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Recent advances in environmental controls outside the home setting

Marissa Hauptman[a,b,c,d] and **Wanda Phipatanakul**[b,c]

[a]Division of General Pediatrics, Boston Children's Hospital, Boston, Massachusetts, USA

[b]Division of Allergy and Immunology, Boston Children's Hospital, Boston, Massachusetts, USA

[c]Harvard Medical School, Boston, Massachusetts, USA

[d]Region 1 New England Pediatric Environmental Health Specialty Unit, Boston, Massachusetts, USA

Abstract

Purpose of review—It has been well studied that aeroallergen, mold, and airborne pollutant exposure in the inner-city home environment is associated with significant childhood asthma morbidity. Although the home environment has been extensively studied, the school environment is less well understood.

Recent findings—In this article, we discuss the relationship between environmental exposures within the school and daycare environment and pediatric asthma morbidity and novel environmental interventions designed to help mitigate pediatric asthma morbidity.

Summary—Studies assessing environmental exposures outside the home environment and interventions to mitigate these exposures have the potential to reduce pediatric asthma morbidity. Further study in this area should focus on the complex cost benefit analyses of environmental interventions outside the home setting, while controlling for the home environment.

Keywords

pediatric asthma; school exposures; school-based asthma management; school-based environmental intervention

INTRODUCTION

Asthma is the most common noncommunicable childhood disease, affecting approximately 14% of children globally, with a rising prevalence worldwide [1–3]. The burden of asthma is not distributed evenly with urban minority children of low socioeconomic status enduring higher morbidity [4]. Data from the US National Interview Survey found that children with

Correspondence to Wanda Phipatanakul, MD, MS, Boston Children's Hospital, 300 Longwood Ave Boston, MA 02115, USA. Tel: +1 617 355 6117; fax: +1 617 730 0310; wanda.phipatanakul@childrens.harvard.edu.

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asthma missed three times more school days and had a 1.7 times increased risk of suffering from a learning disability as compared with children without asthma [4].

It has been well studied that aeroallergen, mold, and airborne pollutant exposure in the inner-city home environment is associated with significant childhood asthma morbidity [5–10]. Although the home environment has been extensively studied, the environment outside of the home, especially in the United States is less well understood, largely because of logistical and community hurdles. Despite this, numerous US-based and European studies have demonstrated considerable asthma exposures present in the inner-city school environment, an occupational model for children given that children spend nearly 6–8 h/day in school [11–27].

A perspective published in 2014 [28], highlighted the limited nature of school-based environmental intervention studies done to date and proposed feasible school-based environmental interventions to mitigate asthma morbidity, which are still ongoing. Given the scarcity of comprehensive data on school-based environmental interventions and health outcomes, successful home-based strategies currently serve as an important model for school-based interventions [28].

In this article, we discuss recent literature that assesses the health effects of environmental (e.g., aeroallergens, mold, endotoxin, and airborne pollutants) exposures outside of the home environment on pediatric asthma morbidity. Subsequently for each environmental exposure, we will review recent advances in school-based environmental controls, including important work conducted by the governmental and nongovernmental organizations alike designed to help mitigate pediatric asthma morbidity. We have focused on inner-city school and daycare environments because of the disproportionately high pediatric asthma burden in these areas and the significant amount of time children spend per day in these environments [5–10]. Although, the primary disease of interest in this review article is pediatric asthma, environmental exposures and interventions outside the home setting may impact morbidity of other allergic and irritant-induced diseases such as eczema and allergic rhinitis [28]. Despite its importance, this article does not include a detailed assessment of school-based asthma therapeutic and educational programs as this is beyond the scope of this review.

REVIEW

The school environment is a significant reservoir for allergens, pollutants, and viral respiratory infections [11–26]. As in home environments, it is unlikely that a single school or classroom-based environmental exposure is exclusively responsible for asthma morbidity [29,30].

Aeroallergens

Higher asthma morbidity in inner-city children has historically been associated with cockroach and mouse allergen more than other commonly encountered allergens in home environments [10,31–34]. Previous studies found cockroach and mouse allergens highly prevalent in school environments [13,21]. The **S**chool **I**nner-**C**ity **A**sthma **S**tudy (SICAS) is a National Institutes of Health (NIH) and National Institute of Allergy and Infectious

Disease (NIAID) funded, comprehensive, prospective study of inner-city school and classroom-specific exposures and asthma morbidity among inner-city students in the Northeast [35]. In SICAS, our study group has reliably detected higher levels of mouse allergen in schools, compared with the same students' home environments, [22,24] with levels similar to those seen in occupational lab animal settings [36]. European school-based studies have demonstrated cat and dog allergen at high levels in schools, likely from passive transfer of students who owned pets in their homes [20,34], although these levels were variable in an inner-city US cohort [22] and not at levels previously demonstrated to exacerbate symptoms [37]. Some school-based studies have found very little cockroach allergen discovered [22,34]. Some of the differences between the European and US inner-city cohorts are likely because of climatic, cultural factors, and occupant factors [34].

An example of a feasible school-based environmental intervention is integrated pest management. Given the markedly high levels of mouse allergen in schools compared with levels in children's individual bedrooms [22,23], our group piloted environmental controls strategies, modeled from successful home-based strategies and adapted for tolerance and acceptability in a school and classroom, to collectively reduce allergen and pollutant levels in preparation for a NIH/NIAID funded School Inner-City Asthma Intervention Study, with results pending. In Sweden, allergen avoidance measures to reduce pet dander in schools have been conducted, including increased cleaning and strict pet ownership ban among staff and schoolchildren [38–40]. Allergen avoidance measures, including increased cleaning, removal of upholstery and curtains, and replacement of bookshelves with cupboards to minimize allergen load found no change in cat allergen levels [38]. However, dedicated school clothing and banning pet ownership showed that airborne cat allergen levels were on average 4–6 times lower in classes with school clothing or a pet ownership ban compared with control classes [39].

Mold

Schools are a unique microenvironment of indoor air pollutants and particulates, as well as associated mold and other allergens carried on these particles. An ongoing multicenter prospective study evaluating indoor air pollution in Europe, entitled the Health Effects of Indoor Air Pollutants (HITEA), has found high levels of mold in schools, particularly those with moisture damage [28,41,42, 43▪▪,44]. These mold findings substantiate the results from SICAS, which found elevated levels of mold in settled dust and airborne concentrations [25]. A recent manuscript from the HITEA study, found an increased prevalence of respiratory symptoms among children aged 6–12 years in moisture damaged schools[43▪▪]. This study demonstrated a significant positive association between school moisture and dry cough at night (odds ratio 1.31, 95% confidence interval: 1.05–1.64) with no significant associations found between school moisture and lung function [43▪▪]. Analyses limited to asthmatics or children with wheeze, however, did not indicate that symptoms or lung function were associated with moisture damage or microbial exposure in these subgroups [43▪▪]. A recent national Taiwanese study, which demonstrated that fungal spore levels, specifically A*spergillus/Penicillium* and basidiospores in classrooms correlated with current asthma and a relief of symptoms on weekends and holidays, in multivariate models that adjusted for visible mold at home [45▪].

There have been limited recent health impact assessments evaluating the effectiveness of repairing water damage outside the home environment. A pilot study showed that High-efficiency particulate arrestance (HEPA) filters reduce mold spore counts in daycare centers [46]. A 2015 Cochrane Review conducted by Sauni *et al.* [47] was conducted to determine the effectiveness of repairing buildings damaged by dampness and mold to reduce or prevent respiratory tract symptoms, infections, and symptoms of asthma. Although the review focused on repairing houses, office buildings, and schools, for school children, there was reportedly low-quality evidence that pupils' visits to physicians because of a common cold were less frequent after remediation of the school based on three studies [47]. Evidence of an effect of mold remediation was inconsistent with respect to respiratory symptoms and out of many symptom measures only respiratory infections might have decreased after the intervention.

Endotoxin

Endotoxin exposure in homes and occupational settings have demonstrated increased wheeze, increased airflow obstruction and bronchial hyper-reactivity in human challenge studies, and potentiated the airway response to allergens in people with asthma [48▪▪,49]. Several studies have identified elevated airborne endotoxin levels in schools [50–52]. The HITEA study above, demonstrated endotoxin, ergosterol, and *Penicillium chrysogenum* DNA levels were higher in moisture-damaged schools as compared with reference schools [42,43▪▪]. A 2015 study published by Lai *et al.* [48▪▪], assessed the relationship between school endotoxin exposure and asthma morbidity in the SICAS longitudinal cohort. This study found that school dust endotoxin levels were significantly higher than home levels; 22% of classroom air levels exceeded 90 EU/m, a recommended occupational exposure limit for adults [48▪▪]. In this novel study, increased school air endotoxin is associated with increased number of maximum symptom days in children with nonatopic asthma, after adjusting for home exposures. This study postulates that high levels of school endotoxin exposure may explain why inner-city children experience a higher burden of disease and higher morbidity because of asthma and represents an important potential area of intervention [48▪▪].

Traffic-related air pollution and indoor air quality

Schools are typically centrally located within a community and a recent study conducted by Kingsley *et al.* [53▪] demonstrated that approximately 3.2 million (6.5%) children across the United States attended schools located within 100 meters of a major roadway as defined by the United States Census Bureau. In addition, to being in close proximity to heavy traffic routes and commercial or industrial exposures, schools frequently serve as a hub for pickup, drop-off, and idling of cars and buses, potentially contributing to a site-specific increase in ambient pollution that are not characterized by typical definitions of major roadways or traffic density [54].

A 2014 study conducted by Rivas *et al.* [55▪▪], as part of the **BR**ain **dE**velopment and **A**ir polluTion ultra fine particles in sc**H**ool childr**E**n (Breathe) study, quantified indoor and outdoor air quality data during school hours in 39 schools in Barcelona. High levels of fine particles or particulate matter with diameter ≤ 2.5 μm ($PM_{2.5}$), nitrogen dioxide, equivalent black carbon, ultrafine particle concentrations and road traffic-related trace metals were detected in school playgrounds and indoor environments [55▪▪]. $PM_{2.5}$ almost doubled from the usual urban background levels reported for Bar-celona [55▪▪]. The research suggested that nitrogen dioxide, equivalent black carbon, and ultrafine particle and antimony appear to be good indicators of traffic emissions and that the concentrations of nitrogen dioxide are 1.2 times higher at schools than usual background levels, suggesting the proximity of some schools to road traffic [55▪▪]. However, $PM_{2.5}$ could not be considered a good tracer of traffic emissions as the higher levels of $PM_{2.5}$ were attributed rather to alternative sources characterized by chalk dust and organic carbon from indoor generated sources (e.g., organic textiles fibers, cooking, and other organic emissions) as well as mineral elements from sand-filled playgrounds detected both indoors and outdoors [55▪▪].

A study conducted by Annessi-Maesano *et al.* [56], as part of the French 6 Cities Study, assessed indoor air quality data in primary schools and investigated the relationships between classroom-based air pollutants and asthma and rhinitis in schoolchildren, this study, however, did not comprehensively adjust for home environmental mold and allergen exposure levels. This study demonstrated that overall about one-third of the 6590 schoolchildren were exposed to high concentrations of $PM_{2.5}$ and nitrogen dioxide, as defined by the WHO [56]. In multivariate linear mixed regression models, asthma was significantly more common in classrooms with high $PM_{2.5}$, after adjusting for age, sex, passive smoking, maternal or paternal history of asthma, dampness, gas appliance, ethnicity, and socio-economic status among sensitized children [56].

Schools also sometimes have poor ventilation [57] and suffer inadequate building maintenance [58]. A review study conducted by Daisy *et al.* [59], found that classroom ventilation is typically inadequate and may exacerbate children’s exposure to indoor air pollutants. A more recent study conducted in 2014 by Ferreira *et al.* [60▪], corroborated these findings and showed a significant proportion of carbon dioxide measurements in urban schools in Portugal were above 1000 parts/million (ppm), the threshold generally regarded as indicative of unacceptable ventilation rates. The study conducted by Ferreira *et al.* [60▪], also demonstrated that lack of concentration and attention was associated with CO_2 concentrations above the maximum recommended level in indoor air ($P = 0.002$).

Several small longitudinal studies in Europe have found improvement in asthma symptoms with repair of air filtration systems, repair of moisture damage, and reduction in mold exposure and other building maintenance [61–63]. A small-randomized trial in Australia found that when controlling for the home environment, replacing school heaters, and thus reducing nitrogen dioxide levels reduced asthma symptoms [28,64]. Another potential school-based intervention is the use of air filtration systems to reduce environmental exposures [65,66] similar to the multifaceted environmental intervention employed in the landmark multicenter home-based study conducted by Morgan *et al.* [67] with regard to types of air filtration systems, room HEPA air filters may be more practical for study purposes [65,68], and may be utilized to control classroom-specific exposures.

Microbial environment

Viral upper respiratory tract infections have been implicated as a major cause of asthma exacerbations among school-aged children. Several studies suggest that hand sanitizer use reduces overall infection-related absenteeism among elementary school students by 20–50%, and respiratory illnesses by 30–50% [69]. A randomized control trial conducted by Gerald *et al.* [69] evaluated whether a standardized regimen of hand washing plus alcohol-based hand sanitizer could reduce asthma exacerbations more than schools' usual hand hygiene practices. The trial enrolled 527 students among 31 schools but did not reduce the number of asthma exacerbations compared with the schools' usual hand hygiene practices, however there was a strong temporal trend as both groups experienced fewer exacerbations in the second year compared with the first [69]. The results of this trial were confounded by the 2009 Influenza A (H1N1) pandemic that resulted in substantial hand hygiene behaviors and resources in the control schools [69].

Multicomponent school-based environmental interventions and public policy

Several national, state, and city governmental and nongovernmental organizations, including the American Lung Association [70], Allergy and Asthma Foundation of America [71], National Heart, Blood and Lung Institute, the Center for Disease Control and Prevention's National Asthma Control Program, which includes 36 state and territorial state asthma programs [72], and the Environmental Protection Agency's Indoor Air Quality Tools for Schools Program have developed a number of school-based asthma programs. These major school-based activities include school-based asthma therapeutic management programs, self-management education for students, indoor air quality and trigger reduction programs, educational trainings for school personnel, and administering asthma medication self-carry law [73]. State asthma programs utilize the data from their Center for Disease Control and Prevention-funded asthma surveillance systems to focus activities in regions with the most hospitalizations and emergency department visits for asthma to identify evidence-based interventions to implement statewide [72,74]. A recent study by Hester *et al.* [74] conducted an analytical framework approach to systematically evaluate three state asthma programs to gain a better understanding for replicable best practices and generalizable logic model for multicomponent state-coordinated asthma interventions in schools. This manuscript highlights the importance of asthma programs to engage diverse stakeholders, including the state's educational and environmental agencies. For example, states engaged their respective state's environmental agency to obtain air quality data and to access monitoring or training services for school indoor air quality walkthroughs as well as creating recess guidance for schools based on the outdoor air quality [74].

CONCLUSION

The school environment where children and school personnel spend a majority of their day is a significant reservoir for allergens and pollutants [11–26]. There are several domains to which to intervene on school-based asthma surveillance, education, optimization of asthma management, and adherence to recommendations as well as environmental interventions that all have the potential to mitigate pediatric asthma morbidity. If it can be demonstrated that reduction of classroom-specific exposures lead to improved asthma outcomes, then these findings can be translated into cost-effective strategies to benefit communities of children through improvement of the school and daycare environment. Although establishment and implementation of public policies is an expensive undertaking for cities, preliminary studies suggest that environmental interventions may be cost beneficial [75]. In inner cities where the burden of disease is so great, interventions may reduce the cost to the community even further. In this limited resource environment, it will be critical to determine, which are the most efficient and cost-effective to implement broadly to improve pediatric asthma morbidity.

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KEY POINTS

- Studies assessing environmental exposures outside the home environment and interventions to mitigate these exposures have the potential to reduce pediatric asthma morbidity.
- The school environment where children and school personnel spend a majority of their day is a significant reservoir for allergens and pollutants.
- Several small longitudinal studies in Europe have found improvement in asthma symptoms with repair of air filtration systems, repair of moisture damage, and reduction in mold exposure and other building maintenance.
- The limited nature of school-based environmental intervention studies done to date highlight the importance of engaging diverse stakeholders and the significant community and logistical hurdles that need to be overcome to carry out this critical research.