway inflammation and airflow limitation. FeNO levels were measured according to the manufacturer's instructions using a handheld electrochemical analyzer, NIOX MINO® (Aerocrine, Solna, Sweden). Lung function including FEV_1 (forced expiratory volume in one second) was assessed using a FlowScreen Jaeger (Viasys, Germany) while standing with a nose clip until two consecutive technically acceptable curves were achieved.

For assessment of symptom in subjects with AR, total nasal symptom scores (TNSS) were used. The nasal symptom scores evaluated nasal symptoms such as itching, sneezing, runny nose, and congestion on a four-point scale: 0 = no symptoms; 1 = mild symptoms (present but bearable); 2 = moderate symptoms (present but uncomfortable); and 3 = severe symptoms (unbearable). TNSS was the sum of itching, sneezing, runny nose, and congestion scores (Svensson et al.,

1998). With regard to AD, the SCORAD (SCORing Atopic Dermatitis) index was used to assess symptom severity. One dermatologist evaluated the SCORAD and serious events for children with AD. The SCORAD index interprets the extent of the disorder (A: according to the rule of nines); intensity composing six items (B: erythema, edema/papules, effect of scratching, oozing/crust formation, lichenification, and dryness with each item assessed by four grades: 0, 1, 2, and 3); and subjective symptoms (C: itching, and sleeplessness). A SCORAD was calculated by A/5+7B/2+C (Oranje et al., 2007). The rule of nine is used to calculate the affected area by AD as a percentage of the whole body. In detail, head and neck is 9%; upper limb is 9%, each (18%, total); lower limb is 18%, each (36%, total); anterior trunk is 18%; back is 18%; and genitals are 1%. The sum of the scores from each site gave a percentage assessment of the total body area, which has a possible maximum of 100%.

Serious adverse events after classroom painting

Serious adverse events were defined as a change in medication, including oral corticosteroid use, and/or healthcare utilization for worsening of symptoms related with asthma, AR, or AD. These events for each allergic disease for all subjects were assessed using structured interview at one and eight weeks after classroom painting.

Skin prick test to aeroallergens

Skin prick tests for 10 common aeroallergens were performed to determine the atopic status. The allergens included mites (*Dermatophagoides pteronyssinus, D. farinae, and Tyrophagus*), cockroach, animal hair (dog and cat fur), and fungi (*Alternaria species and Aspergillus species*), as perennial allergens, and weeds (mugwort and ragweed) as seasonal allergens. Saline was used as a negative control and histamine (1 mg/ml) as a positive control. A positive response to each allergen was determined by a mean wheal diameter ≥3 mm and a ratio of allergen/histamine wheal size ≥1. Atopy was defined as a positive reaction to at least 1 of 10 allergens.

Statistical analysis

Statistical analyses were performed using the SPSS software, version 20.0 (SPSS Inc., Chicago, IL, USA). Results for nominal variables were expressed as frequency, and those for continuous variables were expressed as means ± standard deviation (if normally distributed). A Kolmogorov–Smirnov test was used to assess the normality of variables. Continuous variables including C-ACT scores, FEV_1, and FeNO levels were not normally distributed. In these variables, Mann–Whitney nonparametric *U*-tests were used to compare results between newly painted and existing rooms and Wilcoxon signed ranked test was used to determine whether there were significant changes in results at week one and at week eight from those at baseline (week zero). In other continuous variables (TNSS and SCORAD) showing normal distribution, Student's *t*-tests and a paired *t*-test were performed for statistical analysis. Results for categorical variables were compared using chi-square (χ^2) or Fisher's exact tests. A P value of <0.05 was considered to indicate statistical significance.

Results

Baseline characteristics

We identified 183 children with any allergic diseases. After exclusion, a total of 172 subjects (33 with asthma, 108 with AR and 95 with AD) were allocated to newly painted rooms with low-VOC, water-based paint, or existing rooms previously painted with conventional paint (Figure 1). Table 2 shows the demographic and clinical characteristics of the study subjects with each allergic disease. Of 33 subjects with asthma, 19 were allocated to newly painted rooms while the other 14 were assigned to existing rooms. There were no signifi-

Table 2 Baseline characteristics of schoolchildren with allergic diseases

	Asthma (n = 33)			Allergic rhinitis (n = 108)			Atopic dermatitis (n = 95)		
	Newly painted rooms (n = 19)	Existing rooms (n = 14)	P value	Newly painted rooms (n = 48)	Existing rooms (n = 60)	P value	Newly painted rooms (n = 43)	Existing rooms (n = 52)	P value
Male	12 (63.2)	11 (78.6)	NS	28 (58.3)	38 (63.3)	NS	22 (51.2)	26 (50.0)	NS
Age (year)	10.7 ± 1.0	11.3 ± 0.6	NS	11.0 ± 1.0	11.1 ± 0.9	NS	11.0 ± 1.0	11.1 ± 0.7	NS
BMI (kg/m^2)	19.2 ± 3.1	19.1 ± 2.5	NS	19.4 ± 3.3	19.5 ± 3.6	NS	18.9 ± 3.1	19.3 ± 3.5	NS
SPT positive[a]	8 (44.4)	9 (69.2)	NS	26 (56.5)	34 (57.6)	NS	26 (61.9)	26 (53.1)	NS
Parent smoking	9 (47.4)	9 (64.3)	NS	26 (54.2)	39 (65.0)	NS	25 (58.1)	36 (69.2)	NS
Pet at home	4 (21.1)	2 (14.3)	NS	7 (14.6)	14 (23.3)	NS	7 (16.3)	10 (19.2)	NS

Values are expressed as means ± s.d. or numbers (%). BMI, body mass index; SPT, skin prick test; NS, not significant.

[a]Skin allergy test was carried out in 31 subjects with asthma (two subjects were missing), 105 with allergic rhinitis (three were missing), and 91 with atopic dermatitis (four were missing).

cant differences in age, gender, body mass index (BMI) values, skin prick test positivity, parental smoking, and pet exposure at home between both classrooms. In AR, there were 48 subjects in newly painted rooms and 60 in existing rooms. Of those with AD, 43 and 52 subjects were in newly painted and existing rooms, respectively. There were also no significant differences between subjects with AR and AD in both classrooms with regard to demographic and atopic characteristics.

Classroom painting and asthma

At baseline, there was no significant difference in C-ACT scores between the subjects in newly painted rooms (26.8 ± 0.5) and existing rooms (26.6 ± 1.0). The mean of C-ACT scores in all subjects with asthma was ≥23 points, which reflected well-controlled asthma (Ito et al., 2011). At one and eight weeks after painting classrooms, C-ACT scores were not significantly different compared with baseline in either subjects in newly painted or existing rooms (Figure 2a). Levels of FeNO were not significantly different between subjects in newly painted and existing rooms at baseline, and there was no significant change in FeNO concentrations in either subject in newly painted or existing rooms at one and eight weeks after painting classrooms (Figure 2b). Next, children in newly painted and existing rooms maintained relatively stable FEV_1 throughout the study period (Figure 2c), although FEV_1 in those in existing rooms increased significantly after one week of painting (98.9 ± 8.8%), compared with baseline (91.5 ± 8.5%). Lastly, there were no significant differences in prevalence of reported serious adverse events between the subjects in both classrooms at one and eight weeks (Figure 2d). These findings suggested that painting classrooms with this new paint did not lead to significant changes in severity including general assessment, airway inflammation, lung function, and exacerbations.

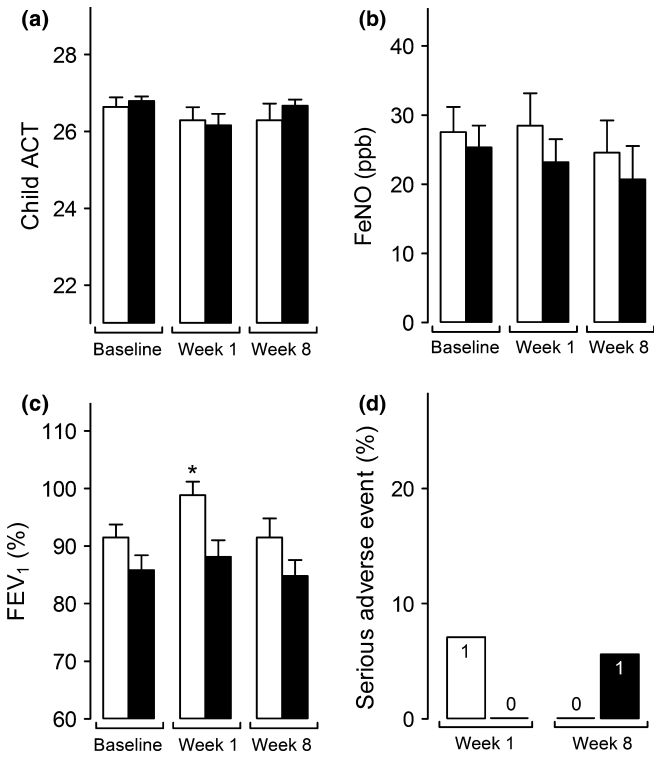

Fig. 2 Asthma control before and after classroom painting. (a) Total childhood asthma control test (C-ACT) score, (b) FeNO concentrations, (c) %FEV_1 predicted value, and (d) prevalence of reported serious adverse events. White boxes depict the existing rooms and black boxes the newly painted rooms. Asterisks indicate a statistically significant difference in the mean change from baseline. Values are shown as means ± s.e.m. FeNO, Fractional exhaled nitric oxide; FEV1, forced expiratory volume in one second

Classroom painting and allergic rhinitis and atopic dermatitis

The majority of subjects with AR in newly painted rooms (85.4%) and existing rooms (76.7%) had mild intermittent symptoms based on the allergic rhinitis and its impact on asthma (ARIA) classification (Jauregui et al., 2011). Four subjects (8.3%) in newly painted rooms and five (8.3%) in existing rooms had mild persistent symptoms. Subjects with intermittent moderate/severe symptoms were more frequently observed in existing rooms, compared with newly painted rooms (nine, 15.0% and two, 4.2%, respectively), but there was no significant difference ($P = 0.068$). Only one subject in newly painted rooms and none in existing rooms had moderate/severe persistent symptoms. At one and eight weeks, TNSS was not significantly different between the subject in both classrooms. Moreover, TNSS in all subject with AR in both classrooms tended to decrease over the study period, although there were no significant differences between baseline and eight weeks (Figure 3a). The prevalence of reported serious adverse events for subjects with AR in newly painted rooms was not significantly different from those in existing rooms at one week (14.6 and 15.0%, respectively) and eight weeks (6.5% and 8.5%, respectively) (Figure 3b).

For the assessment of AD, the mean of SCORAD in all subjects with AD was <25 points, which reflected mild severity (Oranje et al., 2007). They showed a tendency for improvements in SCORAD over time, but these scores were not significantly different between baseline and eight weeks (Figure 4a). There were no significant differences between the subjects in both classrooms in prevalence of reported serious adverse events at weeks one and eight (Figure 4b).

Discussion

We have shown here that classroom painting with new low-VOC, water-based paint has no significant effects

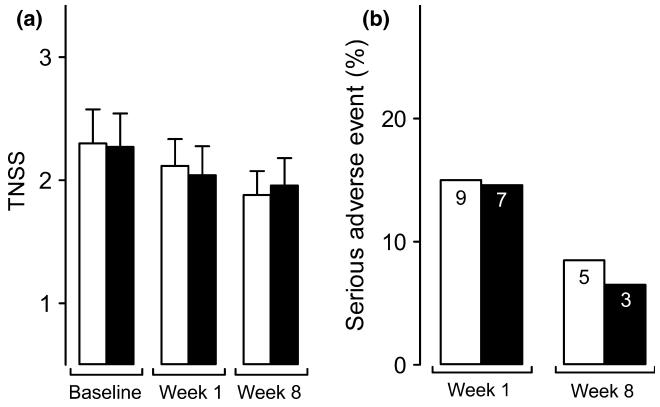

Fig. 3 Allergic rhinitis control before and after classroom painting. (a) The total nasal symptom score (TNSS), (b) prevalence of reported serious adverse events. White boxes depict the existing rooms and black boxes the newly painted rooms. Values are shown as means ± s.e.m. TNSS is the sum of itching, sneezing, runny nose, and congestion scores on a four-point scale (0 = no symptoms; 1 = mild symptoms; 2 = moderate symptoms; and 3 = severe symptoms)

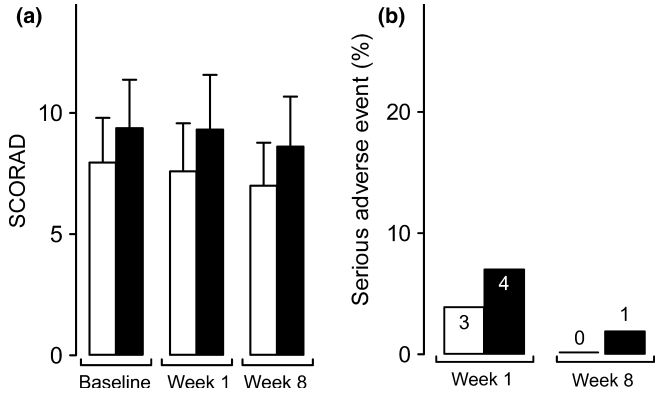

Fig. 4 Atopic dermatitis control before and after classroom painting. (a) The scoring of atopic dermatitis (SCORAD), (b) prevalence of reported serious adverse events. White boxes depict the existing rooms and black boxes the newly painted rooms. Values are shown as means ± s.e.m. The SCORAD index interprets the extent of the disorder (A: according to the rule of nines, which is the tool assessing the affected body surface area); intensity composing six items (B: erythema, edema/papules, effect of scratching, oozing/crust formation, lichenification, and dryness; each item assessed by four grades: 0, 1, 2, and 3); and subjective symptoms (C: itching and sleeplessness). A SCORAD was calculated by A/5+7B/2+C

on aggravation and prevalence of reported serious events in children with allergic diseases, including asthma, AR, and AD. These results suggest that new indoor paint used in this study appears to be less likely to cause a symptomatic worsening for children with allergic diseases. Moreover, there are no significant deteriorations in lung function and airway inflammation based on FeNO levels in asthmatic children after new painting their classrooms. These results would provide convincing explanation that new painting classroom had minimal harmful effect on asthmatic school-aged children.

The study was intended to show the effect of new painting in old school classrooms on allergic health in real-life school environment. However, previous literature has suggested that indoor painting negatively affected allergic health in children (Canova et al., 2013; Mendell, 2007). Among indoor chemicals emitted from indoor painting and drying, various VOCs could enhance allergic diseases in children (Chin et al., 2014; Rumchev et al., 2004; Tagiyeva and Sheikh, 2014). Recently, low-VOC or zero-VOC (VOC-free) paints were made to generate as low as possible emissions of volatile organic or inorganic compounds. However, paints marketed as 'low-VOC' may still have significant emissions of some individual VOCs (Chang et al., 1999). Even VOC-free paint might release high concentration of VOCs during the first few hours after painting (Schieweck and Bock, 2015), so intense ventilation before re-occupying painted rooms should be considered, especially in children, elderly, and sensitive subjects. In particular, in school environment, wood-based products including chairs and desks potentially emit secondary organic aerosols when ozone entered from outdoors, which may adversely affect indoor air quality and allergic health (Toftum et al., 2008). Our results seem to be opposite of what was expected as this study revealed no hazardous effects of painting with low-VOC paint on symptomatic aggravation in allergic diseases.

It might be postulated how paint used in this study could have had an improved material composition. In this study, a new paint with only minimal amounts of propylene glycol and acrylate/methacrylate, and from which other major VOCs, including formaldehyde and benzenes, had been removed, was used. Propylene glycol is a good solvent in paints, with relatively low volatility and antifreeze stability. Propylene glycol in indoor chemicals has been reported to have adverse effects on allergic symptoms and IgE sensitization in preschool-age children (Choi et al., 2010). Exposure to acrylate/methacrylate could result in mucosal irritation and allergic dermal response in adult (Sasseville, 2012); however, their effects in school-aged children have not been thoroughly investigated. Despite these limitations of ingredients, there were no significant differences in the changes of lung function and FeNO levels between both studied classrooms, as well as symptomatic aggravations. This illustrates the fact that this type of low-VOC paint unlikely has significant hazardous effects on airway inflammation and symptomatic exacerbation of allergic diseases. However, most water-based paints with low VOC have been formulated with increasing amount of other compounds including coalescing agent, stabilizer, and biocides that could contribute to exposure of potential health relevance. 2,2,4-Trimethyl-1,3-pentanediol monoisobutyrate

(TMPD-MIB) is added as a coalescing aid and frequently detected in indoor environment after painting with water-based paints (Corsi and Lin, 2009). Emission of TMPD-MIB in schools has been associated with increased prevalence of asthmatic symptoms in schoolchildren (Kim et al., 2007). Moreover, biocide contents in indoor paint materials such as isothiazolones may lead to unnecessary sensitization and increase the health risk of the development of contact eczema (Nagorka et al., 2015). Thus, this study only addressed the impact of certain type of low-VOC paint on allergic health, and generalization of our results may not be possible.

Certain limitation of our study also should be recognized as it may influence our results. First, the degree of exposure in newly painted rooms to this new paint was not adequately controlled, during the study period. There was no direct measurement of indoor chemicals including VOC emitted from school building materials, which could affect allergic health in children. Moreover, all selected classrooms in this study were located in the same building with natural ventilation system, and there was no specific principle in the control of ventilation via opening doors and windows. Airflow from newly painted rooms to existing rooms could occur and influence the indoor air environment in existing rooms. Thus, the impact of new painting classrooms on adverse effects in allergic diseases might be difficult to ascertain. Second, each subject enrolled in this study has own various environmental conditions at home, such as various types of domestic painting, pets, secondhand smoking, and infrequent home renovations, which could have strong influence on our results. There were no significant differences in frequency of parent smoking and pet at home between newly painted rooms and existing rooms. However, exact degree of exposure to environmental tobacco smoking at home also needs to be indicated and cannot be excluded as a potential confounding factor. In this reason, from a clinical perspective, new painting classrooms would seem to be too small to have much effect on allergic health in children. Third, this study focused exclusively on the acute and subacute effects of painting with this new paint. The indoor chemical emissions from painting may persist for up to 200 days (Sparks et al., 1999). Any chronic health effects of painting with this new paint should be considered. Fourth, painting classrooms could also have affected the health status of children without allergic diseases while in the same classrooms. However, this study did not evaluate symptoms suggestive of adverse event for these children, and it was unsuitable to assess the development of allergic diseases in healthy children. It also may not be possible that our results could be applicable to different aged children and adults. Despite these limitations and the confounders, we attempted to figure out the association between new indoor painting with water-based, low-VOC paint and allergic diseases. Even no or low-VOC indoor paints may release significant level of VOCs in indoor painting process, retaining the potential to have negative impact on allergic disease (Chin et al., 2014; Rumchev et al., 2004; Tagiyeva and Sheikh, 2014). However, only little clinical researches have been conducted so far concerning how these new paints with improved composition could affect subjects with allergic disease, especially in children (Schieweck and Bock, 2015). Further research with more rigorous exposure measurement of painting and adjustment of various confounders is needed to address the impact of new paints on allergic diseases.

Interestingly, for AR there was a slight difference between painted and existing rooms for symptom severity in subjects with AR at baseline; however, the difference was not statistically significant. Considering relatively small sample size of this study, that difference could affect TNSS and symptomatic deterioration after new classroom painting. In the present study, AR with moderate/severe symptoms was less frequently observed in newly painted rooms at baseline, compared with those in existing rooms. However, there were no significant differences between both rooms in TNSS and prevalence of serious adverse event throughout the study period. We considered that subjects in newly painted rooms were selected to be a group unlikely to be sensitive to any effect of indoor painting. The true health effect of indoor painting in AR could be underestimated.

Nonetheless, our study deserves to be highlighted as the first experimental study to investigate the direct effect of new painting classrooms on aggravation of allergic disease among schoolchildren. Among the potential health effects of indoor painting on allergic diseases, development of allergic diseases has been in the focus of research in numerous observational and epidemiologic studies. In asthma, new domestic painting was significantly associated with recurrent infant wheezing (Emenius et al., 2004) and childhood asthma (Rumchev et al., 2004). Occupational exposure to indoor painting has been suggested to cause bronchial hyper-responsiveness and asthma-related symptoms among healthy adults (Wieslander et al., 1997b). Even residential exposure increased the frequency of current asthma among subjects whose residences had been painted recently (Wieslander et al., 1997a). However, to our knowledge, no evidence existed on whether indoor painting aggravates preexisting asthma in school-aged children. Beach et al. (1997) conducted experimental research in patients with asthma, to the issue of acute responses to paint fumes. They showed no significant changes in airway responsiveness and lung function after acute exposure to indoor painting in 17 adult asthmatic patients, regardless of the VOC content of paints (Beach et al., 1997). In the present study, we also found no significant differences between

FeNO levels in subjects in both classrooms (Figure 2b). There were also no significant changes from baseline in lung function during the study period. Thus, painting activities in classrooms with this low-VOC, water-based paint do not seem likely to deteriorate asthma symptoms of children to a clinically significant degree.

In regard to AR, prevalence of AR could be related to renovation history and the process of remediation (Hoppe et al., 2012; Seo et al., 2014). One experimental study suggested subject relocation to a newly painted building increased the inflammatory response in the nasal mucosa (Wieslander et al., 1999). In individuals with AD, two observational studies reported that redecoration activities, including indoor painting, were associated with AD severity (Bornehag et al., 2004; Lee et al., 2012). However, previous evidence among AR and AD patients had limited ability to assess painting exposure and symptomatic aggravation of AR and AD. This paint challenge experimental study provides an opportunity to address the effect of indoor painting alone on AR and AD. In the present study, painting classrooms did not induce clinically meaningful deteriorations in AR and AD symptoms.

In summary, any symptomatic deterioration in allergic diseases was minor and clinically negligible in newly painted classrooms with this low-VOC, water-based paint. Switching from conventional paint to this new indoor paint at the levels encountered in this study would be an option for decorating school classrooms without imposing any substantial hazards. In this study, there were considerable limitations and only addressed the impact of certain type of low-VOC paint on allergic health. It is difficult to draw firm conclusions on whether classrooms painted with low-VOC paint exacerbate allergic diseases in school-aged children. Thus, new painting and air quality in school classrooms may still be an area of further research in subjects with allergic diseases. Such studies will help to make indoor air quality cleaner and advance the evidence base for new indoor painting materials.

Acknowledgement

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Conflict of interest

None.

Author's contributions

HJY and SHK conceived the study and had a major role in the coordination of the study. DWP, JSS, JC, and MGJ (dermatologist) gathered the data. DWP, SHK, and JYM reviewed the data and led the statistical analysis. DWP and SHK contributed the preparation of the article. HJK, YSR, THK, JWS, DHS, and SSP helped to draft the manuscript. All authors have read and approved the manuscript.

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